Crop Response Models for Intensive Cereal Management Applied to Barley and Wheat In Québec

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January 16, 1993

A Thesis submitted to the Faculty of Graduate Studies and Research in partial fulfillment of the requirements of the degree of Master of Science in Agricultural Economics

Short Title

Crop Models for Intensive Management Applied to Barley and Wheat

Abstract

This thesis presents an investigation of two production functions (a non-linear-in-parameters and a generalized polynomial) in order to determine which function most appropriately represents the observed relationships of the components of ICM technology Four spring barley and one spring wheat datasets were assembled from ICM field trials conducted in the Montréal region (1987-89).

A quadratic and a Mitscherlich-Baule equation were fitted to the (five) datasets and compared with respect to a number of measures of goodness of fit. One dataset was chosen for generating and graphing a three-dimensional response surface, based on the fitted equations of that dataset The two surfaces were compared in light of expectations regarding the two equations

The fitted equations of three of the five datasets did not produce noteworthy results. The other two datasets provided mixed results The response surfaces provided outcomes that were contrary to prior expectations In general graphing the response surfaces offered limited additional insight Ultimately, this project may have been hampered by the experimental design of the field trials, those designs being oriented to results of agronomic rather than economic significance

RÉSUMÉ

Cette thèse présente une étude de deux fonctions (une non-linéaire dans les paramètres et un polynôme généralisé) qui visait à déterminer laquelle représente le mieux les relations entre les composantes de la régie intégrée des cultures. On a utilisé pour cette étude cinq ensembles de données. Ils provenaient de quatre essais d'orge de printemps et d'un essai de blé de printemps effectués dans la région de Montréal (1987-89)

On a appliqué simultanément aux cinq ensembles de données une équation quadratique et une équation de Mitscherlich-Baule. On a ensuite comparé ces équations à l'aide de diverses mesures de degré de correspondance[1]. Un des ensembles de données a servi à tracer deux représentations graphiques en trois dimensions basées sur les deux équations appliquées. On a ensuite comparé les deux représentations graphiques à la lumière des attentes associées aux modèles leur ayant servi de base.

Les équations associées à trois des cinq ensembles de données n'ont pas produit de résultats dignes de mention. Les deux autres ont abouti à des résultats mitigés. Les représentations graphiques ont donné des résultats contraires à nos attentes. De façon générale, la présentation sous forme graphique n'offrait que peu d'éclaircissement. Ce projet peut avoir été entravé par le design expérimental des essais au champ. Ceux-ci visaient des résultats ayant une valeur agronomique plutôt qu'economique.

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1 Traduction de *goodness of fit*.

ACKNOWLEDGEMENTS

In considering my Master's programme, of which this thesis is a part, I realize that there are a number of people to whom I am deeply indebted. I extend my greatest appreciation to the following, without whom I would not have been able to bring this programme, and especially this thesis, to a successful conclusion. Their support, encouragement and advice were constant, which enabled me to continually move forward to the completion of my Master's degree. They are: Dr. John C. Henning (Thesis Advisor), Dr and Mrs P.F Wade, my parents Garnett and Nordra Stephen, my sister Jennifer, Mr. Laurie Baker (Thesis Committee), Dr. Don L. Smith (Thesis Committee), Dr Paul J Thomassin and Mr. Marcel J. Couture, as well as family and friends

For technical support and intelligent advice, I thank the following contributors: Mr Jay Bodkin (McGill University Computing Centre), Mrs Donna Woodward (Technical Support Service, The SAS Institute), Dr F Nababee (Department of Decisions Sciences and Management Information Systems, Concordia University), Mr. Michael Frank (The Boeing Corporation), Mr Stewart Liebovitch (Department of Plant Science, McGill University), Dr. J. Galbraith (Department of Economics, McGill University), Mr. Jean-François Forest (Department of Agricultural Economics, McGill University), and Ms. Chantal Paul (Extension Service, Macdonald Campus of McGill University)

Of course, I also extend my gratitude to a supporting cast of staff and colleagues, characters all, who made my stay at "Mac" a very pleasant one. There were many serious moments but these people provided support and a spirit of levity which helped to keep it all in perspective. A special "thank-you" is reserved for Janet Broxup, Jackie Jones, Yohannes Kebede and Harry Sertain.

For financial support I thank the Ministère de l'Agriculture, des Pêcheries et de l'Alimentation (MAPAQ) through the Conseil des recherches en Pêche et en Agro-alimentaire du Québec (CORPAQ).

For their timely support and encouragement, I would like to express my appreciation and thanks to Leona McKenty and Yves Delisle

Finally, to Anne, I offer my heartfelt gratitude for your patience, understanding and encouragement. This Master's was a test for us both and may we be stronger and happier for it.

Bruce Stephen (November 1992)

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CHAPTER ONE: INTRODUCTION

1.1 The Development of Intensive Cereal Management

Intensive Cereal Management (ICM) is a high-yield, high-management crop production technology that was developed in Europe after World War II. This was a result of pressure to produce substantial quantities of cereal grains and the provision of research funding to develop new technologies to achieve that goal (Stanton, 1986). The results of the adoption of ICM strategies in Europe are apparent in comparative per hectare yields of various wheat-producing countries (Table 1.1).

TABLE 1.1 WHEAT YIELD (By Major Producing Country) TONNES PER HECTARE

	1990	Average (1981-90)	Predicted (1991)
France	6.51	5.79	6.63
West Germany	6.61	6.04	6.42[1]
Italy	2.92	2.79	3.11
United Kingdom	6.83	6.54	7.18
Australia	1.67	1.44	1.47
Argentina	1.84	1.83	1.84
Canada	2.27	1.89	2.21
United States	2.66	2.45	2.33

Adapted from (Canada Grains Council 1991, 45)

1 Yield for Germany, the union of the former West Germany and East Germany

Of the countries cited in Table 1.1 and Table 1.2, the following extensively practice ICM technology in producing barley and wheat: Denmark, East Germany, France, United Kingdom, West Germany (Stanton 1986).

TABLE 1.2: BARLEY YIELD (By Major Producing Country)
TONNES PER HECTARE

	1990	Average (1981-90)	Predicted (1991)
Denmark	5.62	4.51	5.23
France	5.74	4.87	6.00
West Germany	5.43	4.89	5.62[2]
United Kingdom	5.17	4.92	5.45
East Germany	5.21	4.61	--
Australia	1.65	1.47	1.50
Canada	2.97	2.62	2.68
United States	3.00	2.76	2.99

Adapted from (Canada Grains Council 1991, 45)

Sometimes referred to as *Integrated* or *Intelligent* Cereal Management, ICM technology offers the producer the opportunity to develop a crop production program that adapts, over time, to the specific needs of that producer's particular location, crops and markets. This intensive technology may be different from non-intensive technology in that the required level of management input is greater in the former than the latter.

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2 Yield for Germany, the union of the former West Germany and East Germany.

The setting for ICM is a dynamic one as the producer compares projected conditions (*eg.* weather, pest levels, market fluctuations, *etc.*) to those which are realized as the crop season progresses.

From the research point of view, there are many questions to be addressed. In the last two decades, ICM technology has been a subject of considerable agronomic investigation in North America However, much of this research has been limited to the effects of ICM inputs on the growth stages and yield characteristics of the crop varieties subjected to *partial* ICM packages.[3] The total package of ICM has been applied in very few cases. Complete adoption of the philosophy of ICM technology requires that the producer closely monitor both crops and land, while constantly making decisions regarding input use and the timing of applications. Contrary to commonly held-beliefs, ICM does not mean that all inputs are simply applied in greater amounts Rather, with the exception of the management input, it is not initially clear if any of the inputs will be applied in significantly greater amounts. An ICM program could closely resemble a conventional cereal management (CCM) program with one or two differences, depending entirely upon the crop under production.

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3 A *partial* ICM package refers to a limited combination of ICM inputs (such as high nitrogen fertility rates, a plant growth regulator and a fungicide application) in addition to conventional cereal management (CCM) levels of other inputs

There has been a general trend towards intensification in agriculture over the last decade and the adoption of ICM technology has been seen by economists as an aspect of this trend. Beyond this recognition however, the extent of economic research is very limited with a small number of cost/benefit analyses having been conducted. This research has too often only been partially applied to the *philosophy* that lies behind ICM technology.

The essence of optimal ICM decision making is the determination of the precise amount of each input to apply at the most advantageous time. These decisions should rely heavily upon the expert opinion and guidance of agronomists and agricultural economists with ICM research experience.

In Québec, the most important cereal crop is spring barley, in terms of area of production, indicated in Table 1.3. In 1990, the province's barley crop was grown on 156,000 ha (le Comité de Références Écconomiques en Agriculture du Québec (C.R.E A.Q. 1991). Per hectare yields currently average just under 3.0 tonnes per hectare using CCM systems indicated in Table 1.4 (Smith 1990).

Spring wheat, although not as widely grown, (placing third after barley and oats) is also an important crop. There is some winter wheat produced in Québec although the area devoted to the production of winter wheat is barely one-quarter of that devoted to spring wheat (Smith 1990).

With increasingly competitive cereal markets, Canadian and American cereal producers have been looking for ways to stabilize the grains sector in terms of economic returns.

TABLE 1.3. AREA OF PRODUCTION - Québec
THOUSANDS OF HECTARES

	Barley	Spring Wheat[1]
1990	156.0	46.5
Average 1981-1990	145.4	42.8
Predicted 1991	165.0	41.0

[1] Other than Durham Wheat
Adapted from (Canada Grains Council 1991, 3-4)

The realization of a stable pattern of maximum economic returns to the producer is ultimately the goal of this technology. Given the potential effects of ICM technology on the yield, quality and variability for both spring barley and spring wheat, Québec producers of these crops should be interested in the impact of ICM technology in their province In Canada, ICM research has been carried out in most provinces Some of these projects are on-going whereas others have ceased. APPENDIX ONE provides a partial list of ICM studies in Canada.

TABLE 1.4 PRODUCTION YIELD - Québec
KILOGRAMS PER HECTARE

	Barley	Spring Wheat[1]
1990	3730	3230
Average 1981-1990	2927	3005
Predicted 1991	2970	2630

[1] Other than Durham Wheat
Adapted from: (Canada Grains Council 1991, 7-8)

1.2 Outline of the Project

CHAPTER TWO presents the purpose and rationale the project aims to serve and the context in which they operate. The objectives are presented along with a formal statement of the research problem. The question of ICM research is discussed in the context of the theories of Agricultural Economics and the related fields of Agronomy, Crop Science, Plant Science and Soil Science.[4] The chapter ends with a discussion of the limitations placed on this project and the provision of definitions for a number of relevant terms.

CHAPTER THREE is a literature review, presented in three parts. The first is a survey of the Agronomic literature, focusing on the various inputs that are candidates for ICM technology This survey also discusses two significant problems that are commonly associated with ICM crop production: lodging and

[4] The separate fields of Agronomy, Crop Science, Plant Science and Soil Science are subsumed under the single heading of Agronomy for the purposes of this paper.

increased disease presence. The second part of the chapter is a survey of joint Agricultural Economic and Agronomic research studies, presented on a regional basis, from across Canada. The third and final part of this chapter surveys the Economic literature which would apply to this project. The economic foundations of various agronomic models as well as a popular economic model, the *multi-variable quadratic* model, are discussed. The advantages and disadvantages of the various models are presented and the need for a compromise model is suggested. Finally, one such compromise model is introduced and examined.

CHAPTER FOUR presents the methodology utilized in this project. Beginning with the data collection and preparation steps, the issues of dataset selection, the choice of statistical analysis package and the procedures within the chosen package are examined Next the models generated for analysis and comparison are described in detail. In generating these models, some assumptions are made that are considered to be controversial and an overview of these controversies is provided The use of an independent, unrelated dataset to test the methodology proposed for this project is explained along with the conclusions reached for this test Next, the analytical tests conducted on the models generated in this project are introduced and explained The chapter then presents a brief discussion of some of the modelling and analytical problems encountered.

CHAPTER FIVE presents the results of the model generating procedures on a dataset-by-dataset basis. Within each dataset presentation, the results are discussed in a model-by-model format, as each model generated is related to the previous model. The chapter ends with a discussion of a forecasting exercise carried out on the models of one of the datasets which involved graphing response surfaces for two of the dataset's models.

CHAPTER SIX presents the conclusions and recommendations. Those conclusions are discussed at two levels, those dealing with the project itself (the Micro Conclusions), and those arrived at with respect to the general subject matter and the particular fields of research involved (the Macro Conclusions).

Six appendices are presented to provide further detail to materials discussed in the six chapters

CHAPTER TWO: THE RESEARCH PROBLEM

2.1 Introduction

This project evolved out of an awareness by agronomists and plant scientists at the Macdonald Campus of McGill University (formerly Macdonald College of McGill University) that ICM research experiments were lacking an economic component which could be utilized to determine the optimal economic application of this new technology. This assessment of ICM's viability is crucial to the eventual adoption or rejection of this technology by producers Given this research opportunity, an economic analysis of ICM field trial data was proposed.

2.2 The Purpose of the Project

In general, the purpose of this project is to provide assistance to those who make barley and wheat production decisions in Québec. This assistance is offered in an effort to optimize the economic returns of producing these crops Furthermore, this project attempts to assist those who are making production decisions in agronomic research in Québec. Much of the recent ICM research has not been subjected to any form of economic analysis. In the few cases where it has, the analysis has been scant, consisting mostly of simple cost/benefit techniques

The theoretical background of the relationship between inputs and crop yield has evolved differently in two particular fields of agricultural research. Agronomists have developed crop response models based on theories different from those of agricultural economists, who in turn have their own favored response models. Different models therefore had to be investigated and conclusions drawn as to which model would best represent the physical yield results exhibited in selected crop response data. Ultimately, two production functions, one representing the methodology of agronomists and the other the methodology of agricultural economists, were selected and assessed.

Specifically, the purpose was to investigate two production functions that attempt to explain the relationship(s) between certain variable inputs of ICM technology, and crop yields. However, a specific hypothesis regarding the modelling of these relationships was not proposed. The data for this project were gathered from various ICM crop production experiments designed and implemented for other research projects.

2.3 The Objectives of The Project

In order to properly address the scope of the proposed problem, certain objectives have been set:

(1) to obtain field trial data (from a variety of sites) regarding the application of ICM technology to Québec barley and wheat production;

(2) to conduct a critical review of the published material regarding ICM research in order to determine the acknowledged relationships between various inputs which are considered necessary elements of ICM technology;

(3) to formulate, based on the general agricultural economics theories of crop response, a representative production model for ICM technology,

(4) to formulate, based on the general agronomic and crop science theories of crop response, a representative production model for ICM technology;

(5) to use the data collected to assess the models of (3) and (4) with the aim being to determine which of the two provides a more appropriate fit of the (collected) data,

(6) to identify conclusions and to provide recommendations to guide future agronomic and economic research in ICM in Québec and Canada

2.4 The Statement of the Problem

The problem this project will address is: To identify a crop response model which would appropriately represent the observed relationships resulting from the components of ICM technology, taking into account competing theories of crop response offered by the fields of agronomy and agricultural economics.

2.5 The Rationale for this Project

The rationale for this project can be expressed in terms of interests at three levels: producers' interests, the interests of the secondary sectors, and the interests of researchers in ICM technology.

2.5.1 Producers

The practice of ICM technology is relatively new in Canada and may have significant potential for barley and wheat producers in Québec. These producers are faced with a complex of problems, many of which are beyond their control. Agricultural producers have to cope with their physical and economic environments as they attempt to optimize economic returns. Local weather and other geographical factors are generally present in less than ideal conditions (*ie.* hot, dry summers, relatively short growing seasons, *etc.*), as compared to other growing areas of the world (Smith 1990, 78). These factors make production and economic returns subject to considerable fluctuation.

The economic (or market) environment is another source of uncertainty for producers. Interest rates, input prices and wavering government support programs in agriculture combine to create conditions which make it difficult for the average producer to ensure a stable economic return. Crop markets and prices are factors which are presently not advantageous for Canadian producers. Largely because of an export subsidy war between the United

States and the European Economic Community, Canada's grain producers are caught in a price-squeeze. Furthermore, other grain-producing countries (*eg.* Argentina, the Ukraine, Australia) are becoming increasingly competitive with Canada, intensifying the battle for position in the world grain market.

The recent, generally high interest rate levels (to which many producers may still be committed) and the uncertainty of government support programs also weigh heavily on the success of producers in maximizing their returns. In the current climate of increasing antagonism regarding subsidies (coupled with the suggestion by some of Canada's competitors that the level of subsidization may be higher here than elsewhere), there is concern for the strength of commitment different levels of government are prepared to make to agriculture in this "free trade" environment (Goar 1990, *B3*)

Profitability improvements can generally come about in three ways (or a combination thereof), *ceteris paribus*: increased crop prices, decreased production costs, and/or increased per unit yields ICM technology may improve profitability most directly through increased yields that lead to decreased per unit (variable) production costs Indirectly, ICM technology also presents an opportunity for producers to receive higher prices for their crops by improving the quality of the crop produced

For barley, ICM technology can be applied to bring about increased protein content of the grain produced. This makes barley more valuable as a livestock (mainly pork and poultry) feed, the ultimate use of most of Québec's barley crop (Smith 1990). Higher-protein barley reduces the need for livestock-feed protein supplements (most commonly soybean meal). Therefore, there are positive economic benefits for the barley producer whether fed on farm or sold as a feedstuff.

With regard to wheat, an increase in protein content has the potential to bring about increased revenue for producers. For wheat above 12.5%, there is approximately a $50 per tonne premium paid above the price paid for lower protein feed wheat (Stewart 1985; Melanson 1988; Worden 1988; Lussier 1992).

ICM technology can also influence production costs in that ICM practices encourage tight control of all the factors of production that contribute to costs This technology requires that producers re-think old practices and be prepared to utilize new ones that optimize the potential of every decision and action.

However, ICM, with an extensive list of possible inputs and management requirements, adds a layer of complexity to the producer's decision making process In their interests, a research project such as this can help producers rationalize this decision making process by expanding and clarifying the information base upon which those decision makers must rely.

Ultimately, there is a specific motivation for producers to assess ICM benefits for their own situation. The earliest adopters of the new technology will probably benefit the most, with economic gains being thinned out as the practice becomes more established. In the end, some of the late- or non-adopters may find themselves squeezed out of their traditional grain markets due to their uncompetitive, high production costs. In order to avert further disruptions in the grains sector, especially in Québec, efficient production technologies such as ICM have to be investigated and evaluated. If these practices prove to be appropriate to local production, then they must be adopted and fully applied in order for producers to remain competitive.

2.5.2 Secondary Sectors

There are benefits on a broader scale to be derived from the farm-level adoption of ICM technology. Québec currently imports wheat and barley from Western Canada. Self-sufficiency rates for Québec (1989-90) were 74% for barley and 47% for wheat. The barley rate is a continuation of an annual upward trend since 1983-84 when the rate was 31%. Wheat self-sufficiency has been mixed over the same period with a low of 24% (1983-84) to a high of 52% (1985-86) (le Comité de Références Économiques en Agriculture du Québec [C.R.E.A.Q.] 1991, 2). A modest increase in production could dramatically affect self-sufficiency, especially for barley. Furthermore, there may be spin-off effects in other sectors such as livestock and dairy feeds, grain storage and handling and possibly transportation.

2.5.3 Research Scope

Research into the application of ICM technology in Québec, from an economic point of view, has been very limited. This project offers an initial step toward a greater understanding of the successful application of ICM technology. Initially the proposed plan was to evaluate crop response to ICM technology and subsequently provide a production model which would allow (when complemented with cost constraints) for the optimization of decision making in ICM production. However, due to the absence of previous research in this area, this project was re-directed to a more basic question regarding production research: *What model would adequately represent the physical crop response being exhibited in ICM crop experiments?* By proposing and evaluating different production models that represent crop response, this project aims to begin the process of building a body of research on the economic potential of ICM technology as applied to the Québec production of barley and wheat.

2.6 Theoretical Framework

The investigation of ICM technology brings together the principles of many diverse disciplines. Most importantly, it must bridge the two separate fields of agricultural economics and agronomy. Agricultural economics and agronomy have both examined the issue of yield response to fertilizer applications. However, over the last fifty years, the two disciplines have followed very different approaches in this research. This being so, there are two distinct methodological paradigms to choose from in generating a model to represent ICM technology (Lanzer, Quirino and Williams 1987).

By and large, agricultural economists have been following their path since the end of World War II, and have produced a variety of multivariate, curvilinear production functions. These mathematical statements, in their many forms, implicitly allow for nutrient substitution and generally exhibit point maximums. Agricultural economic theory is based on a paradigm which contains the following principal elements:

- substitution between inputs,
- a response curve with a point maximum,
- diminishing marginal returns to an increasing input

Furthermore, field experiments designed by agricultural economists tend to have many treatments, but few replications. The purpose of this is to generate a large number of points thereby producing a better-represented response curve

Agronomic theory, on the other hand is based on a paradigm which contains these principal elements:

- no substitution between inputs,
- a response curve with a plateau maximum,
- diminishing marginal returns to an increasing input throughout a lengthy Stage II.

Field experiments designed by agronomists tend to have few treatments but many replications. This generates response curves based on fewer data points (by treatment) but more precise averages from which to fit the curve. Contemporary applied models in agronomy have tended to move away from the strict nutrient non-substitution rule although the notion of the plateau yield is still widely held.

The divergence for these two paradigms can be seen to revolve around two important notions: (i) the substitutability of input nutrients in plant development, and (ii) response surfaces exhibiting point versus plateau maximums. This has led to the particular methodologies being followed and specific experimental designs being implemented. As previously noted, experiments designed by agronomists provide fewer points on the response surface than experiments designed by agricultural economists, a problem from the latter's point of view. For this reason, the exchange of data between agronomists and agricultural economists can be somewhat limited.

To represent the two paradigms, common datasets were used to generate two theoretically different models for examination. The models were chosen to be representative of the two research fields. Ultimately this project aims to determine if one model is a better representation of the physical production process. It is important that any model generated be seen to conform naturally to the response surface suggested by the data (observations) rather than the reverse.

It is generally accepted that there are two types of research projects: confirmatory and exploratory (Kerlinger 1975, 406). Exploratory research is generally taken to be research which has little or no guiding theory. This form of research is concerned with developing hypotheses (in the absence of a theoretical background) of the physical process(es) which generated the yield data. As such, exploratory research concerns itself with modelling the possible variables of the production process in a way that makes empirical sense Confirmatory research, on the other hand, has a theoretical background upon which to rely. Here a project is geared to hypothesis-testing, and in doing so, testing a given theory The magnitudes of the parameter estimates and the significance tests of those estimates are all part of confirmatory research

This particular project is of the exploratory type. The theory of ICM crop production is somewhat undeveloped with specific actions and interactions having yet to be developed into testable hypotheses. As such, this project marks a stage in the quest for an appropriate ICM production model.

2.7 Limitations

In this project, two models were chosen which appeared to fit the physical evidence being examined. The choice does not purport to represent the *best* models of each paradigm, rather, the models chosen fit the notions held by the author as to what would constitute a reasonable model-comparison exercise, drawing upon the theories and notions held by the two fields of agricultural research.

Spring barley and spring wheat were the only crops investigated with respect to ICM technology. Furthermore, only the production side was investigated: there was no evaluation of the costs related to this technology. Finally, the relationship between crop quantity, quality and price was not investigated here.

2.8 Definitions of Terms

Certain terms are used in this paper which might have somewhat different meanings to different readers. Therefore, these will be defined to avoid confusion.

(1) The use of the word *adequate* in the statement of objectives and elsewhere is not used to mean necessarily the absolute *best* Rather, to be deemed adequate is to be seen to fulfil some criteria set out as appropriate in the context of this project. An example might be an adequate model which would fulfil certain criteria such as a relatively high R^2, good predictive power, *etc.*.

(2) *Elements*, as the term will be used in this paper, refers to individual inputs such as fertilizers, pesticides, seeding rates or row widths, *etc* in an ICM production process, which may or may not have a physical existence. Hours of management (decision making) input, an intangible, will be considered, as will the number of kilograms of nitrogen fertilizer applied during the crop season (a tangible input).

(3) The term *packages* will be used to refer to the ICM combinations of elements at measured levels of application One package will be distinct from another when, all things being equal, there is a real difference in the level of application of at least one of the elements of the two packages.

(4) The term *variable* will be used in two ways in this project. The first will be use of the term *explanatory variable* and the second, the *regression variable* or *regressor variable*. The term explanatory variable will be synonymous with elements, explained above, or, with variable inputs such as fertilizer, fungicide or management inputs. Therefore, explanatory variable will refer to the input element this variable represents in a model. The term regression variable will refer to any specification of an explanatory variable such as a linear, quadratic or cross-product term. For clarity, the shortened form - *regressor* - will be used instead of regressor variable.

(5) The *philosophy* of ICM refers to an all-encompassing idea that the practice of ICM crop production involves constantly monitoring and assessing a crop's development and requires a variety-specific approach to seeding practices, fertilization and pest control as well as field practices and rotations.

2.9 Summary of CHAPTER TWO

In this chapter, the purpose of this project was expressed as a desire to provide assistance to Québec barley and wheat producers as well as agronomic researchers in the area of ICM Specifically the project aims to investigate production function models which would explain the relationships between ICM variable inputs and crop yields. Six objectives are stated, having been developed to help address the problem of generating a crop response model which will adequately represent the data collected from ICM field trials

The rationale for this project is provided in terms of the opportunities available to producers practicing ICM as well as to the secondary sectors which service those producers. An additional rationale is offered in view of the contribution this project will make to the body of research being compiled on ICM. The chapter then briefly explains the theoretical perspectives upon which this project was founded from the fields of agronomy and agricultural economics. Finally, this chapter enumerates the limitations placed on this project and defines a number of terms.

CHAPTER III: LITERATURE REVIEW

3.1 Survey of Agronomic Literature

3.1.1 General

There are a vast number of ICM (input) packages that the producer can choose from for any one crop. The local conditions of weather and soils, both in the past and future, influence which package the producer might put together. There are also market conditions which affect the producer's choice(s). In addition to these physical and economic factors, there are the recommendations of extension agents, input supply companies and producers' groups (cooperatives, unions, etc.). All of this information can be confusing to the producer when making choices. Compounding this problem, there are the belief systems which producers hold regarding new technologies. For example, many producers may be dissuaded by the media focus on the high input costs of ICM technology, completely missing the possibilities of cost-reductions through the enhanced management role indicated by ICM (Country Guide 1988, 18).

For each ICM package, a decision has to be made on the level of utilization of each of the elements. Although there does not exist a definitive ICM package, there are a number of elements which are generally accepted as being necessary The more prominent of these are nitrogen fertilizers, fungicides and plant growth regulators Most crop-growth programs which follow ICM techniques will have identifiable decisions regarding the utilization levels of these three elements There is little uniformity as to what else constitutes an

ICM program. Some ICM elements may be the same as those applied in a conventional cereal management (CCM) program but at significantly higher levels.

A number of other elements are variously applied to bring together an ICM program, depending upon local crop, soil and weather conditions Furthermore, what is not applied in one year may be applied in subsequent years, and *vice versa*. The inputs applied under ICM can be divided into two categories (Country Guide 1988, 18). The elements of Category I are those which help plants to yield their full potential given prevailing conditions. These include:

- field preparation,
- soil testing techniques,
- crop rotations,
- planting practices,
- seed quality and variety selections,
- seeding depth and rates,
- row width,
- fertilizer requirements and
- harvesting techniques

Category II contains those elements which are used to protect crops from pests and any other factors which can reduce the yield potential Category II therefore includes.

- plant growth regulators (PGR's),
- and pesticides (fungicides, insecticides, herbicides, etc)

Implementing ICM technology requires a knowledge of the stages of plant development, as plants have optimum times at which they respond to various inputs. Farmers would, by necessity, have to look at their ICM program in a dynamic setting and be prepared to react to actual plant needs, rather than a research program, to nourish and protect their crop(s). Practical problems arise because research experiments tend to look at individual inputs in isolation. Furthermore, experiments tend to apply inputs according to research methodologies (protocols) rather than actual plant needs at the various stages of plant development

The following discussion is a limited summary of the expected actions and interactions of some of the most common elements (ordered by Categories I and II) of ICM technology.

Field preparation and planting.

Conventional and Intensive cereal management technologies employ similar practices with respect to crop rotations, cultivation and harvesting practices (Stemeroff 1987).

Seed variety:

There are varieties of seed that are known to be better-suited to the effects of ICM packages. Generally, traditional seed varieties do not respond well to ICM programs. The variety of cereal chosen determines the yield potential and quality and is thus a very important aspect of crop production. Producers have to select those seed varieties which have a proven high-yield potential and respond well to ICM in local weather and soil conditions. Special varieties are continuously being developed for ICM technology (Bolton 1984). Information guides such as Publication 296 - Field Crop Recommendations (OMAF) (Upfold 1988, 1) are especially useful. It gives variety descriptions with respect to area of adaptation, yield potential, straw strength, disease reaction, etc. (Country Guide 1983; Country Guide 1988; Lussier 1990; Mellish and Caldwell 1990).

High quality seed:

The choice of the highest quality of seed available ensures that the ICM package will not fail due to poor germination and/or sparse stands of weak seedlings Stand establishment is a very important aspect with regard to maintaining cost-effectiveness due to input application and harvesting costs and how these are adversely affected by poor stand establishment (ICM Task Force 1988; Union Carbide Agricultural Products Company 1985). Seeds that are certified as to their germination potential (minimum 85% for barley and wheat) and yield potential under specified conditions of soil and weather are essential for ICM packages (Union Carbide Agricultural Products Company, 1985; Country Guide 1988; ICM Task Force 1988).

Seeding rates:

Rates should approximate ICM recommendations of: 375-400 seeds per square metre (at 85% germination) for spring barley; 400-500 seeds per square metre (also at 85% germination) for spring wheat (Vanasse and Bastien 1986). It has been suggested that seeding rates may determine up to 67% of yield potential, depending upon variety (Oplinger, Wiersma, Grau and Kelling 1985; Union Carbide Agricultural Products Company 1985; Schaad 1988, 2; Lussier, 1990).

Seeding depth:

Adequate moisture and mineralization are important to cereal crops (Vanasse and Bastien 1986). Clay and loam soils are better suited to intensification due to their ability to retain moisture. Planting depth should be 3-5cm, early in the spring on fields with good drainage (Vanasse and Bastien

1985). Deep seeding delays emergence, exposes the plant to excessive disease pressure and reduces tillering ability (Oplinger *et al.* 1985; Union Caıbide Agricultural Products Company 1985; Schaad 1988, 2).

Planting date:

In spring cereals, early seeding may be the single most important factor in achieving maximum yields. The best date is the earliest that a particular variety can be planted without risking damage due to cold weather (Union Carbide Agricultural Products Company 1985; ICM Task Force 1988).

Row width:

Decreasing row widths from 14 to 7 inches (20 to 10 cm) may increase yield 10% (ICM Task Force 1988). European ICM row spacings exhibit yield increases of 9-12% with spacing decreases from 18 to 10cm (Van.ıssc and Bastien 1986). Theoretically, decreasing row widths gives more space to each plant and can allow for the establishment of more plants per metre squared. (These conclusions may be variety-dependant.) It has been suggested that narrower row widths also affect weed control by squeezing out competitive weeds (Lussier 1990; Oplinger and Wiersma 1984a).

Tramlines:

These are tracks made on the field which allow the producer's equipment to pass through with the minimum of damage to existing crops. They also set a pattern over the field which ensures that, if properly followed, the entire field will be covered during input applications. Vanasse and Bastien (1986) have suggested that tramlines are not much used in Québec because of equipment differences required for narrower row spacings etc. (Country Guide 1983; Oplinger and Wiersma 1984a; Oplinger and Wiersma 1984b; Oplinger *et al.* 1985).

Timing of input application.

The timing of application has been strongly linked to weather. Results for ICM inputs vary from region to region, and over time, suggesting a strong influence of geographic and climatic conditions. Further research into the role of timing of application is needed (Bridger and Klinck 1986; Stemeroff 1987; Smith 1990).

Nitrogen.

The use of high levels of nitrogen fertilizers on small grain cereals is expected to produce dense stands of tall, lush plants with plump seeds. These seeds are significantly higher in protein than otherwise. Split applications must be considered as large amounts of nitrogen are utilized during early plant development stages (*ie.* the stem elongation phase), limiting the available nitrogen for later development stages. There is also the expectation that high rates of nitrogen will bring about lodging, where the plant tends to fall over in the wind, rain or under the weight of its own seeds. Therefore, harvesting problems as well as greater disease infestations usually accompany high nitrogen rates. Finally, high nitrogen rates also result in higher rates of plant transpiration (a negative effect of high nitrogen) resulting in moisture stress, as well as the plant exhibiting an extreme sensitivity (usually negative) to PGR's (Kelling and Oplinger 1984; Oplinger and Wiersma 1984b; Union Carbide Agricultural Products Company 1985, Vanasse and Bastien 1986; Sheard, Newdick and Beauchamp 1986, Bossuyt 1987, Stemeroff 1987; Bartlett, Sanderson, Caldwell and Mellish 1988, Country Guide 1988; ICM Task Force 1988; Lussier 1990; Smith 1990)

Plant growth regulators:

Again, the use of high rates of nitrogen creates a problem for the resulting crop The plant can become so top-heavy that it tends to lodge. PGR's are used to reduce the effort the plant exerts in attaining height, instead diverting that effort towards strengthening the stalk of the resulting shorter plant. PGR performance can be affected by crop type and variety, specific geographical area, application rate and timing, ambient temperature at the time of application. Common ICM plant growth regulators are CERONE, CYCOCEL and TERPAL (Country Guide 1983; Oplinger and Wiersma 1984b, Oplinger *et al.* 1985; Union Carbide Agricultural Products Company 1985; Vanasse and Bastien 1986; Bartlett *et al.* 1988; Country Guide 1988; ICM Task Force 1988; Bridger and Klinck 1990; Smith 1990).

Fungicides:

The need for fungicides stems from the plant environment created by high nitrogen rates and applied PGR's. It is expected that non-chemical control measures will be inadequate to deal with the greatly increased disease pressures of ICM technology (Union Carbide Agricultural Products Company 1985, 19, Smith 1990, 81) Fungicides are required (over and above any genetic resistance incorporated in the crop variety) to control the spread of crop diseases and to protect the yield potential (Stemeroff 1987; ICM Task Force 1988). Seed treatments with fungicides uniformly exhibit positive results: emergence not significantly affected, similar vigor, significant control of powdery mildew(s), and yield increases in most cases. The use of fungicides is well-accepted although there is a somewhat limited selection of choices, and therefore some diseases may go unchecked. Common fungicides are BAYLETON, DITHANE M-45 AND TILT (Grau 1984; Stewart 1985; Stemeroff 1987; Bartlett *et al.* 1988; ICM Task Force 1988; Lussier 1990).

Insecticides and Herbicides:

While field monitoring for the presence of insect infestations is highly recommended, it is worthwhile to note that serious pest (insect) infestations are very rare in Canada (Country Guide 1988). Weed problems are much more common although many of the herbicides used in conventional cropping systems are adequate for ICM programs (Union Carbide Agricultural Products Company 1985).

Producer management effort·

One factor which tends to receive little research attention but is usually mentioned in the conclusions and/or recommendations is that of increased grower (management) effort (Bossuyt 1987; Stemeroff 1987).

3.1.2 Causes of ICM-induced Yield Variability

There are two important and significant problems which can induce dramatic yield variability in an ICM program, although ironically it is the program which exacerbates these problems. The first is lodging. Lodging can reduce small grain cereal quality, cause uneven plant maturity and excessive moisture content. Lodged crops can take up to three times as long and cost twice as much to harvest (Country Guide 1983, 38).

There are different kinds of lodging in small grain cereals. One is root lodging, characterized by straight, intact culms leaning from the crown. This form of lodging involves a certain disturbance of the root system and is likely caused by rain or irrigation (ICM Task Force 1988). Stem lodging is characterized by bending or breaking of the lower culm internodes, and is usually caused by storms, diseases and/or insects (Sikkema 1988, 4). Finally, head lodging refers to bending of the peduncle at the base of the head, and is likely caused by excessive grain weights in relation to culm strength.

Lodging is generally promoted by factors such as: over-abundance of moisture, high nitrogen fertility, dense plant stands, warm temperatures and storms. Lodging control can be influenced by appropriate timing of nitrogen fertilizer(s) and proper seedbed preparation, seeding depth and rate. If these measures produce, or cannot control, lodging, the use of a PGR may be required (Country Guide 1983; Country Guide 1988; Smith 1990).

The second problem is that of increased disease pressure, created by crop density conditions in ICM technology. Although there may not be any new diseases presented by the use of an ICM program, there is a greatly increased risk of infestation. The choice of crop variety, use of certified, high-quality seed, proper seedbed preparation, crop rotations and the timely use of fungicides are measures which help control the rate of crop infestation, and any resultant losses.

3.2 Survey of Agronomic-Agricultural Economic Literature

3.2.1 Introduction

There have been a number of ICM research projects carried out in the various regions of Canada through the 1980's. Due to differences in climate and soils, among other things, there have been varying results and conclusions drawn as to the viability of ICM for Canadian producers. This section presents a partial survey of ICM research projects in barley and wheat production Projects from the following four regions will be discussed:

Atlantic Canada,
Québec,
Ontario,
Western Canada (Manitoba, Saskatchewan, Alberta and British Columbia)

Each of the studies cited are discussed according to the following format:

- geographic area of study
- the objectives and assumptions of the study
- the methodology applied (with inputs and application levels)
- the form of economic analysis (if applicable)
- results and discussion (benefits and drawbacks)
- conclusions

3.2.2 Atlantic Canada

3.2.2.1 Peill (1983-88)

An on-going ICM research project has been conducted in Nova Scotia by Peill on a number of wheat varieties imported from Europe (Country Guide 1983, 36-8). The most successful varieties were found to be MONOPOL, ABSOLVENT and VUKA. MONOPOL and VUKA exhibited protein contents similar to those of Western Canadian spring wheats. In tests using PGR's, Peill suggests that CERONE is most effective on spring barley whereas CYCOCEL shows the best effects on shortening straw lengths in winter wheats.

3.2.2.2 Stewart (1985)

Stewart (1985) produced a report for the New Crop Development Fund (Agriculture Canada), reviewing the ICM experiences of numerous projects across Canada He states that the Canadian experience with ICM began in the Annapolis Valley of Nova Scotia in the early 1970's. It was found that the wheat varieties MONOPOL and VUKA were well adapted to the region and responded well to high nitrogen fertilization Under ICM conditions, MONOPOL exhibited good bread wheat potential The report suggests that the economic benefits of ICM production in Nova Scotia would be limited (at that time) only by the available milling capacity. Even so, Stewart concludes that the positive response of MONOPOL and VUKA to ICM techniques accounted for a 70% increase in wheat acreage and a 30% increase in yields in the late 1970's and early 1980's (p.8).

On Prince Edward Island, Stewart (1985) reported that the ICM emphasis was on spring barley. One project cited demonstrated a consistent doubling of net returns to barley production (pp.9,13). Further, this report quotes a P E I Department of Agriculture and Forestry statement which suggests that, in 1985, 20% of all barley production (20% of 20,000ha in production) utilized one or more of the components of ICM (primarily high nitrogen fertilization)(p 9)

3.2.2.3 Stemeroff (1987)

The primary goal of Stemeroff (1987) was to evaluate the economic potential of ICM, as well as fungicides within ICM packages, in Atlantic Canada as applied to cereals ICM was here defined as

> " a high yield management strategy that requires greater inputs of high quality seed, nitrogen, fungicides, plant growth regulators (PGR's), in addition to more grower attention/time in cereal production management " (Stemeroff, 1987, II)

Furthermore, this study was to provide a step-by-step guide to farmers for the practical assessment of pesticide-use problems Lastly, this study aimed to develop a format that could be easily adaptable to other Canadian ICM production situations.

The methodology used was a cost/benefit analysis based on a series of partial-budgets. Break-even ICM production levels were also calculated. In this study, it was assumed that ICM technology would have no influence on the market pricing of inputs and outputs throughout the crop season and that ICM-specific variables would have no effect on the cost structure of production (when comparing ICM to CCM). Therefore, there were no required changes in machinery or shifts in fixed resources (Stemeroff 1987, 19).

The author looked specifically at nitrogen rates, fungicides and PGR's and surveyed the 1983-85 crop seasons in the following production regions: Nova Scotia (Cambridge, Canning, Great Village, Nappan and Truro); New Brunswick; and Prince Edward Island (Meadowbank). Stemeroff reported the results for barley trials involving LEGER and BRUCE varieties. Both varieties were found to respond well to ICM practices with a relatively small degree of yield variability.

This study also found that two spring wheat varieties, MAX and MILTON, were well adapted to Atlantic Canada conditions. However, the yield results were highly variable for MAX and less favorable for MILTON. Furthermore, in both cases, results varied significantly over time and locations.

Benefits were categorized at the farm and secondary sector levels. At the farm level, benefits in terms of net returns per hectare for barley and wheat grown under ICM practices were extremely variable from one year to the next, between locations and between crops and varieties. In general, this study found that producer returns were extremely variable, with results ranging from losses to a profit of 400$/ha (Stemeroff 1987, 112).

The results for winter wheat indicated great potential for positive net returns but coupled with a high degree of variability. Spring wheats were reported to be less attractive, again due to extremely high variability in net benefits. Finally, the net benefit results for barley indicated the greatest potential for positive results. Even then, Stemeroff reported that the results from one experiment could differ significantly from another (p. 113)

The expected secondary sector benefits included increased grain storage and handling demand, reduced government subsidies and increased local employment (Stemeroff 1987, 94-5). It was concluded that there was little potential for wheat in Atlantic Canada, although prospects for ICM barley production were much better. However the nature of the experimental results were such that further conclusions were difficult to draw. There was no real consistency of varieties tested, sites or years, and researchers doing the experimentation. The recommendations did suggest that management is an important variable and should be researched more carefully Because of the developmental status of ICM technology, and inter-regional differences in production, a typical ICM combination was not presented.

As more producers became experienced with ICM, it was expected that there will be major impacts on self-sufficiency rates and therefore output prices. This would tend to benefit local livestock producers most. The author ultimately concluded that a 30% adoption rate (based on acreage) of ICM could result in a 73,000 tonne increase in production for small grains in Maritime Canada (Stemeroff 1987, 97). In turn this was projected to increase self-sufficiency rates from 40% to 53% (p.104).

3.2.3 Québec

3.2.3.1 Vanasse and Bastien (1986)

Vanasse and Bastien (1986) looked at spring barley and wheat as well as winter wheat grown on a number of farms in the Ste. Hyacinthe/Ste. Rosalie area in 1985. Data were collected from each farm, particularly the yield statistics for each of five management systems. These systems were:

1 control,
2 CERONE/BAYLETON,
3 control + nitrogen,
4 CERONE + nitrogen, and
5 CERONE/BAYLETON + nitrogen

The goal was to determine which of the systems could achieve economically profitable yields. Three barley varieties were tested: LEGER, LAURIER and SOPHIE. The wheat variety tested was CONCORDE.

In the barley experiments, fungicides generally proved to be effective at minimizing losses to infestations of powdery mildew. BAYLETON however, showed little effectiveness at controlling other diseases such as *SEPTORIA* or *FUSARIUM* diseases, both of which were prevalent. Overall, the authors deemed fungicides to be problematic and proved to be profitable only where conditions were right for continued or increased development of fungal diseases (such as powdery mildews and rusts). Barley crops were found to be very susceptible to lodging under high nitrogen rates (p.44). The plant growth regulator CERONE was effective at reducing stem height and increasing the strength of that stem thereby reducing the lodging indices.

For barley, three of five producers made money, an average of 184.10$/ha using CERONE + nitrogen. PGR plus nitrogen gave the optimum results. For spring wheat, the conclusion was that ICM could be profitably applied to this crop in some regions of Québec if PGR's are used The complete ICM package of [PGR/F + N] showed the highest yields (a very significant increase). These trials also showed however, a decreased thousand kernel weight (TKW). The PGR/fungicide package gave the optimum spring wheat results However, even with a fungicide, the experiment was unable to make the increased fertility range of 100-120kg N/ha profitable due to high disease pressure and lowered TKW's

Because each producer had a different climate, farm/crop/soils history and management tradition, Vanasse and Bastien (1986) found that conclusions across the results were difficult to make. There is a temptation to put forth a generalized ICM package based on the results of several ICM field trials. This however would be contrary to the philosophy of ICM technology and would be misleading to producers (p.97). The ICM philosophy suggests that producers not look for *a priori* recipes, but rather be able and prepared to react to changing conditions as the crop season progresses. This study suggests that prospective ICM adopters look at the texture, structure and fertility of their soils as well as the percentage organic matter, the pH level and moisture availability. The optimal nitrogen level is suggested to be 100kg/ha for spring barley, and, 120-150kg/ha for spring wheat (p 100) These are however, general guidelines and should be adapted to the individual producer's situation (eg. previous crop, green manure, soil test results, etc)

3.2.3.2 Bridger and Klinck (1986)

Bridger and Klinck (1986) set out to determine the optimal rate(s) and growth stage(s) for plant growth regulators in addition to determining the influence of the time of day of the PGR applications. They also wanted to determine the effects of various CYCOCEL-CERONE combinations with respect to plant height reduction, lodging and crop yields. The test crop was barley, and the varieties were LEGER, BOWER, JOHNSTON, MICMAC, BIRKA and RODEO. Seven experiments were conducted in 1985 and 1986.

(i) cultivar comparisons with three rates of CERONE (0, 0 24, 0 48, kg/ha) applied to all six cultivars at Zadoks' Growth Scale (ZGS) 39 in 1985,[5]

(ii) CERONE rates (0, 0 1, 0 2, 0 3, 0 4, 0 5 kg/ha) applied at ZGS 39 and only to cultivars LEGER and BIRKA (1985),

(iii) CERONE rates (0, 0 12, 0 24, 0 36, 0 48 kg/ha) applied to all six varieties at ZGS 43 (1986),

(iv) CERONE rates (0, 0 24, 0 48) applied to BIRKA and LEGER at five growth stages, starting with Day 0 (ZGS 37) with successive applications approximately every four days until about sixteen days have passed (1985),

(v) same as (iv) for 1986,

(vi) CERONE (0 24 kg/ha) applied at two hour intervals between 0400 and 2000h, each interval consisting of a separate treatment applied to BIRKA (start at ZGS 41) and LEGER (start at ZGS 45)(1985),

(vii) same as (vi) except final application occurred at 1800h (1986)

The results reported by Bridger and Klinck exhibited a height reduction for experiments (i), (ii) and (iii) The results showed height reductions with an increased rate of CERONE application without apparent regard to cultivar In these experiments, lodging was not a problem in 1985 and nearly absent in 1986. Finally, CERONE was reported to delay days-to-heading over all cultivars. Yield was not significantly affected in 1985 experiments although there

5 Refer to APPENDIX TWO for an illustration of Zadoks' Growth Scale The scale is explained in detail in Zadoks, Chang and Konzak (1988)

were significant differences in 1986 yields. BOWERS yield was increased slightly with increasing CERONE: LEGER was not affected whereas the remaining cultivars were reduced only at the two highest rates of CERONE application. CERONE also exhibited effects on yield components: headcounts increased significantly with increased CERONE in experiment (ii). It was also reported that seed headcounts and TKWs were reduced especially at higher rates.

In experiments (iv) and (v), heights were significantly increased by the later growth stage. In 1985, plant height was reduced most by the application at day nine for both cultivars. In 1986, height was increased linearly by CERONE applications at successive stages. Overall yields were not affected by the growth stage application in either year Of the yield components, growth stage application had greater effects on the headcounts and TKWs. LEGER headcounts were reduced significantly by application at later growth stages in 1986. In 1985, BIRKA was reported to exhibit a decreased headcount as a result of CERONE at ZGS 45 (day 9) and ZGS 47 (day 12). However, in 1986, BIRKA headcounts were increased by CERONE at earlier growth stages. Finally, in 1985, CERONE was found overall to increase TKWs at successive growth stages.

Experiments (vi) and (vii) were reported to show 4:00am and 6:00am treatments to be most effective at reducing plant height. In 1985, height was reduced significantly by 4:00am and 6:00am treatments while in 1986, height was reduced by all treatments although the two earliest applications were most effective. (Bridger and Klinck 1986, 1-2,9-10,33-34)

3.2.3.3 Smith (1990)

Smith (1990) set out four objectives to assess the effects of ICM practices on spring barley. The objectives included a test of nitrogen uptake efficiency for typical ICM and CCM rates of fertilization. The author also set out to examine the effects of the timing, formulation and method of nitrogen fertilizer application on the final protein content of the spring barley test crop. Identifying the cultivars of spring barley that were responsive to ICM conditions and to test the effects (on the crop development and yield) of PGR types and application timing were the third and fourth objectives.

Five barley cultivars were tested (LEGER, LAURIER, JOLY, CADETTE and ARGYLE) on three soil types (clay, loam and sand) and at two management levels (ICM and CCM). A very limited cost/benefit analysis was conducted. The results indicated that:

(i) CERONE was much more effective at reducing plant heights than was CYCOCEL,

(ii) CERONE at ZGS 30 increased yields of LEGER without affecting lodging,

(iii) applications at ZGS 39 significantly decreased yields (p.80).

Furthermore, the application of plant growth regulators exhibited a significant increase in protein content in both the barley seed and straw but also tended to decrease the harvest index.[6] Additional nitrogen (especially split-applications) also increased protein content of the seed and straw (p.80). Overall, the effectiveness of ICM practices may be reduced by the hot and dry summers experienced in Québec: high nitrogen increases plant transpiration and drought susceptibility which in turn makes the drought-stressed plant overly sensitive to PGR's (Smith 1990, 78).

3.2.3.4 Coopérative Fédérée de Québec

Coopérative Fédérée de Québec (Coop) has been an integral part of Québec's ICM development since the mid-1980's. The extent of their involvement makes a summary of their experimental results difficult: in the 1985-87 period, experiments were conducted which tested in excess of 40 barley and 50 wheat varieties The results of some of these experiments are

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6 A harvest index is the ratio of the weight of grain yield to the weight of harvested dry matter (Smith 1990)

presented in the annual Coop reports. Coop experimental results are compiled with other ICM projects to produce the Canada Grains Council's Intensive Culture of Wheat in Canada (Québec) Annual Report (Canada Grains Council 1988). This report provides a summary of the activities in Québec with respect to ICM production of spring and winter wheat (Mailloux, 1990; Migner 1989)

3.2.4 Ontario

3.2.4.1 Stewart (1985)

Stewart (1985) refers to encouraging ICM field trial results collected by the Ontario Red Wheat Association for the variety MONOPOL. Similar tests on the soft white winter wheats which are most common in Ontario were not as positive (p.10). Stewart reports on a number of other small studies being conducted by private companies and/or universities with varying results. One of the more active of these study groups has been the Ontario ICM Task Force Made up of representatives from chemical companies, equipment manufacturers and distributors, seed companies, government agencies and other interested parties, this group publishes an annual report, The ICM Reporter, in which current research into ICM is discussed. The 1987 ICM Reporter includes research on Production, Fertility, Fungicides and Plant

Growth Regulators (ICM Task Force 1988). These reports are somewhat limited in focus, being presented for individual experiments of various concerned parties to the ICM Task Force.

3.2.4.2 Sheard, Newdick and Beauchamp (1986)

Barley trials were conducted on the variety LEGER in 1985 and 1986 by Sheard, Newdick and Beauchamp (1986). The ICM variables of interest were: nitrogen, seeding rates, row widths, PGR (CERONE) and fungicide (TILT). In addition to conducting ten field trials, the authors also estimated quadratic regression equations (for each of the field trials) in order to calculate the nitrogen rate at which the maximum yield was obtained. By estimating a quadratic equation for the results of each field trial, optimization allows for the determination of the nitrogen rate required to produce the maximum yield.

An interesting economic perspective of this study was the calculation of a *Most Economic Yield* (MEY)[7] that the producer could determine prior to production. MEY is defined by the authors as that level of production which, taking into account the prices of the input (nitrogen) and output (barley), would optimize the Law of Diminishing Returns. The result is the calculation of that rate of nitorgen application where the cost of the last unit of applied nitrogen is equal to the value of the additional barley produced. Through a MEY-estimating

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[7] In Sheard (1988), the abbreviation MEY is used interchangeably to represent (i) Most Economic Yield and (ii) Maximum Economic Yield

Through a MEY-estimating equation presented in this paper, rates of nitrogen fertilization required to attain the MEY could be determined. To improve this equation, the authors then recommend adjustments to the economic equations for variations due to site differences (climate and soil conditions, *etc.*). The field trial results indicated that two of ten barley sites exhibited better CCM yields than the ICM plots. This could have been due to moisture stress the crops experienced (p.3). Finally, the authors generated response surfaces to depict yield responses to nitrogen for both ICM and CCM crop management regimes: In both cases, there was little response at low nitrogen levels, whereas at higher levels, ICM practices showed a levelling off of the response surface and the CCM response surface actually exhibited a yield depression (p.9). Ultimately, the authors concluded that there was little interaction between the management system and nitrogen use (p.3).

3.2.4.3 Martin and Brown-Andison (1986)

Martin and Brown-Andison (1986) studied the effects of ICM components in Ontario (winter) barley and wheat production. Their objectives were to determine the effects of high nitrogen fertility, CERONE and BAYLETON on yield and quality, defined as protein content (PC), moisture content (MC) and thousand kernel weight (TKW) (p 1). The report also discussed the variable production cost effects of the various ICM treatments in order to determine profitability. The barley variety LEGER was tested at five locations across Western Ontario, whereas the winter wheat AUGUSTA was tested at a single location (Chatham). Conventional versus intensive crop packages were differentiated with respect to higher nitrogen fertilization and seeding rates as well as to whether or not CERONE and BAYLETON were applied.

The results were reported to show no significant location differences across the barley trials (p.3). CERONE was reported to be highly effective at reducing plant heights and lodging, while exhibiting no effect on PC or MC. BAYLETON also exhibited no effects on yield quality measures, while showing significant increases in yield quantity. Finally, increased nitrogen and seeding rates similarly exhibited increased yields (p.13). In the wheat trials, CERONE significantly reduced plant heights and increased protein content. BAYLETON applications increased TKWs whereas increased nitrogen rates exhibited no effects of significance.

The economic assessment consisted of a cost/benefit analysis with harvesting time and yield quantity as parameters. For barley, the results suggested that CERONE and CERONE+BAYLETON treatments would have been profitable only from CCM plots, based on five-year barley price averages (p 22) The CCM barley plots exhibited yield increases of higher significance than the ICM plots. Fungicide trials were inconclusive. For wheat, no analysis was performed due to a lack of significant data.

In their conclusions, Martin and Brown-Andison referred to a serious need for time-series data. Barley was considered to be more prone to lodging, and therefore more likely to benefit from ICM inputs. However, for the 1985 growing season, the expected effects of ICM inputs were not substantiated, likely due to the highly favorable growing conditions (no serious disease or lodging problems)(p.26). Wheat may have similarly been affected by the favorable weather, thereby limiting the expected benefits of the ICM inputs (p.26). The authors noted that high levels of nitrogen fertilizer were imperative to the success of an ICM program. They suggest that producers were probably applying less than 75% of the recommended Ontario Ministry of Agriculture and Food (OMAF) nitrogen levels in 1985 (p.27).

3.2.4.4 Bossuyt (1987)

The primary objective of a research project by Bossuyt (1987) was to determine the economic feasibility of adopting ICM components in Western Ontario. Bossuyt suggested that conditions in Atlantic Canada are dissimilar enough that the results of those trials were not of much value in making recommendations to Ontario producers It was therefore necessary to design ICM experimental packages which were better-suited to Ontario conditions.

To control for variations due to weather and market conditions, constraints were placed on varieties and locations to reduce variability as well as derive results which were practical and representative (p.6). Yield parameters that were measured include: yield, protein content, moisture content, thousand kernel weight and harvest time. These were used to calculate an associated benefit for each of the parameters. Plant heights and a lodging index were also reported but no costs were evaluated for these measures. Weather conditions were briefly described. The study used marginal analysis to develop a methodology based on cost/benefit analyses. Break-even prices were calculated based on inputs and costs.

Barley was tested by Bossuyt at two seeding rates and two nitrogen rates Each of these was then sub-divided into three trials: (i) check; (ii) CERONE at Feekes' Growth Stages (FGS) 8 to 10[8], and, (iii) BAYLETON at the same time as CERONE Winter wheat trials were conducted at one seeding rate only, and with high nitrogen rate (185kg/ha) and conventional rates (101kg/ha), in three applications

Bossuyt reported the following results on spring barley:

(1) significantly reduced lodging index and plant heights with CERONE in both ICM and CCM plots,

(2) CERONE applied to CCM plots exhibited non-significant yield increases although the increases were significant in the ICM system,

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8 Refer to APPENDIX TWO for an illustration of Feekes' Growth Scale

(3) thousand kernel weight slightly increased under ICM,

(4) CERONE did not appear to affect protein content, moisture content;

(5) thousand kernel weight, protein content and moisture content did not appear to be affected by CERONE/BAYLETON applications in ICM and/or CCM,

(6) fungicide alone affected yields in both packages,

(7) increased nitrogen and seeding rates increased yields significantly,

(8) thousand kernel weight appears to be decreased by higher nitrogen rates and seeding rates although other results tend to dispute this finding (p 36)

Ultimately, the economic analysis was conducted solely on the barley results This was due to not having significant yield increases available for the wheat trials. All ICM components increased barley yields and PGR plots were all fully erect at harvest time whereas lodging occurred in check plots (p.36) Conventional (CCM) packages produced the highest average yields. Bossuyt found that 1985 would not have been profitable for wheat or barley Barley prices were highly variable and 1985 prices did not support the increased costs of ICM inputs Other years in the 1980's exhibited higher barley prices and in most of these years, production under similar ICM conditions could have been profitable (p.83)

Bossuyt's study was limited by the fact that data were collected for one year only. No optimization was attempted, nor were soil tests conducted All of this makes the task of drawing realistic and practical conclusions almost impossible. Bossuyt recognizes that inputs are frequently applied in research even though they may not be required. This has an influence on the cost-effectiveness of the program. Mention is made that production functions can be used to give response curves for inputs, but there is no further comment on using this procedure (p.15). Bossuyt also recognizes the need for expanded role for management input (p.21). Bossuyt cited other studies conducted on ICM in 1985, but generally these exhibited mixed results with respect to yields and profitability.

3.2.4.5 Sheard (1988)

Sheard (ICM Task Force 1988) evaluates three varieties of hard red spring wheat for *Maximum Economic Yield* (MEY), across two seeding rates, five nitrogen rates, and, with and without the fungicide TILT. Results showed that all varieties responded positively to TILT, with the variety MAX out-yielding varieties from Western Canada two-fold. Increasing seeding rate by 25% resulted in increases of heads per meter squared in MAX by 22%, KATEPWA 11% and COLUMBUS 4.6%

Furthermore, these experiments suggested positive interactions between seeding rates and fungicide application Three-way interactions between seeding rates, fungicides and nitrogen showed positive responses in kernels

-per-head at low seeding rates, no fungicide and low nitrogen. A low seeding rate with fungicide and high nitrogen showed a greater increase in yield response (ICM Task Force 1988).

3.2.5 Western Canada

3.2.5.1 Stewart (1985)

Stewart (1985) notes that, although there was considerable interest in the 1980's, the Western Canada ICM test results were either inconclusive or negative (economically infeasible). Feasibility in these studies was apparently carried out through cost/benefit analysis. However, in spite of this, Stewart suggests that coastal British Columbia and irrigated prairie croplands could have good potential for ICM production (p.11).

3.2.5.2 Stobbe, Rourke and Bedard (1985)

In 1985, Stobbe, Rourke and Bedard reported on a Manitoba project with objectives to evaluate the grain yields of several wheat cultivars across a number of management levels The trials were carried out at three locations Portage la Prairie, Minto and Morris The ICM management components were higher seeding rates, increased nitrogen and varying seeding dates This study did not include an economic analysis. The authors concluded that increases in management generally brought about increased yields, as did earlier seeding dates (pp.3,4). Furthermore, the study concluded that neither higher seeding rates nor higher nitrogen rates had any significant yield effect, whereas location did (p.5). Finally, it was concluded that the highest yields were obtained when a complete ICM program was practiced (no single input could be used to adequately measure ICM technology). This study's results were affected by the 1985 crop season's weather: a season cooler and wetter than normal contributed to very high yields.

3.3 Survey of Economic Literature

3.3.1 General

The issue of nutrient (input) substitution was raised in the Section 2.6 (*cf.* p.17) as a determining factor in the choice of production (response) function to be used to model ICM technology As mentioned, economic production models tend to differ from agronomic growth models on this question of substitution. Some agricultural economists have tried over the years to reconcile this difference by incorporating aspects of the agronomic growth into economic models

Lanzer, Paris and Williams (1987) suggest that setting the problem of fertility analysis into a joint agronomic and economic context requires that five agronomic principles be considered. They are:

1) the *Law of the Minimum* proposed by Justus von Liebig,
2) the notion of a plateau maximum of a yield response function,
3) the influence of weather and soil-type conditions upon the response function,
4) fertilizer carry-over effects,
5) the calibration of soil tests (p 2)

Lanzer *et al.* go on to list a number of early attempts by agronomists to explain yield response functions to nutrient inputs (pp.2-5). Included in their list are models proposed by von Liebig (Liebig 1840; Redman, J.C. and Allen 1954), Mitscherlich (Russell 1973), Baule (Heady and Dillon 1961) and Balmukand (Balmukand 1928; Heady and Dillon 1961).

An example of an agronomic model attempting to be set into an economic context is the *Linear Plateau and Response Function* (LPRF) (Cate and Nelson 1971; Waugh, Cate and Nelson 1973). This function brings together the notions of a plateau yield (maximum) over a range of nutrient addition, as well as an input substitution elasticity close (but not equal) to zero The basis of this model can be traced to two earlier models, von Liebig's and Mitscherlich's

Justus von Liebig proposed a law of plant growth which was developed into a central principle of agronomic theory, *The Law of the Minimum* (Lanzer *et al.* 1987) This law states that plant growth is limited by the availability of individual nutrients. Furthermore, the plant will respond in a linear fashion to the most limited nutrient. As long as any one nutrient is limited, further plant growth is impeded (Lanzer and Paris 1981; Ackello-Ogutu, Paris and Williams 1985; Lanzer *et al.* 1987; Paris and Knapp 1989).

The Mitscherlich model was originally proposed in 1909:

$$y=A*(1-\exp(-c*(b+x))) \qquad [3.1]$$

where y is yield, x represents a variable nutrient, and A, b and c are parameters (Lanzer *et al.* 1987, 2). This equation exhibits diminishing returns for all $x>0$, and y approaches A asymptotically from below. As illustrated in Figure 3.1, the shape of equation [3.1] is that of a plateau function,

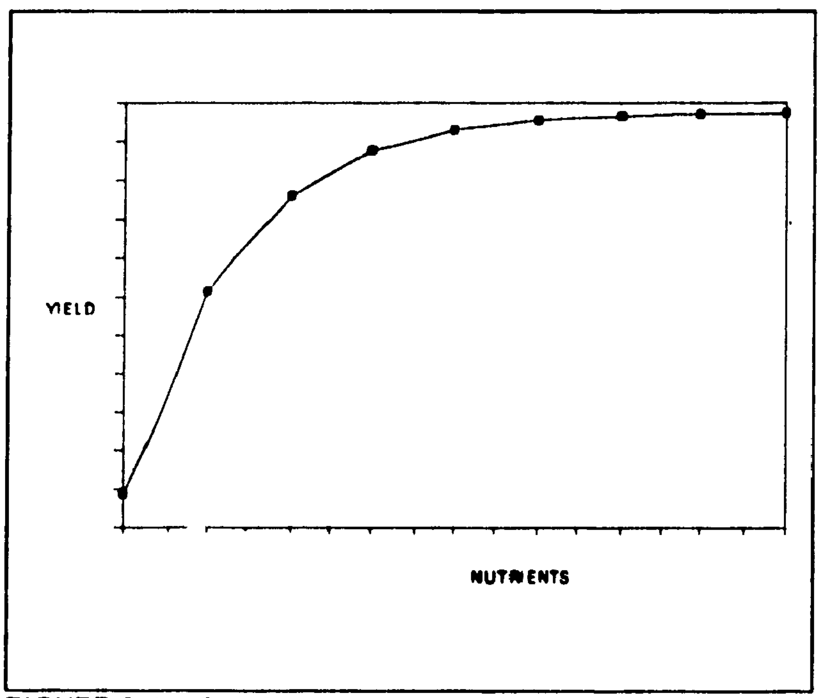

FIGURE 3.1: The Generalized Mitscherlich-Baule

extending over a significant range for macro- nutrients such as nitrogen, phosphorous and potassium (Lanzer and Paris 1981, 94; Lanzer *et al.* 1987, 2) The parameter *A* expresses Mitscherlich's proposition that plants exhibit a maximum yield even in circumstances of unlimited nutrient availability. This parameter incorporates the notion of the yield plateau and in more contemporary research, this notion is discussed in terms of a maximum yield potential for plant varieties (Waugh *et al.* 1973; Union Carbide Agricultural Products Company 1985, 5).

Beyond this (maximum) threshold, it is suggested that the plant has exhausted its potential for incremental growth response to available nutrients. This threshold is sometimes referred to as the *genetic yield potential* of a variety, and such a threshold may be calculable for each variety of plant under managed conditions. Parameter *b* represents the level of nutrient fertilizer in the soil prior to the addition of *x* Finally, the coefficient *c* was theorized by Mitscherlich to be a constant for each nutrient, unchanging in different crops or even under different growing conditions. (These effects would instead influence the parameter *A*.) This parameter *c* represents the proportion of each nutrient that could be utilized for plant growth This parameterisation of the nutrient effect (*c*) and the inclusion in *A* of all environmental effects created a considerable controversy among Mitscherlich's contemporaries, who suggested that the use of *A* to measure crop, soil and weather effects on yield was inappropriate (Lanzer *et al.* 1987, 2).

A second point of contention was that equation [3.1] did not account for possible yield depressions with increasing nutrient levels. This possibility was reported by Mitscherlich's critics who had tested his equation (Jonsson 1974, 88). In fact, the original Mitscherlich equation did not allow for either an initial stage of increasing returns to an added nutrient, nor a final stage of yield depression. Agronomists have since concluded that the initial stage is relatively short, and the final stage is well beyond the range of sensible nutrient applications (Lanzer *et al* 1987, 2).

In response to his critics, Mitscherlich reformulated his model although Jonsson (1974) reports that the reformulation appears to have been used by no one except Mitscherlich himself Lanzer and Paris (1981) suggest that the notion of a plateau response as presented by Mitscherlich is still widely used by applied researchers in the soil sciences (p 94).

Mitscherlich's Relative Yield Theory (MRYT), as developed from the original Mitscherlich equation, recognizes that yield could be expressed as a percentage of A, the asymptotic maximum. This gives rise to an expression of the relative yield, and hence the MRYT:

$$\frac{y}{A} = 1 - \exp(-c*(b+x)) \qquad [3.2]$$

where all symbols are the same as in [3.1] (Lanzer *et al.* 1987, 5).

The notion of soil fertility carried over from past seasons, represented by the parameter *b* in [3.1; 3.2], is another aspect of agronomic modelling Fertilizer carry-over functions have been developed to express the observations that soil nutrients can be carried in the soil from season to season, and that these nutrients are available in subsequent seasons to new plants These functions point to the importance of soil tests in determining the requirement for additional nutrients to reach and maintain optimum soil fertility for profitable crop production (Lanzer *et al.* 1987; Stemeroff 1987).

In past research, von Liebig's *Law of the Minimum* has been brought together with *Mitscherlich's Relative Yield Theory* (MRYT) to develop response functions referred to as either

(i) a von Liebig Function (VLF) (Ackello-Ogutu, Lanzer and Paris, 1981 Paris and Williams 1985, Paris and Knapp 1989) or,

(ii) a Mitscherlich-von Liebig model (Lanzer *et al* 1987)

By bringing together Mitscherlich's model (incorporating the MRYT and a plateau yield) and von Liebig's (nutrient non-substitution and linear response functions), the LRPF model presented a link between agronomic and agricultural economic research into crop response The LRPF model is characterized by the linear functions of increasing response, a plateau maximum and decreasing returns only after a great range of increased nutrient application. Elasticity of input substitution equals zero in the von Liebig model although limited nutrient substitution is allowed in the LRPF model (Waugh *et al.* 1973, 43).

Perrin (1976), in referring to the LRPF model, notes that the response curves generated are quite flat on the top, similar in shape to those of empirical agricultural economic studies. Given this, Perrin concludes that there are only two nutrient levels of interest in the LRPF model: none at all, and the amount required to reach the yield plateau (p.57).

The LRPF model has two potential virtues according to Perrin. Firstly, because polynomial production functions tend to result in fertilizer recommendations at levels higher than farmers are willing to undertake, recommendations from linear production functions will be, on average, as valuable to producers (p.59) The second potential virtue is the easy graphical estimation. Perrin refers to a possible drawback in that serious specification errors are possible with estimating this model due to model inflexibility regarding the slopes of the response surface, and the unlimited availability of other major nutrients (p.57) The estimation technique of the LRPF model is carefully outlined in (Waugh, *et al* 1973). The estimation of von Liebig functions is detailed in Perrin (1976), Lanzer and Paris (1981), Ackello-Ogutu *et al.* (1985), Paris and Knapp (1989).

The *Generalized Polynomial Production Function* (GPPF) is the family of multi-variate production functions reflecting classical economic theory. Since Baum, Heady, Pesek and Hildreth (1957) set fertilizer response research into an economic framework, there have been innovative specifications of the basic response function as well as methods by which to estimate these including first, second and third-degree functions, square-root, translog and transcendental functions (Parks 1956; Lanzer *et al.* 1987) Frank, Beattie and Embleton (1990), and others suggest that the quadratic (second-degree) function has become the most popular specification for crop response functions (Lanzer *et al* 1987, 2, Frank *et al.* 1990, 598). The quadratic is characterized by an isoquant map which exhibits smooth, convex curves suggesting input substitution elasticities which are non-zero. Furthermore, the quadratic function exhibits diminishing marginal productivity (no yield plateau), and linearity in the parameters that makes Ordinary Least Squares (OLS) regression a possibility (Lanzer *et al.* 1987). With respect to Mitscherlich's "parameterisation" of soil and weather effects, agricultural economists recommend that these effects be incorporated as explicit variables in generalized yield response (production) functions (GPPFs) for each of the conditions (Lanzer *et al* 1987, 6) This approach is in contrast to Mitscherlich's incorporation of these effects in the parameter *A* Note that Sheard *et al.* incorporate soil management and weather effects as a single, comprehensive variable (similar to Mitcherlich) and set this variable into a quadratic equation where it is treated like any other input variable.

Generalized polynomial functions however have been criticized by a number of authors for the restrictions they impose on the data as well as the inadequate recommendation estimates they generate (Waugh, *et al.* 1973, 4; Perrin 1976, 57; Just and Pope 1979; Lanzer and Paris 1981, 102; Ackello-Ogutu *et al.* 1985, 879). In crop response investigations, the exact physical relationship is usually unknown. Therefore, polynomial approximations (such as the quadratic) have often been chosen for economic analyses because of the computational ease and high degree of fit (Ackello-Ogutu 1985, 873). Traditionally agricultural economists have analyzed fertilizer response by imposing smooth response curves (Perrin 1976, 59-60). By fitting smooth curves, quadratic equations introduce the appearance of biological substitution between nutrients which may not be present. Paris and Knapp (1989) suggest that the effects of nutrient carryover are largely ignored in polynomial specifications (p 102) Further, Ackello-Ogutu *et al.* (1985) suggest that the quadratic equation parameters do not lend themselves to easily discernible agronomic interpretation

With regard to fertilizer recommendations, Waugh *et al.* (1973) suggest that quadratic equations characteristically over-estimate the measured yield at the zero rate of applied nutrient. This specification tends to underestimate yields at the first nutrient rate and overestimate at intermediate rates Fertilizer rates for maximum yields are thereby unrealistically high (p. 51)

In cases where the functional specification is not obvious, there are a number of ways production function research can commence Waugh *et al* (1973) suggest submitting the results of individual experiments to several linear and curvilinear models and subsequently selecting the model with the best R^2 fit (p.3). Wade (1961) suggests estimating regression equations, starting with a first-degree function, then a second-degree function, and so on. If one model is only marginally better in terms of fit (or unexplained variability) than a previous model of a lesser degree, then it is suggested that the simpler model be chosen over the more complex one (p 8) Heady and Dillon (1961) proposed a number of criteria to guide the selection Their suggested first step of consulting previous research was not successful in this project (p 203) To date, the survey of ICM has produced only one production function study, that of Sheard *et al.* (1986) where quadratic regression equations were estimated for nitrogen in order to determine the Most Economic Yields for barley production (*cf* p 48) The most common form of economic assessment for other studies surveyed was the cost/benefit analysis. Indeed, the role of the production function was not discussed in any of the other studies although it was sometimes mentioned as a factor to be investigated (*eg.* Bossuyt (1987)).

A subsequent survey of conventional (CCM) input technology research literature produced possible alternatives, many of which have been previously mentioned. The von Liebig and the quadratic production function models represent divergent choices from this survey. However, from the previous discussion it is apparent that both are restrictive in one regard (*eg.* the existence of a yield plateau) or another (*eg.* nutrient substitution). Clearly, the appropriate functional specification lies in a mix of these two paradigms. The required specification would need to be flexible enough to allow for both nutrient substitution, albeit to a limited extent, as well as a yield plateau.

Frank *et al.* (1990) suggest the *Mitscherlich-Baule Model* as a flexible specification which embodies these characteristics. Further examination of this functional form suggests that it is capable of representing an appropriate union of agronomic and economic theory while being true to the observed realities of crop growth In testing the Mitscherlich-Baule model against the quadratic and von Liebig models, Frank *et al* found the Mitscherlich-Baule to be very promising, in some cases outperforming the other two models.

For this project the Mitscherlich-Baule model was chosen as a compromise model for parameter estimation. This specification incorporates the agronomist's notion of a yield plateau. However, the Mitscherlich-Baule is a compromise in that the model allows for limited nutrient substitution, a notion not widely recognized in the agronomic paradigm of crop response (*cf* pp 17-18).

3.3.2 The Mitscherlich-Baule Model

In 1918, Baule generalized Mitscherlich's original equation to two or more nutrients:

$$y = A * \prod_{i=1}^{n} (1 - \exp(-c_i * (b_i + x_i))) \qquad [3.3]$$

In this model, all symbols are the same as in [3.1] (Lanzer *et al.* 1987). Like most agronomic models of crop growth, the Mitscherlich-Baule equation was not initially accepted by agricultural economists Slowly, and mostly in the last two decades however, there has been an acceptance of models like the von Liebig and the Mitscherlich-Baule by agricultural economists As these models have been tested, they have often been found to be as good as, and in some cases better than, the generalized polynomial specifications favored by economists (Perrin 1976; Ackello-Ogutu *et al.* 1985; Grimm, Paris and Williams 1987; Frank *et al.* 1990).

The Mitscherlich-Baule specification takes the exponential form that soil scientists favor. It incorporates the notion of the von Liebig-like yield plateau, expressed through parameter *A*. Frank *et al.* (1990) state that the Mitscherlich-Baule form is very flexible with regard to isoquant convexity (p.598). The isoquants derived from the Mitscherlich-Baule model have a rectangular-like shape, but not rigidly right-angled as would be expected with a fixed-proportions technology model (such as the LRPF or a Leontief model) (p.601) This suggests a capacity for the equation to exhibit factor substitution if the experimental data so indicate On this matter, Frank *et al.* note that, as the nutrient input levels get arbitrarily large, the elasticity of substitution approaches zero This indicates that the isoquants will exhibit flat or vertical portions at high rates of input On the other hand the authors conclude that, as the response surface is not everywhere vertical or horizontal, then there is a limited range of substitution possible (pp 598-9)

Frank *et al* (1990) reported that when tested against the quadratic and von Liebig models with respect to nutrient substitution and yield plateaus, the restrictions imposed by the Mitscherlich-Baule model were deemed to be quite appropriate. Other properties of the Mitscherlich-Baule model suggest that this is an appealing specification to represent ICM technology. The function is parsimonious in parameters and exhibits an ease of interpretation and computation. These are qualities highly desirable of the chosen form for a production function study (Hu 1973, 62-3; Fuss, McFadden and Mundlak 1978, 224). Finally, a recommended characteristic of the designated functional form, namely good predictive power, seems to have been verified by Frank *et al* (1990)(p.599). Furthermore, this article suggests that the Mitscherlich-Baule model minimizes the costs of mis-specified fertilizer recommendations when compared to two other models (a quadratic and a transcendental function). Frank *et al.* ultimately conclude that the Mitscherlich-Baule model equation is a suitable form to represent growth response to added nutrients. The authors suggest that there are no empirical grounds to rule out a limited degree of nutrient substitution, nor to rule in a point maximum on the response curve and thereby diminishing productivity (within a reasonable application range)

3.4 Summary of CHAPTER THREE

In a review of the agronomic literature, the inputs of ICM technology were found to be classified into two categories. those which aid plants to yield their full potential, and those which protect the plant's potential yield from yield-reducing pests and other factors The most common elements of an ICM package were determined to be·

- nitrogen fertilizer,
- a plant growth regulator,
- a fungicide

The following elements were also reviewed:

- field preparation and planting,
- seed varieties and quality,
- seeding rates and depth,
- planting date,
- row width,
- tramlines,
- application timing,
- insecticides and herbicides,
- producer management efforts

A survey of Agronomic-Agricultural Economic literature follows, which reviews a number of studies, region by region, from across Canada and presents the results and conclusions of each study. This is followed by a survey of economic literature which suggests that the two distinct paradigms upon which the theories of crop response are based, differ on the treatment of the issue of nutrient substitution Three studies which have been identified as attempting to bridge the two paradigms are reviewed and their results presented The model specification presented in one of these studies (Frank, Beattie and Embleton (1990)) is selected as a compromise for parameter estimation in this project

CHAPTER FOUR: RESEARCH METHODOLOGY

4.1 General Methodology

This chapter begins with a discussion of data collection along with the steps taken to prepare the data for analysis. The criteria used to select specific datasets for model formulation is set out and explained. Next, the equations to be fitted are stated and variations explained. A discussion of the statistical procedures used in estimating the quadratic and Mitscherlich-Baule equations follows. The expected results of these procedures are discussed where applicable.

Finally, a description of the analysis of fitted equations is presented Since the purpose of this project is to determine whether the Mitscherlich-Baule or the quadratic is a better fit of selected datasets, an analysis is carried out on the residual (error) values generated by the predicted equations for each of these models.

4.2 Data Collection and Preparation

Data were solicited from a number of cereal producers in Canada and the North-Eastern United States who were known to be using ICM technology. Data were received from four Québec research projects and a single producer in Western Canada. The decision was made to go forward with the data supplied by the Québec sources only, largely for reasons dealing with local climatic conditions and the varieties for which these conditions are most favorable. These four were ICM research projects being conducted in the Montréal and Lac St. Jean areas:

1) Lod's Research Centre
   Macdonald Campus of McGill University
   Ste Anne de Bellevue

2) Coop Fédérée Centre de Recherche
   Ste -Rosalie/Ste. Hyacinthe

3) Centre de Recherche, SEMICO Inc
   c/o CONCEPTRA Inc
   Ste -Rosalie/Ste Hyacinthe

4) Ministère de l'Agriculture, des Pêcheries et de l'Alimentation du Québec (MAPAQ)
   Station de Recherche de St-Bruno,
   St-Bruno-De-Montarville

All the data collected were standardized with respect to units of measure (Table 4.1), and subsequently coded according to crop, variety, management system, inputs, output, project site and crop year (Table 4.3).

TABLE 4 1 UNITS OF MEASURE

	PLANT GROWTH REGULATORS				FUNGICIDES				
NITROGEN	CERONE	CYCOCEL	TERRA.	BAYLETON	TILT	DITHANE	SEEDING RATES	ROW WIDTH	YIELD
kg/ha	<------		grams active ingredient per ha	-		>	seeds per metre²	centimetres	kg/ha

Table 4.2 illustrates the crops, number of varieties and experiments provided by each of the four projects (sites). For example, the Macdonald Campus provided barley data from nine separate experiments, involving four varieties collected over the 1987, 1988 and 1989 crop seasons.

TABLE 4.2 YEARS, VARIETIES AND EXPERIMENTS BY SITE AND CROP

	Site 1	Site 2		Site 3
	Macdonald Campus	Coop Fédérée	SEMICO (CONCEPTRA)	MAPAQ
BARLEY				
Experiments	9	9	3	N/A[1]
Varieties	4	50	4	N/A
Expt. Years[2]	3,4,5	4,5	1	N/A
WHEAT				
Experiments	N/A	7	1	1
Varieties	N/A	35	4	3
Expt. Years	N/A	3,4,5	1	6

1 - N/A (data not available)
2 - Experiment years coded as

CODE	1	2	3	4	5	6
YEAR.	1985	1986	1987	1988	1989	1990

After the data from each experiment were coded, all experimental data were aggregated into a single spreadsheet file and sorted by (i) variety, (ii) site, and (iii) year. This sort allowed for the enumeration of the number of observations

TABLE 4.3 LISTING OF EXPLANATORY VARIABLES

FACTOR:	ABBREVIATION	EXPLANATION
CROP	-	Barley: variety code 1-56 Wheat: variety code 9901-9947
VARIETY	VAR	Barley 56 varieties Wheat 47 varieties
NITROGEN	NI	All forms applied (urea, ammonium nitrate, anhydrous)
CERONE	CE	Plant Growth Regulator: active ingredient ... ETEPHON (480 grams ai./litre)
CYCOCEL EXTRA	CY	Plant Growth Regulator: active ingredient ... CHLORMEQUAT CHLORIDE (480 grams ai./litre)
TERPAL C	TE	Plant Growth Regulator: active ingredient ... CHLORMEQUAT CHLORIDE (460 grams ai./litre) + ETEPHON (230 grams ai./litre)
BAYLETON	BA	Fungicide: active ingredient ... TRIADIMEFON (50%) (140 grams ai./litre @ 50% wettable product)
DITHANE M-45	DI	Fungicide: active ingredient ... MANCOZEB - powder (80%) - granular (75% MANCOZEB + 15% manganese + 2% zinc equivalent
TILT	TI	Fungicide: active ingredient ... PROPICONAZOLE (250 grams ai./litre)
SEEDING RATE	SR	Seeds/metre squared
ROW WIDTH	RW	ICM = 10 cm CCM = 20 cm
YIELD	YLD	Adjusted to 14.5% Moisture Content
SITE	SITE	Macdonald Campus = Site 1 Ste.-Rosalie/Ste. Hyacinthe = Site 2 St. Bruno-De-Montarville = Site 3

available for each *variety/site/year* combination. Each such combination was considered to be a *dataset*. Individual datasets were then selected for further analysis based on the following criteria:

(1) that there be sixty or more observations available in a single dataset;

(2) that the selected dataset(s) exhibit a degree of variability among the input variables (*ie.* for all variable inputs applied, each was applied at a minimum of two levels, and that at least one of the variables be applied at three different levels.).

At this stage further criterion were imposed on the selection process:

(3) for barley, datasets containing the variety CADETTE be selected as this variety is considered to be well-suited to both local growing conditions and the conditions imposed by ICM technology, for wheat, the variety MAX be selected as this variety is considered to be well-suited to both local growing conditions and the conditions imposed by ICM technology

This last criteria was imposed largely due to the relatively small number of observations available for all other varieties (for both crops). Once subjected to this selection process, four barley and one wheat datasets emerged for further analysis (Mailloux, A. 1990; Smith, Leibovitch, Ma and Maloba 1992). These datasets, along with the relevant functional relationships are:

B113 Barley/CADETTE/Site 1/Year 1987
YIELD = f(NI, CE, BA, RW)

B114 Barley/CADETTE/Site 1/Year 1988
YIELD = f(NI, CE, BA, RW)

B115 Barley/CADETTE/Site 1/Year 1989
YIELD = f(NI, CE, BA, RW)

B125 Barley/CADETTE/Site 2/Year 1989
YIELD = f(NI, CE, TI, SR)

W123 Wheat/MAX/Site 2/Year 1987
YIELD = f(NI, CE, CY, TE, DI, TI, SR, RW)

The three Macdonald Campus experiments also included dummy variables to represent soil types. However, a soil type variable was not included in these three datasets. This was due to the complexity of measuring the influence of individual soil types on the ICM packages. Furthermore, soil type factors could not be explicitly accommodated in the Mitscherlich-Baule model. The datasets were then subjected to the steps outlined in Section 4.3. These individual datasets are compiled in APPENDIX THREE.

4.3 Specific Procedures

In the model generation process, estimations were accomplished through the use of: STATISTICAL ANALYSIS SYSTEM (SAS: Ver. 6.06), a statistical program available as a mainframe package (The SAS Institute Inc, 1988; 1990). Two SAS procedures (PROC REG and PROC MODEL) were utilized in order to generate both models and a brief explanation of each of the two procedures follows. A sample study will show examples of the options utilized with each of the two procedures (Section 4.8).

(i) PROC REG:

Through the use of its many options, PROC REG can produce a great deal of information on the fitting of an equation to given data, as well as extensive analysis of the generated model. In general, PROC REG produces a model for the variables entered and identified by the MODEL statement. Among the options available are nine methods which aid in the selection of an appropriate model to fit the given data. Two such methods were utilized in this project:

(a) OPTIONS = NONE
(b) OPTIONS = STEPWISE[9]

The specifics of these options are discussed in APPENDIX FOUR.

(ii) PROC MODEL:

This procedure provides a tool for the estimation parameters in systems of linear and non-linear multi-variate equations, utilizing iterative minimization methods. All estimation methods invoked by PROC MODEL "... aim to minimize a generalized mean square value, referred to in this procedure as the *OBJECTIVE*." (The SAS Institute 1988, 342)

PROC MODEL requires the use of a FIT statement that is responsible for the fitting of the equations based on initial parameter START values in the input data file. Convergence is judged to have occurred when the CONVERGENCE MEASURE is less than a pre-determined CONVERGE = value (default = 0 001, utilized throughout this project)(pp.331,347). Non-linear OLS was utilized throughout this project. With this method, the disturbance for each observation is assumed to be identically and independently distributed with a zero mean

9 For all stepwise regressions, the F-test significance level of 0 1500 was set for regressor "entry" and "stay" criteria

and positive definite covariance matrix (pp.342-3). Otherwise, there are no further assumptions concerning the distribution of errors and they need not be distributed normally (p.343).

The two methods available for the minimization of the objective function are: the Gauss-Newton and the Marquardt-Levenberg (p.346). The difference between the two is in the size of change vector that is used to calculate the objective function at the changed parameter values in between iterations (p.346). The Marquardt-Levenberg method was utilized in all PROC MODEL estimations.

4.4 Terminology

For the purposes of clarity, the following terminology will be used with regard to the various models:

FULL MODEL .. A model containing all the linear, quadratic and cross-product regressors appropriate to a specific dataset.

REDUCED MODEL ... The model that results from dropping, from the *FULL MODEL*, any regressors that are exact linear combinations of other regressors.

PARTIAL MODEL . A model where quadratic and cross-product regressors were dropped (by assumption) in order to determine the regressors for a Mitscherlich-Baule model

ADJUSTED DATASET . A dataset where the yield values have been adjusted to compensate for input variables that could not be accommodated in one of the models to be generated.

4.5 Models To Generate

4.5.1 Introduction

In order to compare the two production function specifications (the quadratic and the Mitscherlich-Baule), a number of models were generated for each dataset. Table 4.4 lists the various models under three primary headings

Model I ... The Quadratic;
Model II .. The Mitscherlich-Baule;
Model III ... The Post-Mitscherlich-Baule Quadratic.

Given different assumptions regarding the regression procedures used for Model II, a number of steps (Table 4.4) were utilized to generate the Mitscherlich-Baule model Of these, the first two are required to generate the Mitscherlich-Baule model The third step is optional, utilized to generate a second Mitscherlich-Baule model, the necessity of which is explained in Section 4.5.3.

TABLE 4.4: Models To Generate

MODEL I	QUADRATIC MODEL	
		- quadratic (non-stepwise) regression - linear quadratic and cross-product terms (*FULL MODEL*) - if linear combinations indicated, *REDUCED MODEL*
MODEL II	MITSCHERLICH-BAULE MODEL	
Step 1		- linear (stepwise) regression - partial, *REDUCED MODEL*
Step 2		- Mitscherlich-Baule (Marquardt method)
Step 3		- Mitscherlich-Baule (Marquardt method) *ADJUSTED DATASET*
MODEL III	POST-MITSCHERLICH-BAULE QUADRATIC MODEL	
		- Post-Mitscherlich-Baule quadratic (non-stepwise) - based on results of Step 2 or 3, Model II

4.5.2 Model I: The Quadratic

Model I is the model formulated from fitting a quadratic (multiple) regression equation to each of the datasets. First, regressors that were linear combinations (exact collinearity) of other regressors were eliminated from the dataset in an OLS (non-stepwise) regression of the *FULL MODEL* Once these were removed, the quadratic equation (*ie.* the *REDUCED MODEL*) was estimated. Since this was an exploratory research project, the parameter estimates with probabilities less than or equal to 0.1500 were considered to be significant.

4.5.3 Model II: The Mitscherlich-Baule

Model II consists of a number of steps to facilitate the estimation of a representative Mitscherlich-Baule equation for each dataset Initial attempts to include all relevant explanatory variables in estimating Mitscherlich-Baule equations were unsuccessful for each of the five datasets. Therefore, a step-by-step approach was adopted as a rational procedure for the selection of Mitscherlich-Baule regressors, as some orderly pre-selection of regressors was necessary For each dataset, this step was accomplished by a stepwise regression performed with linear regressors only (*PARTIAL MODEL*) The alternative was to enumerate all possible combinations of regressors and to attempt an estimation of each combination. This would have been a time-consuming and costly approach and was therefore not adopted.

Step 1 represents this stepwise regression of the terms of the *PARTIAL MODEL* estimated under the assumptions that:

(i) a linear model would be a better approximation of the Mitscherlich-Baule equation than would be a quadratic, and,

(ii) the Mitscherlich-Baule model accommodates input interaction, but only in a limited sense

Figure 4.1 exhibits the shapes of a Mitscherlich-Baule, a linear and a quadratic

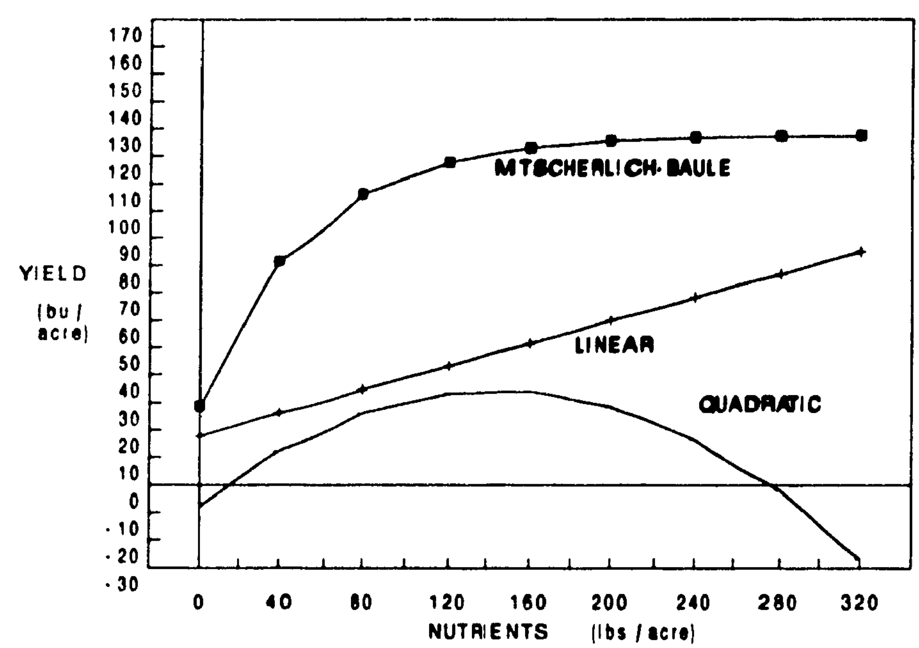

FIGURE 4.1: Single Variable Response Curves

response curve (for one explanatory variable).[10] Step 1 is therefore performed with a single objective: to indicate which linear regressors, and in which order, should be used to construct the Mitscherlich-Baule model Hence, the values of the RMSE and R^2 do not have any particular importance in Step 1 In Step 2, the Mitscherlich-Baule equation ([4.1]) was estimated based on the results of the Step 1.

$$y=A*\prod_{i=1}^{n}(1-\exp(-c_i*(b_i+x_i))) \qquad [4.1]$$

Only nitrogen (NI) was assumed to exhibit a carryover effect (from previous crop seasons). Therefore a carryover parameter, identified as *N2*, is used in the Mitcherlich-Baule equation. All other elements are expected to be entirely utilized by the crop in the season of their application. Two Mitscherlich-Baule models were generated The first was that generated in Step 2 However, due to either the nature of the dataset(s) or the limitations of the Mitscherlich-Baule model itself, the situation arose where the quadratic equation would fit many more explanatory variables than could the Mitscherlich-Baule This case was provided for in Step 3. This step is explained in relation to Model III in the next section, 4.5.4.

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10 Based on the Frank *et al* (1990) dataset

4.5.4 Model III: The Post-Mitscherlich-Baule Quadratic

For Model III, the following question was posed: *If the Mitscherlich-Baule equation were fitted first, how would a quadratic equation compare when fitted to the same explanatory variables?* This question implies the estimation of a second quadratic equation (Model III) in any situation where the terms fitted in the Mitscherlich-Baule equation are not identical to those of Model I. Two of outcom - could arise in answer to this question.

In the situation where the results of Step 1 indicate a larger number of regressors to be fitted to the Mitscherlich-Baule equation than is subsequently possible, another Mitscherlich-Baule parameter estimation could be run on an *ADJUSTED DATASET* For example, suppose that Step 1 indicates that six explanatory variables (X_1, X_2, X_3, ,X_6) should be fitted to the Mitscherlich-Baule and the subsequent Step 2 estimation(s) only converge on three of these, say X_1, X_4 and X_5 Then the dataset could be filtered to remove the influence of the variables that the Mitscherlich-Baule model could not accommodate (*ie.* X_2, X_3 and X_6). The procedure to remove the influence of these explanatory variables from the dataset is explained in APPENDIX FIVE.

Once removed, the Mitscherlich-Baule was re-estimated on the resulting dataset, referred to as the *ADJUSTED DATASET*. A second quadratic equation, the Post-Mitscherlich-Baule Quadratic Model was then estimated, based on the results of Step 3 In those cases where Step 2 successfully converged on all (or most) of the regressors indicated by Step 1, then these regressors were fitted to a quadratic equation (linear, quadratic and cross-product terms)

4.6 Comparison of Models

For comparative purposes, several models will be reported Model I, the quadratic, is based on the original dataset and therefore is only directly comparable to the Mitscherlich-Baule model generated in Step 2 On the other hand, the Step 3 Mitscherlich-Baule is generated based on the *ADJUSTED DATASET*. Therefore, any comparisons with this model must also be based on the same *ADJUSTED DATASET* Hence, when a Step 3 Mitscherlich-Baule is generated, the Model III generated will also be based on the *ADJUSTED DATASET*. Finally, Model I and Model III will be comparable, regardless of the dataset utilized in Model III This is due to the fact that here two quadratic models are being compared to determine the effect of removing certain explanatory variable influences A summary of Models I, II and III will be presented for each dataset where applicable In these summaries, the Models II and III will be those based on the *ADJUSTED DATASET* if such models were generated. Otherwise, the models presented will all be based upon the original dataset.

4.7 Notes on the Use of Multiple-regression Procedures

The question of using stepwise regression in a model-fitting procedure is the subject of considerable debate among economists, econometricians and statisticians Hocking (1976) discussed the problem of appropriate model formulation based on subsets of the original set of variables.

This problem contains three basic ingredients:

1 the computational technique used to provide the information for the analysis,
2 the criterion used to analyze the variables and to select a subset of these variables (if that is appropriate), and
3 the estimation of the coefficients in the final equation (p 3)

Hocking suggests that generalized stepwise regression is a procedure which embodies these three ingredients in the process of selecting a subset of variables to fit the final equation He notes that the stepwise procedure has been criticized on a number of points, the most common being that there is no assurance that the best subset will be revealed He suggests that this problem may not be as great as some critics assert, notwithstanding some notable exceptions (p 9) Indeed, this criticism may be somewhat hollow in that Hocking refers to another study that expresses the view that it is unlikely that there will ever be a single best model instead there will likely be several equally good models (p.9)

Wittink (1988) states that, in empirical work, the use of stepwise-like iterative procedures is often unavoidable for the purpose of identifying appropriate models (p.103) Furthermore, stepwise procedures can be used to great benefit where there are many relevant predictor variables to sort through The author goes on to suggest that the most serious limitation of stepwise procedures is that all statistical tests may subsequently be inapplicable, because the usual statisticai procedures require an *a priori* specification of the model: in stepwise procedures, the data are utilized to determine that model (p 259).

On the other hand, there are those who would dismiss stepwise and similar regression procedures as unworthy of the practice of econometrics. Leamer (1983) does not accept the use of stepwise procedures

> "It is to the credit of economists that they rarely turn over the task of selecting variables to a computer Aside from lacking a clear logical foundation, stepwise procedures almost always seek sets of variables which are relatively uncorrelated " (p 320)

The user of stepwise regression has been characterized as

> " a person who checks his or her brain at the entrance to the computer centre " (Wittink 1988, 259)

For the practitioners of the alternative approach, model selection theoretically begins with a specification the analyst knows intuitively to be correct, and is then be followed by the estimation of the parameters of the model The problem with this approach, according to Gilbert (1986) is that these practitioners are using the econometrics to illustrate theories which they believe prior to and independent of, the data. Gilbert suggests that the alternative approach might be to use the tools of econometrics to discover which views of the data are reliable, and to scientifically test any rival views.

While one may be willing to accept and rely upon prior information to propose intuitive models, the absence of such information restricts the likelihood of a prior model being formulated. In this case, alternative procedures, such as stepwise regression, become more valuable. This is especially the case when the research is of an exploratory nature, as it is in this project (Maddala 1977, 127; Wittink 1988). Over time, other research may reject this procedure in favor of more intuitively-appealing ones.

Finally, stepwise regression can also provide a clue as to the relative importance, in terms of yield effect, of each of the explanatory variables. The SAS stepwise regression procedure produces a summary of the regressors as they entered into and were deleted from the fitted model, in ascending order according to their contribution to R^2. (Refer to APPENDIX SIX.) This is a controversial move, as Hocking (1976) refers to a criticism that the order of entry (or deletion) in stepwise procedures falsely implies an order of importance of those regressors. Hocking states that this was never a claim of the original proponents of stepwise (and similar) procedures (p.9). However, there is some order implied in a model that is formulated solely by entries (*ie.* there were no deletions of regressors). This too is an assumption that may be relaxed in future research.

4.8 Testing of the Modelling Procedures

In order to ensure that the modelling process would be appropriate, especially for estimating Mitscherlich-Baule parameters, an independent dataset was acquired In their article, Frank *et al* (1990) used a dataset resulting from a 1955 "... agronomic experiment involving the yield response of corn to application of nitrogen and phosphorus . " (p 599).[11]

The data were submitted to the procedures developed in this project for the estimation of Models I-III to see if these modelling procedures would generate the same results reported in Frank *et al* (1990) Successful duplication of these quadratic and Mitscherlich-Baule model results provided confidence for the subsequent estimation of Models I-III for Datasets B113, B114, B115, B125 and W123 The resulting models (I and II) generated from this 1955 dataset are contained in APPENDIX SIX

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[11] This dataset was originally published by Heady *et al* (1955), and consists of 114 observations and involves combinations of the following input levels

Nitrogen (0, 40, 80, 120, 160, 200, 240, 280, and 320 lbs/acre)
Phosphorus (0, 40, 80, 120, 160, 200, 240, 280, and 320 lbs/acre)

4.9 Analysis of Models Generated

In each of the models generated, some measure of the goodness of fit was needed in order to compare the quadratic with the Mitscherlich-Baule specifications. Due to the fact that a non-linear regression can produce a negative R^2 value, this statistic was set aside [12] Furthermore, Aigner (1971) has suggested that the comparison of models on the basis of R^2 does not rest on a firm statistical foundation (p 91).

The statistic chosen to compare the different models was the Root Mean Square Error (RMSE) RMSE is considered a good measure of model validity as well as a surrogate measure of model predictability (Sobol 1991, 107). To ensure that the parameter estimates, standard errors and other related statistics, are unbiased and efficient, an analysis of residuals was performed. As explained in Gujarati (1988) and Wittink (1988) OLS regression requires that four assumptions be satisfied

Assumption 1 $E(\mu_i) = 0$, for all i
Assumption 2 $Var(\mu_i) = \sigma^2$, for all i
Assumption 3 $Cov(\mu_i, \mu_j) = 0$, for all $i \neq j$
Assumption 4: μ_i is normally distributed for all i

The first of these assumptions is the most important: the expected value of the error term is zero for all observations. This ensures that the parameter estimates be unbiased Usually the cause of this assumption not being satisfied

[12] R-squared values may become negative in models for which there is no intercept parameter (The SAS Institute Inc 1988, 367)

will be the omission of a relevant predictor variable or an incorrect functional form of the model being generated. Testing this assumption was carried out with the use of MERLIN (Wade 1990), to calculate the mean of the residuals as well as plotting them by observation

The second assumption states that the error variance is *homoscedastic* This assumption is most often violated by an incorrect specification (omitted variable or wrong functional form). It is important to determine if problems are due to the first assumption before attempting to remedy problems dealing with the second assumption (Wittink 1988, 181) If the second assumption is not satisfied, it is possible to generate a model with unbiased parameter estimates but inefficient standard errors. Testing of this assumption was carried out in SAS through invoking the SPEC option in PROC REG. This option generates a *Chi-squared* value, where obtaining a *Chi-squared* value corresponding to a value of 10% or more is accepted as evidence to not to reject the hypothesis of homoscedasticity (White 1980, Gujarati 1988, 316-52, Wittink 1988, 181-6, Nabebee 1992) There is no test option for heteroscedasticity in PROC MODEL

The third assumption is that errors are uncorrelated (Wittink 1988, 186) A violation of this assumption means that the error terms of the model are subject to *autocorrelation*. Again, shortcomings in the model's specification can account for non-satisfaction of this assumption. Like the second assumption, if the third is not satisfied, parameter estimates are unbiased but the standard errors are inefficient The model regressors can be transformed so that the assumption of uncorrelated errors holds for the transformed model regressors The Durbin-Watson (DW) statistic is used to test this assumption (Gujarati 1988, 353-97, Wittink 1988, 187-98) When autocorrelation was detected in models using PROC REG, the Cochrane-Orcutt method was utilized However, there was no procedure available in PROC MODEL for dealing with autocorrelation problems (Woodward 1992).

The fourth assumption states that all error terms have a normal distribution (Wittink 1988, 33). This assumption too can be violated by model mis-specification This assumption was tested along with Assumption 1 through the utilization of the FREQUENCY procedure in MERLIN. Mis-specification of the model is the most likely cause of problems with any or all of the four assumptions (Wittink 1988, 197) and will be discussed along with the solution techniques employed in the individual dataset section(s) of the CHAPTER FIVE.

As a final analysis of the modelling processes, one dataset was selected for a limited forecasting-type (prediction curve) exercise In this exercise, Dataset W123 was utilized for graphing predicted yields based on the estimated Model II and Model III equation parameters These models were generated based on the *ADJUSTED DATASET* as described above. Dataset W123 was particularly successful for this procedure as it, in its adjusted form, presented yield as a function of two inputs, nitrogen and row width This relationship of dependent variable as a function of two independent variables allows for a three-dimensional graph to be plotted using the software package SMARTWARE II[13] The three-dimensional surface allows for a visual inspection of the influence of the two independent variables on the dependent variable

4.10 Methodological Problems and Solutions

In the development of Models I-III, several problems were encountered A brief discussion of these follows Each of the datasets exhibited *exact collinearity* (linear combinations or dependency) when the *FULL MODEL* was submitted for regression Therefore, *REDUCED MODELS* had to be generated, eliminating this problem of exact collinearity However, and especially with Datasets B113-5, multicollinearity problems remained Steps to solve this problem were not taken

The nature of this research project, as an exploratory exercise, leads to models which include large numbers of explanatory variables This frequently gives rise to multicollinearity (Freund and Littell 1992, 93) The effect of multicollinearity is evident in the inflated variances of predicted values and parameter estimates The existence of multicollinearity does not violate the assumptions underlying the use of OLS regression, so the estimates are still

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13 SMARTWARE II is a PC Integrated Software package with graphics capabilities (INFOMIX Software Inc 1991)

best linear unbiased (BLUE). More to the point, the nature of multicollinearity, once detected, is difficult to diagnose and more difficult to correct. There is no universally accepted strategy for this task (Freund and Littell 1992, 93).

Non-linear-in-parameters (OLS) regression was performed using PROC MODEL to estimate the parameters of the Mitscherlich-Baule equation (Model II). (Refer to APPENDIX SIX for an illustration of the estimation procedure.) A number of problems were encountered. The first problem resulted from the failure of the program to converge given the data and start values, a problem encountered with all datasets. Two potential solutions were attempted (Frank 1992) The first involved scaling the input data. This was effective once all data were scaled-down by a factor of 1000. The second was the use of the Marquardt-Levenberg iterative minimization method (The SAS Institute 1988, 346), coupled with an Ordinary Least Squares (OLS) parameter estimation technique to generate the Mitscherlich-Baule model (Model II) (*cf.* Section 4.5.3) These two suggestions were implemented for all subsequent Mitscherlich-Baule parameter estimations.

Another problem encountered was due to the nature of the input data and the Mitscherlich-Baule model Early attempts to simultaneously estimate the parameters *A*, *N1* and *N2* were unsuccessful and a strategy was developed to obtain better starting values As previously discussed, *A* represents a genetic yield maximum for each crop variety (*cf* Section 3.3) and *N2* represents an estimate of the nutrient carry-over from the previous growing season, measured as a percentage. The solution implemented was to impose a value for *A* based on the yield data in each dataset and practical knowledge of the crop-growth process. In consultation with agronomists, including soil scientists familiar with the soils from which these crop yields were gathered, an estimate of *N2* was also made. This value was initially set at 10%.

The Mitscherlich-Baule equation was then re-estimated, first by imposing values for *A* and *N2*, and estimating *N1*. The parameter estimate for *N1* was then imposed, along with *N2*, and the value for *A* was estimated Subsequently, with parameter estimates for *A* and *N1* used as start values and only *N2* being imposed, the estimation was re-run (two out of three parameters are freely estimated) If the equation was not successful after a number of different starting values, the model was considered to be unable to converge for this particular dataset

Where there was a successful convergence, the model-building continued. The next step was to impose *A* and *N1* and estimate the value of *N2* With an estimated value for *N2*, all three (*A*, *N1* and *N2*) were set as start values and finally re-estimated simultaneously. There was now a model, assuming successful convergence, in which all three parameters were fitted freely from the dataset

Once an equation fitting the parameters *A*, *N1* and *N2* converged, another explanatory variable was brought into the Mitscherlich-Baule equation. Only if all parameters could be entered as start values (*ie*. no parameter values imposed) and the equation converged, was that model considered to be successful. This step-by-step model-building process was the most efficient method found although not all datasets supported the development of a multi-variate Mitscherlich-Baule model.

4.11 Summary of CHAPTER FOUR

CHAPTER FOUR presents a discussion of the methodology utilized in this project, beginning with the data collection and preparation steps. This is followed by identifying and briefly discussing the procedures that were used to generate the models (PROC REG and PROC MODEL in the program SAS).

The development of the three models generated for this project is then explained in detail accompanied by a discussion of the controversial nature of certain of the model-generation steps. The analysis used for all models was then presented along with the assumptions and test statistics that were utilized to compare the different models The chapter ends with a discussion of problems encountered in the modelling steps and the solutions subsequently implemented.

CHAPTER FIVE: RESULTS AND DISCUSSION

5.1 Introduction

In this chapter, all results are arranged by dataset, B113-5, B125 and W123. The models generated by each dataset are presented and discussed in the following order (as applicable):

- Model I . Best-fit Quadratic model
- Model II . Mitscherlich-Baule model
- Model III Post-Mitscherlich-Baule Quadratic model

Model I was generated by fitting all possible regressors to an OLS, quadratic regression Model II results from the estimation of the Mitscherlich-Baule equation. Model III is a quadratic regression that used the same regressors as the Mitscherlich-Baule equation in Model II. Only those datasets that generated a result from Model II were used to subsequently generate a Model III result. In some datasets, an additional Mitscherlich-Baule and quadratic model were generated, based on an *ADJUSTED DATASET* (*cf.* Sections 4.5.3, 4 5.4)

First the equations for Models I-III will be presented, accompanied by a discussion of each of the models and their significant details. Those datasets which did not produce a Mitscherlich-Baule equation (namely, Datasets B113-5) were not subjected to any further analysis, such as testing for heteroscedasticity or autocorrelation. Hence, Datasets B113-5 are discussed only in terms of RMSE's and R^2's, and Durbin-Watson and Chi-squared test statistics are not presented.

This is followed by a brief summary of the steps taken in the formulation of the reported Mitscherlich-Baule model equation, and a residual analysis (cf. Section 4.9). After the presentation of the estimation results, the quadratic (Model I) and the Mitscherlich-Baule (Model II) equations will be compared where applicable. This discussion will focus on the root mean square error (RMSE) statistic as the measure of goodness of fit. The results for the Mitscherlich-Baule (Model II) and the Post-Mitscherlich-Baule Quadratic (Model III) equations will also be discussed. Note again, that these models will be compared based on the dataset from which they were generated. This is followed by a comparison of Model I and Model III, the two quadratic model equations.

Following the presentation of Datasets B113-5, a test is run to determine if there are significant differences between the estimated Model I quadratic functions for these three datasets. This step is undertaken as there is a unique opportunity offered by these datasets. Each dataset results from the same experiment, carried out in the same location for three consecutive years. The Chow Test (Chow 1960) was selected to test whether the estimated functions are significantly different from year to year. This test suggests that if the estimated functions are found to be significantly different from one another, then the relationship represented by these functions changes from one dataset to the other (Koutsoyiannis 1984, 164-167).

Lastly, Dataset W123, the one with the closest relative fit between the Mitscherlich-Baule and the Post-Mitscherlich-Baule Quadratic models will be used to carry out a prediction surface analysis. This analysis will be used to generate graphs (response surfaces) that will be used to illustrate the differences and similarities of the two models

5.2 DATASET B113:

5.2.1 Introduction

Dataset B113 consists of seventy-two observations of an field trial conducted on ICM technology, utilizing the following protocol:

crop	.. barley
variety	CADETTE
site	Macdonald Campus
crop season	1987
ICM inputs and rates	
	nitrogen (0, 70 & 140 kg/ha)
(EXPLANATORY	CERONE (0 & 480 g ai/l)
VARIABLES)	BAYLETON (0 & 140 g ai/l)
	row width (10 & 20 cm)

This experiment involved seventy-five trials. The Dataset B113 consisted of only seventy-two observations after three of the trial observations were rejected as they were incorrectly recorded. This experiment is the first year of a three-year experiment on ICM barley production conducted at Lod's Research Centre, Macdonald Campus.

5.2.2 Quadratic Model: Model I (B113)

The initial regression procedure indicated four regressors which exhibited linear dependency (exact-collinearity) with other regressors in the *FULL* model. These regressors were dropped and the regression run again on the *REDUCED* model. Table 5.2.1 presents the results of this regression

TABLE 5 2.1   MODEL I   REGRESSION OPTION = NONE

Variable	Parameter Estimate	Standard Error	T for H0. Parameter=0	Prob > |T|
INTERCEPT	4173 659857	1727 9434959	2.415	0.0186
NI	9 067737	16 4116505	0 553	0.5825
CE	- 0 713187	1 2928063	- 0 552	0.5831
BA	9 590538	8 3650307	1 147	0.2559
RW	26 682975	62.0547042	0 430	0 6686
NI**2	0 053468	0.0823164	0.650	0.5183
NI*CE	- 0 011607	0 0126832	- 0 915	0.3635
NI*BA	- 0 093187	0 0729691	- 1 277	0.2062

R^2 = 0 1218   ADJ R^2 = 0 0258   RMSE = 968 6660

Model I is a poor fit for this dataset on the basis of t-statistics and the adjusted R^2 value (2 6%), both of which indicate that the model has little explanatory power Clearly this dataset has structural problems possibly inherent in the experimental design The t-statistics for the regressors suggest that none of these terms are significant (Prob > |T|) are all greater than 0.1500) at the 15% level.

5.2.3 Mitscherlich-Baule Model: Model II (B113)

This section describes the processes used for selecting the regressors for the Mitscherlich-Baule parameter estimation and the subsequent specification of the Mitscherlich-Baule model. Step 1 consists of conducting a stepwise regression on the linear terms using a 0.1500 significance criterion The results are presented as Model II - Step 1 in Table 5.2.2. Presented with this model is a summary of the stepwise selection process which indicates the order in which regressors enter the stepwise procedure

TABLE 5.2 2 MODEL II - Step 1 (0 1500) REGRESSION OPTION = STEPWISE

Variable	Parameter Estimate	Standard Error	F	Prob>F
INTERCEPT	5773 617647	162 8893261	1256 35	0 0001
CE	- 1 125190	0 4671171	5 80	0 0186

R^2 = 0.0765 ADJ R^2 = N/A RMSE = 949 7998

Summary of Stepwise Procedure

step	Variable entered	removed	Number in	Partial R^2	Model R^2	F	Prob>F
1	CE		1	0 0765	0 0765	5 8023	0 0186

Only the regressor CE is selected by the stepwise regression for building the Mitscherlich-Baule model The other regressors, NI, BA and RW were not significant at the 15% level Note that the R^2 values are not of concern in Step 1. The sole objective of this step is the order of selected regressors in the generation of a Mitscherlich-Baule model. Step 2 of Model II uses the regressors selected in Step 1 to build the Mitscherlich-Baule model. In spite of the fact that Step 1 (Table 5 2.2) indicated that CE should be entered into the Mitscherlich-Baule equation, one by one, CE, NI, BA and RW were tried, yet none converged, possibly due to the nature of the dataset (Table 5.2.3).

5.3 DATASET B114:

5.3.1 Introduction

Dataset B114 consists of seventy-six observations of a field trial conducted on ICM technology, given the same protocol as the 1987 experiment. The 1988 experiment involved seventy-seven trials and the B114 dataset consisted of seventy-six observations, one trial observation being dropped as it was incorrectly recorded

5.3.2 Quadratic Model: Model I (B114)

Table 5.3.1 presents the results of this regression.

TABLE 5 3 1 MODEL I REGRESSION OPTION = NONE

Variable	Parameter Estimate	Standard Error	T for H0 Parameter=0	Prob > |T|
INTERCEPT	8396 668601	1413 2871932	5 941	0 0001
NI	- 28 308501	13 4609877	- 2 103	0 0392
CE	- 0 330246	1 0727333	- 0 308	0 7591
BA	- 24 487833	6 8652692	- 3 567	0.0007
RW	- 148 648785	49 3414550	- 3 013	0 0036
NI**2	- 0 022343	0 0675742	- 0 331	0 7419
NI*CE	- 0 003178	0.0105241	- 0 302	0 7636
NI*BA	0 215018	0 06010517	3.577	0 0006

R^2 = 0 2302 ADJ R^2 = 0 1509 RMSE = 803 7711

The results for this dataset are an improvement over B113, on the basis of the adjusted R^2 and RMSE. The fit improved although it is still low (adjusted R^2 = 15%) and only four of eight parameter estimates are significant at the 15% level. All of the regressors with significant parameter estimates indicate that the individual inputs NI, BA and RW have a negative impact on yield This result is contrary to expectations. The expected outcome would have at least the influence of NI being positive. Section 3.1.1 suggested that nitrogen was a Category I ICM input element which would act to assist plants in attaining their full yield potential (*cf.* p.30). Possibly the residual nitrogen in the soil prior to field preparation and planting (*ie.* the carryover NI) was at such a high level that additional nitrogen, as required by the experimental protocol, was not required The negative NI parameter estimated may be the result of excessive nitrogen fertilization.

The negative sign on the parameter estimate for BA is not unexpected in that BA is a Category II element which acts to stem the reduction of yield resulting from pests and similar yield-threatening factors (*cf* p 32) The negative sign of the RW parameter estimate is expected as the survey of ICM literature suggests that yields would decrease with increasing row widths Note that the intercept of this equation is significant, although it is estimated at nearly twice the expected ICM yield for barley.

5.3.3 Mitscherlich-Baule Model: Model II (B114)

Table 5.3.2. summarizes the stepwise selection process for regressors.

TABLE 5 3 2· MODEL II - Step 1 . REGRESSION OPTION = STEPWISE (0 1500)

Variable	Parameter Estimate	Standard Error	F	Prob>F
INTERCEPT	3467 527027	222.2098396	243.51	0.0001
NI	- 4 293004	2.1224994	4.09	0 0467

R^2 = 0.0524 ADJ R^2 = N/A RMSE = 854 8583

Summary of Stepwise Procedure

step	Variable entered	removed	Number in	Partial R^2	Model R^2	F	Prob>F
1	NI		1	0 0524	0 0524	4.0910	0.0467

Step 1 suggests that NI is the only significant input in this dataset since the remaining regressors, CE, BA and RW, were not significant at the 15% level. As was the case with Dataset B113, Mitscherlich-Baule equation convergence could not be attained with the NI regressor and therefore there were no results forthcoming for Model II (Steps 2 and 3) or Model III.

5.4 DATASET B115:

5.4.1 Introduction

Dataset B115 consists of seventy-six observations from the third year (1989) of the barley field trial at Macdonald Campus, given the same protocol as the 1987 and 1988 experiments.

5.4.2 Quadratic Model: Model I (B115)

TABLE 5 4 1 MODEL I REGRESSION OPTION = NONE

Variable	Parameter Estimate	Standard Error	T for H0 Parameter=0	Prob > |T|
INTERCEPT	5645 611111	975 0217227	5 790	0 0001
NI	- 24 789286	17 8178854	- 1 391	0 1687
CE	- 2 192361	1 7930950	- 1.223	0 2257
BA	- 7 798016	17 4065792	- 0 448	0 6556
RW	20 655556	62 8555915	0 329	0 7435
NI**2	0 181196	0 1178296	1 536	0 1293
NI*CE	0 025536	0 0198417	1 287	0 2025
NI*BA	- 0 093101	0 1105107	- 0 842	0 4025
BA*RW	0.162103	0 6544784	0 248	0 8051

R^2 = 0.3627 ADJ R^2 = 0 2866 RMSE = 1333 3685

In MODEL I, only one regressor (NI^2) was significant at the 15% level, although NI was close at 16.87%. The value of the RMSE is quite high indicating a large error component in this equation (compared to Datasets B113 and B114). The adjusted R^2 value has increased over the two previous models, but is still low at 29%.

5.4.3 Mitscherlich-Baule Model: Model II (B115)

Step 1 results are presented as Model II - Step 1 in Table 5 4.2.

TABLE 5 4 2 MODEL II - Step 1 REGRESSION OPTION = STEPWISE (0 1500)

Variable	Parameter Estimate	Standard Error	F	Prob>F
INTERCEPT	4909 899267	336 8637887	212 44	0 0001
NI	6 636813	3 8253059	3 01	0 0870
BA	- 13 813566	2 4061699	32 96	0 0001

R^2 = 0.3147 ADJ R^2 = N/A RMSE = 1324 6051

Summary of Stepwise Procedure

step	Variable entered	removed	Number in	Partial R^2	Model R^2	F	Prob>F
1	BA		1	0 2864	0 2864	29 7043	0 0001
2	NI		2	0 0283	0 3147	3 0101	0 0870

Step 1 indicated that BA was an important explanatory variable, followed by NI. The other regressors, CE and RW were not significant at the 15% level. Step 2 of Model II uses the regressors selected in Step 1 to build the Mitscherlich-Baule model Step 1 indicated that BA and NI should both be entered into the Mitscherlich-Baule equation. As previously discussed, this involves the simultaneous estimation of parameters *A*, *BA1*, *N1* and *N2* for a successful convergence. However, all cases of parameter estimation were unsuccessful The Model III regressions were not forthcoming as there were no results from Model II

5.5 CHOW TEST RESULTS

The Chow Test was carried out to determine if the underlying crop response relationships represented in each of the datasets (B113, B114 and B115) are statistically different from one another The null hypothesis is that there is no difference in the estimated coefficients obtained from any pair of the datasets. Rejection of the null hypothesis leads to the conclusion that the crop response function has changed from one dataset to the other in the pair-wise test (Koutsoyiannis 1984, 167). Table 5.5 presents the results and conclusions of the Chow Tests.

TABLE 5.5. CHOW TEST RESULTS FOR DATASETS B113-5

	Pair-wise datasets		
	B113-114	B113-115	B114-115
$F_{0.01}$	2.34	2.34	2 34
F^*	9 8355	2 7446	4 0236
Conclusion	reject	reject	reject

In all pair-wise comparisons of Datasets B113-115, the results indicate that there are significant differences

5.6 DATASET B125:

5.6.1 Introduction

Dataset B125 consists of one hundred and thirteen observations from a field trial with the following protocol

crop	... barley
variety	.. CADETTE
site	... Ste.-Rosalie/Ste. Hyacinthe
crop season	1989
ICM inputs and rates	
	. nitrogen (0, 80, 90, 120, 150 & 160 kg/ha)
(EXPLANATORY	CERONE (0 & 240 g ai/l)
VARIABLES)	.. TILT (0, 125 & 250 g ai/l)
	seeding rate (275, 350, 375 450 475 & 575 grains/m^2)

Dataset B125 originally consisted of one hundred and fourteen trial observations gathered from a number of different experiments conducted at Ste.-Rosalie/Ste. Hyacinthe in 1989. One of these observations was deleted as it was incorrectly recorded.

5.6.2 Quadratic Model: Model I (B125)

This dataset offered a better series of observations than previous datasets, and the OLS results are presented in Table 5.6.1, Section (a). However, the Durbin-Watson test indicated autocorrelated errors (DW = 0.925). A Cochrane-Orcutt[14] transformation was performed and the resulting Generalized Least Squares (GLS) parameter estimates and their relevant statistics are presented in Table 5.6.1, Section (b).

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[14] The Cochrane-Orcutt transformation is explained in Gujarati (1988) and Wittink (1988)

TABLE 5.6 1. MODEL I . REGRESSION OPTION = NONE

(a) Ordinary Least Squares Estimates

Variable	Parameter Estimate	Standard Error	T for H0 Parameter=0	Prob > |T|
INTERCEPT	81156	35682 935142	2 274	0 0251
NI	- 458 248698	238.894945	- 1 918	0 0579
CE	2 732431	2 726674	1 002	0 3187
TI	- 52 865034	39 248984	- 1.347	0 1810
SR	- 230 517964	95 823936	- 2 406	0 0180
NI**2	- 0.093469	0 033550	- 2 786	0 0064
TI**2	0 011717	0 013629	0 860	0 3920
SR**2	0 045466	0 019007	2 392	0 0186
NI*CE	- 0.034442	0.025929	- 1 328	0 1871
NI*TI	- 0 023632	0 017375	- 1 360	0 1768
NI*SR	1.290803	0 635174	2.032	0 0448
TI*SR	0.139638	0 103143	1 354	0 1788

R^2 = 0.4206 ADJ R^2 = 0.3575 RMSE = 931 8880 DW = 0 925

(b) Generalized Least Squares Estimates (Cochrane-Orcutt Transformation)

Variable	Parameter Estimate	Standard Error	T for H0 Parameter=0	Prob > |T|
INTERCEPT	33084	13474 773425	2 455	0 0158
NI	- 434 236134	193 234244	- 2 247	0 0268
CE	0 684393	2 029190	0 337	0 7366
TI	- 44 737756	34 369477	- 1 302	0 1960
SR	- 189 791973	78 396197	- 2 421	0 0173
NI**2	- 0 091926	0 027298	- 3 368	0 0011
TI**2	0 005444	0 009043	0 602	0 5485
SR**2	0 009610	0 011639	0 826	0 4109
NI*CE	- 0 008732	0 018723	- 0 466	0 6420
NI*TI	- 0 008117	0 012015	- 0 676	0 5009
NI*SR	1 216516	0 513757	2 368	0 0198
TI*SR	0.119581	0 090701	1 318	0 1904

R^2 = 0 3316 ADJ R^2 = 0 2580 RMSE = 725 0409 DW = 1 418

As a result of the Cochrane-Orcutt transformation, parameter estimates have changed as have standard errors and t-statistics. The OLS equation contained six significant parameter estimates at the 15% level, while the GLS equation has only five The transformed model exhibited a DW test statistic of 1.418 and a lower RMSE All of these (with the exception of the R^2 values) point to an improved quadratic equation resulting for the transformation, relative to the original (OLS) equation.

Testing for heteroscedasticity indicated that the hypothesis of homoscedasticity could not be rejected. The intercept value of the GLS quadratic is extraordinarily high, indicating that there may be factors exerting an influence on the dataset which are not included in the model. The small number of significant parameter estimates as well as the high value estimated for the intercept indicate this is a model in which one can place little confidence.

The negative signs on the parameter estimates for NI and SR are contrary to ICM package expectations. The relatively high and negative NI parameter estimate may be the result of higher than expected carryover nitrogen in the soil and therefore excessive nitrogen fertilization during this experiment. The expectation regarding SR is that the sign would be positive as higher seeding rates would improve yield potential (*cf.* p.28). The sign and magnitude of the SR parameter estimate may be accounted for by extreme competition for space and nutrients at high seeding rates. This may result in smaller and weaker plants which are less productive.

5.6.3 Mitscherlich-Baule Model: Model II (B125)

Results from a linear stepwise regression are presented as Model II - Step 1 in Table 5.6.2.

TABLE 5.6.2: MODEL II - Step 1 REGRESSION OPTION = STEPWISE
(0 1500)

Variable	Parameter Estimate	Standard Error	F	Prob>F
INTERCEPT	1495.436708	185.5555121	64.95	0 0001
NI	10.104165	1 6117073	39 30	0 0001

R^2 = 0.2615 ADJ R^2 = N/A RMSE = 1003 5534

Summary of Stepwise Procedure

step	Variable entered	removed	Number in	Partial R^2	Model R^2	F	Prob>F
1	NI		1	0 2615	0 2615	39 3033	0 0001

Step 1 indicates that, at the 15% level of significance, NI was the only regressor to be included in the Mitscherlich-Baule equation. In an effort to provide more variables for Mitscherlich-Baule equation estimation, the explanatory variables CE, TI and SR, resulting from the Model I quadratic regression (Table 5.6.1), were included in Step 2 of the Mitscherlich-Baule equation estimation. Note that these additional variables (CE, TI and SR) were not significant at the 15% level in Model I

The Step 2 estimation of the Mitscherlich-Baule equation was ultimately successful at fitting two explanatory variables, NI and TI. Although Model I (GLS) indicated that both NI and SR were highly significant, all attempts to estimate a Mitscherlich-Baule model with SR included were unsuccessful. With TI included, the estimation procedure was successful, simultaneously fitting *A*, *N1*, *N2* and *T1*. However, in the parameter estimation procedure for this model, a particular problem was encountered. The structure of the Mitscherlich-Baule equation is such that it is undefined for an input level of zero for TI (no carryover effect for fungicides). Forty-eight of the one-hundred and thirteen (48/113) observations were non-zero for TI. Zero carryover of TI was not a concern as it was imposed *a priori*. To compensate for the problem with TI values equal to zero, a small carry-over value was set at one-half of one percent (0.005).

In the resulting equation, the t-statistics indicate that the parameter estimates are not significant at the 15% level, with the exception of *A* (Table 5.6.3). The Root Mean Square Error (RMSE) was quite high indicating a poor fit as the negative R^2 values also indicate problems with the estimation results. Model II - Step 3 was not generated as all the variables that were indicated for inclusion in Step 2 were indeed fitted and therefore no data adjustments were made in this dataset.

TABLE 5 6 3 MODEL II - Step 2 . MARQUARDT METHOD[15]

Parameter	Estimate	Approx Std Error	'T' Ratio	Approx Prob>|T|
A	2 742532	0 86003	3 19	0 0019
N1	43 698113	306 96008	0 14	0 8871
N2	0 016963	0 11630	0 15	0.8843
T1	22 0[illegible]928	39 17497	0 56	0 5744

R^2 = -2 8408 ADJ R^2 = - 2 9465 RMSE = 2309.52

15 Note that the parameter *A* is expressed in tonnes per hectare in the Mitscherlich-Baule equation and the SAS modelling procedures due to scaling.

5.6.4 Post-Mitscherlich-Baule Quadratic Model: Model III (B125)

The initial OLS regression of Model III indicated the presence of autocorrelation (DW = 0.743). The resulting OLS parameter estimates and their relevant statistics are presented in Table 5.6.4, Section (a). A Cochrane-Orcutt transformation was performed and the resulting GLS parameter estimates and their relevant statistics are presented in Table 5.6.4, Section (b). The GLS equation is homoscedastic as well as displaying a normal distribution of residual values. After the Cochrane-Orcutt transformation, the Durbin-Watson statistic (1.518) was significant at the 5% level (Gujarati 1988, 688).

TABLE 5.6 4: MODEL III REGRESSION OPTION = NONE

(a) Ordinary Least Squares Estimates

Variable	Parameter Estimate	Standard Error	T for H0 Parameter=0	Prob > |T|
INTERCEPT	1201 061138	260 20573069	4 616	0 0001
NI	26 010433	5 86787532	4 433	0 0001
TI	-1 522045	3 72241295	- 0 409	0 6834
NI**2	-0 090043	0 03452663	- 2 608	0 0104
TI**2	0 014090	[illegible]	1 007	0 3160
NI*TI	-0 025731	[illegible]	- 1 486	0 1402

R^2 = 0 3258 ADJ R^2 = 0 2943 RMSE = 976 6481 DW = 0 743

(b) Generalized Least Squares Estimates (Cochrane-Orcutt)

Variable	Parameter Estimate	Standard Error	T for H0 Parameter=0	Prob > |T|
INTERCEPT	616 114268	91 79346781	6 712	0 0001
NI	22 950683	4 03460894	5 688	0 0001
TI	0 044784	2 36835255	0 019	0 9849
NI**2	- 0 104788	0 02498658	- 4 194	0 0001
TI**2	0 004878	0 00838760	0 582	0 5621
NI*TI	- 0 005416	0 01112665	- 0 487	0 6274

R^2 = 0 2989 ADJ R^2 = 0 2659 RMSE = 706 7532 DW = 1 518

As a result of the Cochrane-Orcutt transformation, parameter estimates changed as did standard errors and t-statistics. The OLS model contained four significant regressors at the 15% level. The GLS model has only three, including the intercept. The RMSE was decreased yet the R^2 and adjusted R^2 values were also reduced. The results of this regression indicate that GLS Model III is an improvement over the OLS model on the basis of RMSE although it is still a poor fit of the dataset (adjusted R^2 = 27%). With this model the signs and magnitudes of the significant parameter estimates were closer to the results expected. However, nitrogen was the only element which had a significant influence on this model which suggests that the inclusion of TI did little to explain the yield. This result confirms the outcome of the stepwise regression, Model II - Step 2

The GLS Model III can be compared to the Mitscherlich-Baule (Model II) and in doing so, one sees that this quadratic is a better fit (in terms of RMSE). In comparing the RMSE for Model I (the quadratic: RMSE = 725.04) and Model II (the Mitscherlich-Baule: RMSE = 2309.52), it is clear that the quadratic model was a better fit for this dataset. Furthermore, the t-test statistics for Model II suggest that only the yield potential parameter (*A*) is significant whereas a number of the parameter estimates in the Model I were significant. Finally, comparing the two estimated quadratic equations, Models I and III are similar in terms of R^2 and RMSE even though there is a considerable difference in terms of the number of regressors contained in the two equations.

5.6.5 Summary of DATASET B125

The first-fit quadratic, Model I was subject to the presence of first-order autocorrelation (DW = 0.925), and Cochrane-Orcutt transformation was performed. The resulting GLS model was homoscedastic and the residuals were normally distributed, satisfying the assumptions of the residual analysis.

The Mitscherlich-Baule equation (Model II) successfully converged on two input variables (NI and TI) although the parameter estimates were not significant. The Post-Mitscherlich-Baule Quadratic model (Model III) was initially heteroscedastic and exhibited a problem with first-order autocorrelation (DW = 0.743). A Cochrane-Orcutt transformation corrected the autocorrelation problem

In comparing the RMSE for Model I (the quadratic: RMSE = 725.04) and Model II (the Mitscherlich-Baule: RMSE = 2309.52), it is clear that the quadratic equation was a better fit for this dataset. However, an extremely large intercept for Model I and the characteristics of the parameter estimates (with respect to parameter signs and significance tests) suggests this model is of questionable value to represent this dataset. The t-test statistics for Model II suggest that only the yield potential parameter (*A*) is significant whereas a number of the parameter estimates (five) in the Model I were significant.

A comparison of the Mitscherlich-Baule and the quadratic model (Model III) generated from the variables of the Mitscherlich-Baule indicated again that the quadratic (Model III) was a better fit (RMSE = 2309.52 *versus* 706.75 respectively) even though the inclusion of the variable TI was of questionable significance in Model III. All parameters estimated with respect to TI were not significant at the 15% level.

A comparison of Model I and Model III indicates similar adjusted R^2 values (27 and 26% respectively) and RMSE more in line with each other than with the Mitscherlich-Baule model Note that Model III indicates that only NI is of significance, whereas Model I suggests that SR would play a significant role in influencing yield. Model III did not include the parameter SR as Model II could not accommodate the inclusion SR.

5.7 DATASET W123:

5.7.1 Introduction

Dataset W123 consists of two hundred and forty-eight observations collected in field trials conducted on ICM technology, utilizing the following protocol:

crop	... wheat
variety	.. MAX
site	. . Ste.-Rosalie/Ste. Hyacinthe
crop season	1987
ICM inputs and rates	
	. nitrogen (0, 120, 150, 180 & 210 kg/ha)
(EXPLANATORY VARIABLES)	CERONE (0 & 360 g ai/l)
	CYCOCEL (0, 240 & 345 g ai/l)
	TERPAL (0 & 345 g ai/l)
	.. DITHANE M-45 (0, 2.25, 4 50 & 6.75 g ai/l)
	... TILT (0, 125 & 250 g ai/l)
	seeding rate (353, 500, 647 & 794 grains/m^2)
	row width (10 & 20 cm)

5.7.2 Quadratic Model: Model I (W123)

OLS applied to Dataset W123 indicated an autocorrelation problem (DW = 1.447). The parameter estimates and their relevant statistics are presented in Table 5.7.2, Section (a). A Cochrane-Orcutt transformation was performed and the resulting GLS results are presented in Table 5.7.1, Section (b). The SAS heteroscedasticity test indicated that the hypothesis of homogeneity could not be rejected.

TABLE 5 7 1 MODEL I REGRESSION OPTION = NONE

(a) Ordinary Least Squares Estimates

Variable	Parameter Estimate	Standard Error	T for H0: Parameter=0	Prob > |T|
INTERCEPT	- 1855 460335	1128 056797	- 1 645	0.1014
NI	17 633478	4 163708	4 235	0.0001
CE	0 620236	1.882645	0 329	0 7421
CY	2 524899	2 645564	0.954	0.3409
TE	- 0.117244	2 524628	- 0.046	0.9630
DI	75 770003	72 080757	1.051	0.2943
TI	0 772772	1 885632	0.410	0.6823
SR	- 0 161332	1.715182	- 0.094	0.9251
RW	303 661624	50 945490	5.961	0.0001
NI**2	- 0 043596	0 006092	- 7.156	0 0001
DI**2	- 6 526721	5 511447	- 1.184	0 2376
TI**2	- 0 002325	0 004342	- 0.535	0.5928
SR**2	0 000013	0 001463	0 009	0 9931
NI*CE	0 000953	0 009973	0 096	0.9239
NI*CY	- 0 014736	0 014273	- 1.032	0 3030
NI*TE	- 0 000832	0 013898	- 0.060	0.9523
NI*DI	- 0 093636	0 178428	- 0 525	0 6002
NI*TI	- 0 001284	0.004365	- 0 294	0.7690
CE*DI	- 0 004708	0 057693	- 0 082	0 9530
CE*TI	- 0 001202	0 001461	- 0 823	0.4113
DI*SR	0 004129	0.092832	0 045	0 9645
TI*SR	0 001278	0 002376	0 538	0 5910

R^2 = 0 8040 ADJ R^2 = 0 7858 RMSE = 281 6175 DW = 1.447

(b) Generalized Least Squares Estimates (Cochrane-Orcutt Transformation)

Variable	Parameter Estimate	Standard Error	T for H0: Parameter=0	Prob > |T|
INTERCEPT	- 811 976002	842 492044	- 0 064	0 3362
NI	15 826785	3 941705	4 015	0 0001
CE	- 0 397195	1 723009	- 0 231	0 8179
CY	1 952584	2 479588	0 787	0 4318
TE	- 1 183630	2 411988	- 0 491	0.6241
DI	58 969307	76 696930	0 941	0 3479
TI	0 804189	1 611074	0 499	0 6182
SR	- 0 505288	2 048218	- 0 247	0.8054
RW	277 185331	51 973815	5 333	0 0001
NI**2	- 0 042289	0 007034	- 6 012	0.0001
DI**2	- 4 181407	4 940994	- 0 846	0 3983
TI**2	- 0 003332	0 003851	- 0 865	0 3878
SR**2	0 000277	0 001760	0 157	0 8715
NI*CE	0 005182	0 009147	0 567	0 5716
NI*CY	- 0 012242	0 013434	- 0 911	0 3631
NI*TE	- 0 004829	0 013253	0 364	0.7159
NI*DI	- 0 093714	0 152946	- 0 613	0.5407
NI*TI	- 0 001317	0 003737	- 0 352	0 7248
CE*DI	- 0 007253	0 049706	- 0 146	0 8841
CE*TI	- 0 000852	0 001279	- 0 666	0.5062
DI*SR	0 004512	0 080335	0 056	0 9553
TI*SR	0 001534	0 002034	0 754	0 4515

R^2 = 0 7357 ADJ R = 0 7110 RMSE = 269 6149 DW = 1.944

The OLS equation contained four significant regressors, including the intercept, at the 15% level, while the GLS equation has only three (NI, RW and NI^2) The R^2 and adjusted R^2 values have been reduced and the RMSE value is reduced (281.62 *versus* 269.62 respectively). The transformed model exhibited a DW statistic of 1.944, significant at the 1% level, increased from the OLS DW statistic of 1.447. In general, these results (with the exception of the R^2 values) indicate an improved quadratic equation resulting for the transformation, relative to the original (OLS) equation. Model I indicated a good fit with an adjusted R^2 = 71%.

The GLS equation indicated that NI and RW were significant in influencing yield, with RW having a large, positive estimated linear parameter (277.19). This result suggests that increasing row width will increase yields which is contrary to ICM expectations, as discussed in Section 3.1 1 (*cf* p.29). Furthermore, the negative intercept estimate could indicate a model specification problem However, as the magnitude of the intercept estimate is within the range of the standard error, this was not considered to be the case Rather, the negative intercept sign was considered to be a result of an approximation in the equation-fitting procedure.

5.7.3 Mitscherlich-Baule Model: Model II (W123)

Results for the linear stepwise regression are presented in Table 5.7 2, along with a summary of the stepwise selection process.

TABLE 5 7 2 MODEL II - Step 1 . REGRESSION OPTION = STEPWISE (0.1500)

Variable	Parameter Estimate	Standard Error	F	Prob>F
INTERCEPT	- 1892 761479	439 237821	18.57	0 0001
NI	8 492033	0 405726	438 08	0 0001
CE	0 822245	0 193287	18 10	0 0001
DI	22 115899	10 313749	4.60	0 0330
TI	0 397544	0.255823	2.41	0.1215
RW	319 893064	36 796684	75 58	0.0001

R^2 = 0 7352 ADJ R^2 = N/A RMSE = 316 2995

Summary of Stepwise Procedure

step	Variable entered	removed	Number in	Partial R^2	Model R^2	F	Prob>F
1	NI		1	0 6107	0 6107	385 9236	0 0001
2	RW		2	0 0958	0 7065	79 9287	0.0001
3	CE		3	0 0236	0 7300	21 2925	0 0001
4	DI		4	0 0025	0 7326	2.2974	0 1309
5	TI		5	0 0026	0 7352	2 4149	0 1215

The results indicate that NI, RW, CE, DI and TI were significant and should be included in the Mitscherlich-Baule model. The Mitscherlich-Baule equation converged while simultaneously estimating parameters for *A*, *N1*, *N2* and *RW1*. No other estimations were successful in terms of identifying additional parameters. The results of Step 2 are presented in Table 5.7.3.

TABLE 5 7 3 MODEL II - Step 2 MARQUARDT METHOD

Parameter	Estimate	Approx Std Error	T Ratio	Approx Prob> |T|
A	6 921491	1 19613	5 79	0 0001
N1	15 803781	3 59926	4 39	0 0001
N2	0 038438	0 00810	4 74	0 0001
RW1	63 228739	15 97651	3 96	0 0001

R^2 = 0 7698 ADJ R^2 = 0 7669 RMSE = 293 72

Due to the non-linear nature of the Mitscherlich-Baule equation, the interpretation of estimates is complex Decreasing any of the estimated parameters will result in a decrease in the dependant variable (YLD). All of the parameter estimates in this equation are significant, a result which suggests that this equation is a good representation of the dataset

As discussed in the Methodology chapter (CHAPTER FOUR), a situation could arise where it would be possible to invoke Step 3, the generation of a second Mitscherlich-Baule model, and for this dataset, this was the case Step 1 indicated the following functional relationship, based on the significance of parameter estimates:

YLD = f(NI, CE, DI, TI, RW)

Therefore, compensation was made for the fact that the Mitscherlich-Baule could not accommodate three of the five significant regressors This was accomplished by adjusting the dataset to remove the influence of explanatory variables CE, DI and TI (*cf* APPENDIX FIVE) This *ADJUSTED MODEL* dataset was used for subsequent Mitscherlich-Baule parameter estimation (Step 3 of Model II). The results are presented in Table 5 7 4

TABLE 5 7 4 MODEL II - Step 3 MARQUARDT METHOD

Parameter	Estimate	Approx Std Error	'T' Ratio	Approx. Prob> |T|
A	7 045060	1 33061	5 29	0 0001
N1	15 695482	3 46739	4 53	0 0001
N2	0 036195	0 00744	4 87	0 0001
RW1	58.892457	15 83651	3 72	0.0002

R^2 = 0 7785 ADJ R^2 = 0 7758 RMSE = 287 01 DW = 2 130

The equation estimated in Step 3 exhibits a marginally better fit than Step 2 both in terms of R^2 and RMSE. The Step 3 model exhibited a higher R^2 (78%) and a decreased RMSE (287.01). In both cases all the estimated parameters are still significant at the 1% level. The RMSE is low suggesting a good fit based on the residual (error) terms A plot of the equation's residuals exhibit a normal distribution with a mean of zero. The Durbin-Watson test statistic was 2.130, indicating the absence of autocorrelation. This equation appears to be a good fit for this dataset.

5.7.4 Post-Mitscherlich-Baule Quadratic Model: Model III (W123)

The regressors from Step 3 were also used for a quadratic regression to generate Model III, the results of which are exhibited in Table 5.7.5.

TABLE 5 7 5 MODEL III REGRESSION OPTION = NONE

Variable	Parameter Estimate	Standard Error	T for H0 Parameter=0	Prob > |T|
INTERCEPT	- 624 502553	208 6188626	- 2 994	0 0030
NI	17 871757	1 2091142	14 781	0 0001
RW	198 511941	20 1286565	9 862	0 0001
NI**2	- 0 047053	0 0055593	- 8.464	0 0001

R^2 = 0 7794 ADJ R^2 = 0 7767 RMSE = 286 4403 DW = 2 142

The quadratic model resulted in four significant parameter estimates. There was no evidence of autocorrelation (DW = 2.142) and the plot of the equation residuals was normal. However, testing this equation did indicate the presence of heteroscedasticity. Attempts to correct for this presence were not implemented. This equation exhibits a low RMSE (286.44) and a relatively high adjusted R^2 (77.67%). Other than the intercept, the signs and magnitudes of parameter estimates conform to the results of previous Dataset W123 equations The RW parameter estimate suggests that increasing row widths will increase yields, a result contrary to ICM expectations.

5.7.5 Summary of DATASET W123

This dataset consisted of two hundred and forty-eight observations of a number of ICM wheat trials conducted in the Ste Rosalie/Ste Hyacinthe area in 1987. The estimation of Model I quadratic equation using OLS indicated the presence of first order autocorrelation (DW = 1 447), and was corrected using the Cochrane-Orcutt transformation. The residuals for this GLS equation were homoscedastic, and normally distributed. The parameter estimates indicate that NI has a positive influence of yield The regressor RW has a particularly large positive coefficient, contrary to expectations On the basis of RMSE and R^2, Model I is an adequate fit of the W123 dataset.

The Mitscherlich-Baule model generated in Step 2 did not accommodate all of the regressors indicated as significant by Step 1. Therefore, a second Mitscherlich-Baule model was generated in Step 3 utilizing the *ADJUSTED DATASET*, with the influence of CE, DI and TI removed. The Step 3 Mitscherlich-Baule exhibited a better fit than the Step 2 model in terms of RMSE (287.01 *versus* 293.72) and R^2 (77.58% *versus* 76.69%). All parameter estimates were significant and the equation was considered to be a good fit of the dataset. Furthermore, the estimated equation indicated that row widths had a significant influence on yield. For residual analysis and comparisons with other equations, the equation estimated in Step 3 is used as the representative Model II.

The Model III quadratic model was not autocorrelated (DW = 2.142) but was indicated as heteroscedastic This was not corrected for. Nitrogen and row width were included in this equation and produced significant parameter estimates The equation suggests that RW has a large positive effect on yield, a result contrary to expectations

Comparing Models I and II (Step 2) indicated that, on the basis of RMSE, the quadratic model was a better fit (269.62 *versus* 293.72). It is noteworthy that only three of the parameters estimated for the quadratic equation (Model I) were significant whereas all of the parameters estimated for the Mitscherlich-Baule were significant.

Comparing Models I and III suggested that the initial quadratic was a better fit in terms of RMSE values, 269.62 *versus* 286.44. However, only three regressors in Model I were significant whereas all regressors (3/3) in Model III were significant at the 1% level.

Comparing Models II (Step 3 - *ADJUSTED DATASET*) and III indicated again that the quadratic equation exhibited a smaller RMSE value, although in this case it is just slightly smaller (287.01 *versus* 286.44 respectively) For both of these equations, all parameter estimates are significant.

5.8 Comparison of Yield Prediction Curves

As a final analysis of the modelling processes, Dataset W123 was used for a limited yield prediction exercise. In this exercise, Model II - Step 3 (the *ADJUSTED DATASET* Mitscherlich-Baule) and Model III (the Post-Mitscherlich-Baule Quadratic, based on the *ADJUSTED DATASET*) are graphed and compared. The graph of the Mitscherlich-Baule is presented as Figure 5 1 and the Post-Mitscherlich-Baule Quadratic as Figure 5.2.[16] As both models had

[16] Note that the measured row widths are 10 and 12 cms, nitrogen rates are 0, 120, 150, 180 and 210 kg/ha

the same dependant and independent explanatory variables (YLD, NI and RW), it was possible to graph and compare the response surfaces in three dimensions.[17] The two equations are:

Model II (Step 3 - Mitscherlich-Baule). *ADJUSTED DATASET*

$$YLD = 7.0451 * (1 - EXP(-15.70 * (0.04 + NI))) * (1 - EXP(-58.89 * RW)) \quad [5.1]$$

Model III (Quadratic) *ADJUSTED DATASET*

$$YLD = -624.50 + 17.87 * NI + 198.51 * RW - 0.05 * NI^2 \quad [5.2]$$

These graphs allow for the visual comparison of the two models as well as a discussion of the evident functional relationships.

5.9 Results of Comparison of Yield Prediction Surfaces

These graphs suggest that the range of input application was not sufficient for real differences to be detected between the two models. Considering the effects of increasing row widths, the graphs offer limited insight. Model II - Step 3 indicates an increased rate of response to increased row width over the range of nitrogen application. This is exhibited by the width of the yield contours along the ridges of RW = 10 and RW = 12 in Figure 5.1. The

17 This was accomplished with the use of SMARTWARE II (INFOMIX Software Inc 1991)

FIGURE 5.1: Mitscherlich-Baule Model II - Step 3 Response Surface

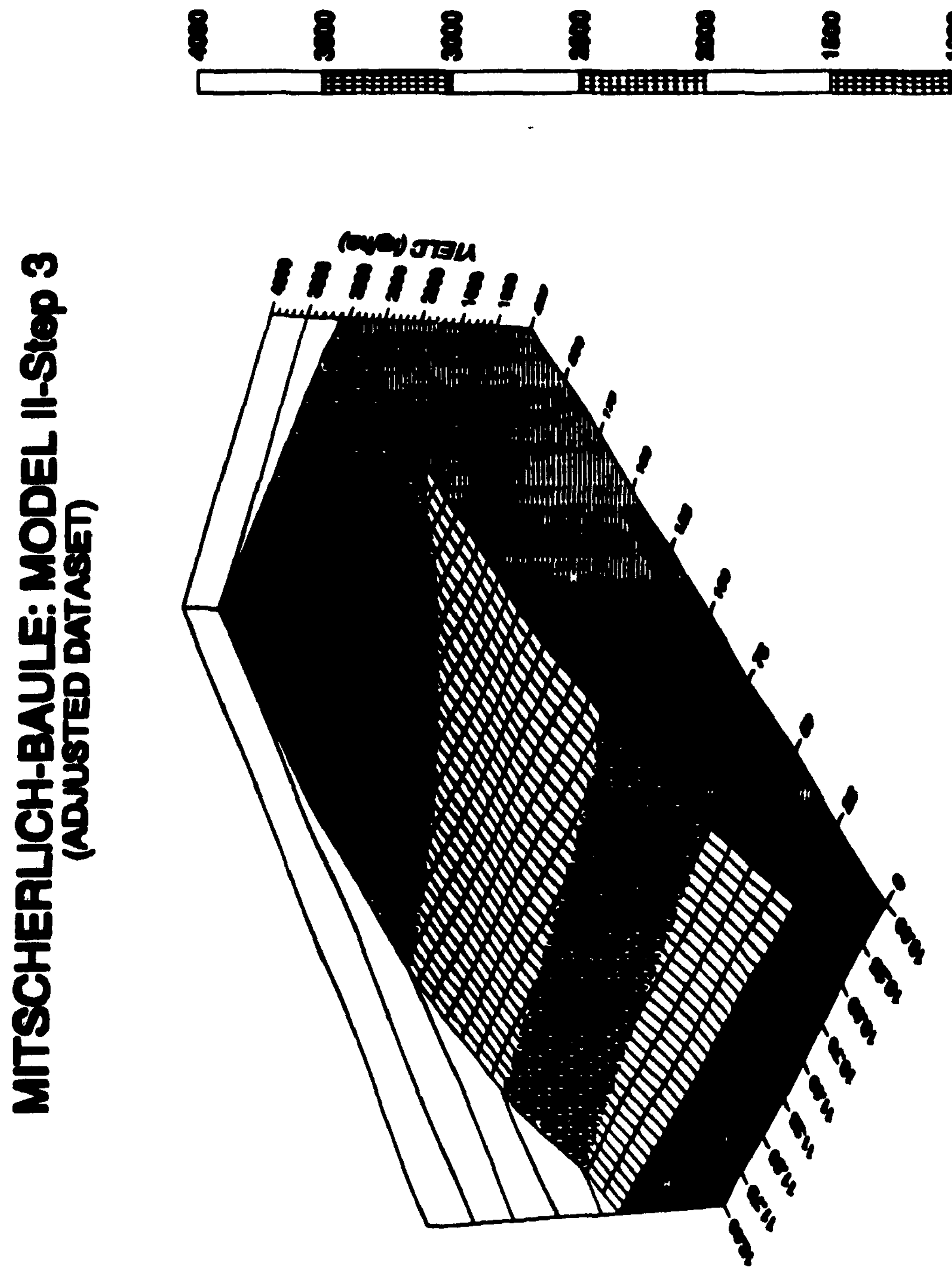
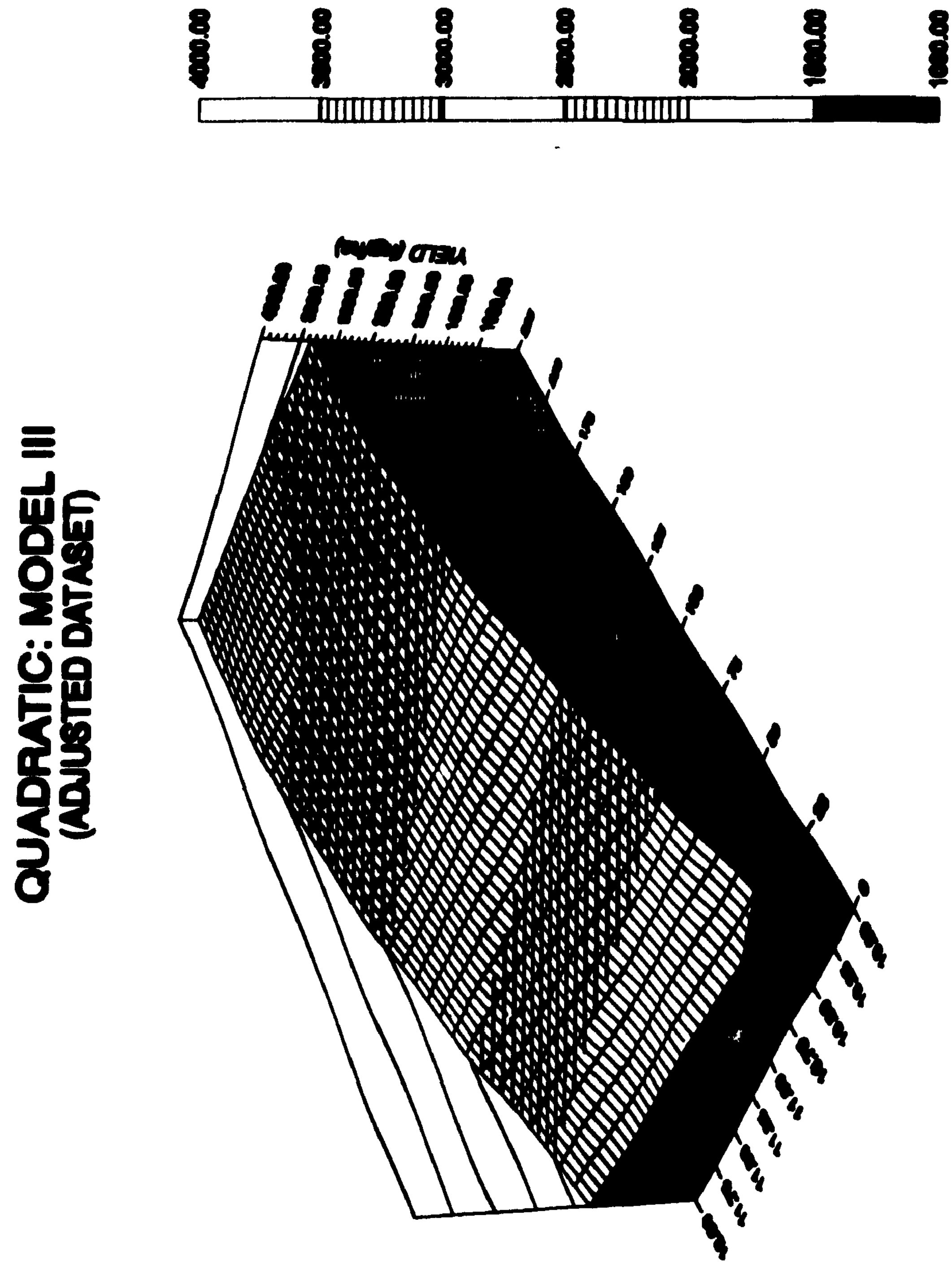


FIGURE 5.2: Post-Mitscherlich-Baule Model III Response Surface



The implication is that, for this dataset, the decreased row widths of ICM programs may inhibit yield response to increasing application of nitrogen fertilizer. This is contrary to the expected outcome of ICM row width-nitrogen response although Model II exhibits this result.

For Model III, the effect of row width on yield is somewhat more evident in Figure 5.2. At RW = 10 (NI = 0), the yield value is the lowest of the two models. As the level of nitrogen increases, the rate of yield increase remains relatively constant. At RW = 12, the yield level at the highest rate of nitrogen application is quite high, higher than for RW = 10. Furthermore, it is only between RW = 10 and RW = 12 that yield surpasses 3.5 tonnes per hectare. Again, the implication is that the response from high nitrogen rates is impeded at lower row widths. This is not the result expected from ICM technology with respect to row width

Both graphs also suggest a degree of input interaction as evidenced by the changing widths of the yield contour as one moves across the surface Were there to be no interaction, it would be expected that a contour would be a constant width in moving across the response surface from RW = 10 to RW = 12. This implication fits well with the notion that the Mitscherlich-Baule as well as the LRPF models allow for limited interaction between inputs (Waugh *et al* 1973; Frank *et al.* 1989)(*cf* p 61)

In comparing the graphs of the two models, one can see that the quadratic (Model III) exhibits both the lowest and the highest yields. Both of these extremes are dependant upon the row width, a phenomenon not as clearly evident in the Mitscherlich-Baule (Model II-Step 3). With the exception of the yield contour 2500-3000 kg/ha, the two models are quite similar in shape. This particular contour is extended in the Mitscherlich-Baule at the row width of 10 centimetres.

Finally, the question of yield plateaus *versus* point maximums cannot be clearly assessed utilizing these two graphs. The range of NI application in this dataset allows for diminishing marginal productivity but the graphs do not exhibit negative marginal productivity Clearly, the graphs both exhibit Stage II of the economic *Stages of Production*, but do not extend into Stage III.[18] It would be at the point of entry into Stage III that the question of point *versus* plateau maximums could be assessed.

[18] Neither the quadratic nor the Mitscherlich-Baule models exhibit a Stage I of the economic Stages of Production

CHAPTER SIX: CONCLUSIONS AND RECOMMENDATIONS

6.1 Introduction

This chapter is presented in two sections in order to discuss conclusions at two levels. The first section presents the conclusions drawn with respect to the project itself (Micro Conclusions). The second section (Macro Conclusions) presents those which are more broadly based, dealing with the subject matter and the fields of agricultural research examined in this project It is in the Macro Conclusions section that recommendations for future research are incorporated

6.2 Micro Conclusions

Only one conclusion was drawn with regard to the assessment of the models generated in this project.

1 Based on the datasets available, and the estimation results, the quadratic specification was an adequate fit of the data, but only slightly more so than was the Mitscherlich-Baule specification

In a general sense (other than the fact that all five datasets were gathered from ICM field trials), neither the philosophy nor the technology of ICM was dealt with in a significant way in this project The timing of applications of various inputs was not accounted for in any of the models generated Beyond this, the experiments from which these datasets were collected tended to follow set schedules with respect to applications, rather than fully utilizing the *ad hoc*, reactive basis of the ICM philosophy.

As the comparison of the Mitscherlich-Baule and the quadratic models was a major objective of this project, the results were successful for two datasets. However, a clear conclusion was not possible, even though five datasets were available with which to work. Three datasets (B113, B114 and B115) yielded no useful results. Of the remaining two, one (B125) strongly indicated that the Mitscherlich-Baule model was an inadequate model when compared to the quadratic generated from the same data. This dataset exhibited such a large RMSE for the Mitscherlich-Baule equation, one is led to question if the experimental design and/or the data collection techniques, or some other unexplained influence corrupted the dataset.

Finally, the last dataset (W123) did indicate that the two models (the quadratic and the Mitscherlich-Baule) were similar, comparable even, with the quadratic however, exhibiting a somewhat better fit. Graphing the two models for this dataset illustrated two response surfaces which were not very different from each other. With respect to th results obtained from W123, the two models did not settle the question of which model is a better representation of the dataset's yield observations. Of the other datasets, B125 was less clear on this question whereas Datasets B113-5 were inconclusive.

6.3 Macro Conclusions

Three conclusions can be drawn at this level:

1. Agricultural economists and agronomists must jointly design field trial experiments if the data to be generated are to be of use to both groups for their individual analytical purposes.

2. As agricultural economists generally choose to use historical, or "secondary" agronomic data for economic analysis, sufficient data have to be gathered to ensure that data problems such as collinearity will be absent or overcome, if present.

3. Agronomists have to ensure that the experimental conditions are specified in enough detail that the results can be reproduced

6.4 Discussion of Conclusions and Recommendations

Conclusion 1:

Agronomists are mostly interested in field-testing packages to determine if one package is significantly different from any of the others It was unclear if the packages selected for the datasets gathered in this project were selected based on any specific theory regarding the package elements, or a more general theory regarding crop response to added nutrients (or other elements). In either case, economists can offer their experience in regression analysis to agronomists to assist them in selecting packages for testing.

Regression analysis, as an exploratory research tool, would aid the development of a general theoretical model of crop response. Such a model can then be utilized to predict optimal combinations of input elements (packages) which can subsequently be tested in field trials. This form of confirmatory research further develops the theories of crop response, and thereby builds a greater understanding of the underlying relationships. Without a theoretical basis for selecting packages for field trials, a research program might lack a coherent plan of package assessment. An optimum package might only be selected by chance or be missed completely.

Finally, the design of the experiment (package selection, degree of replication, field trial data collection and measurement, *etc.*) must be structured in a manner to generate data of value to all analysts who will use it. Agronomists may, by their choice of a specific design, produce data which will generate satisfactory datasets for testing agronomic hypotheses. However, when economic analysis is required of the same data, the usual agronomic design confounds the problems facing the economic analyst. As referred to in CHAPTER THREE, agronomic designs tend to plan for many repetitions (of the same package) but few treatments (different packages). This results in few actual data points on a regression-fitted curve (or surface), and thereby leads to much interpolation between the few data points. The response surface spanned by this interpolating may be rich in relevant information.

Therefore, agricultural economists must join agronomists in designing agronomic experiments which will include a component of economic analysis. The agricultural economist must ensure that a sufficient number of treatment combinations are included to explore a representative portion of the response curve or surface.

A word of caution regarding treatment combinations is called for The simultaneous variation of a large number of elements (input factors) causes considerable analytical problems in regression analysis. Again, carefully considered experimental designs should be able to anticipate and avoid such problems as multicollinearity, autocorrelation and so on

Conclusion 2·

Agricultural economists are usually dependant upon others for crop data for their economic analyses Problems mentioned in Macro Conclusion 1 can ensue with this kind of data gathering. Sample studies, using sub-sets of the larger datasets are recommended to seek out these problems Most data problems in regression analysis can be overcome by adding more data to the troubled dataset.

Conclusion 3:

To ensure that experiments are capable of withstanding duplication and verification by others, all relevant details have to be recorded and made evident as part of the research process Changes in protocols, timing of applications, units of measures, *etc* have to be recorded and reported for inclusion in any subsequent, confirmatory research.

APPENDIX ONE: ICM Projects in Canada

APPENDIX ONE presents a selected listing of ICM projects from across Canada, for the period 1968-1990 (Stewart 1985).

Selected ICM Projects in Canada (1968-1990)

PEI Soil and Crop Improvement Association, Charlottetown, PEI (1982-85)	Barley (BRUCE)	Fungs , PGRs, Nitrogen
PEI Soil and Crop Improvement Association Charlottetown, PEI (1979-82)	Barley (VOILA) Wheat (NEEPWA, GLENLEA, OPAL)	Fungs , PGRs, Nitrogen
PEI Soil and Crop Improvement Association, Charlottetown, PEI (1983-86)	Barley (LEGER, VIOLA) Wheat (LENNOX, OPAL, VALOR)	Fungs , PGRs, Nitrogen
Agriculture Canada Research Branch, Charlottetown Research Station, PEI (1982-83)	Barley (BIRKA, VIOLA) Wheat (OPAL)	Fungs , PGRs
PEI Soil and Crop Improvement Association, Charlottetown, PEI (1984)	Barley (BIRKA, BRUCE, VIOLA) Wheat (VERNON, LENNOX)	
Minas Seed Co-operative, Canning, N S (1978-81)	Wheat (LENNOX, MONOPOL, VUKA) Rye (ANIMO)	Fungs , PGRs Nitrogen
Nova Scotia Winter Grain Marketing Board, Canning, N S (1984-85)	Wheat (MONOPOL)	Nitrogen

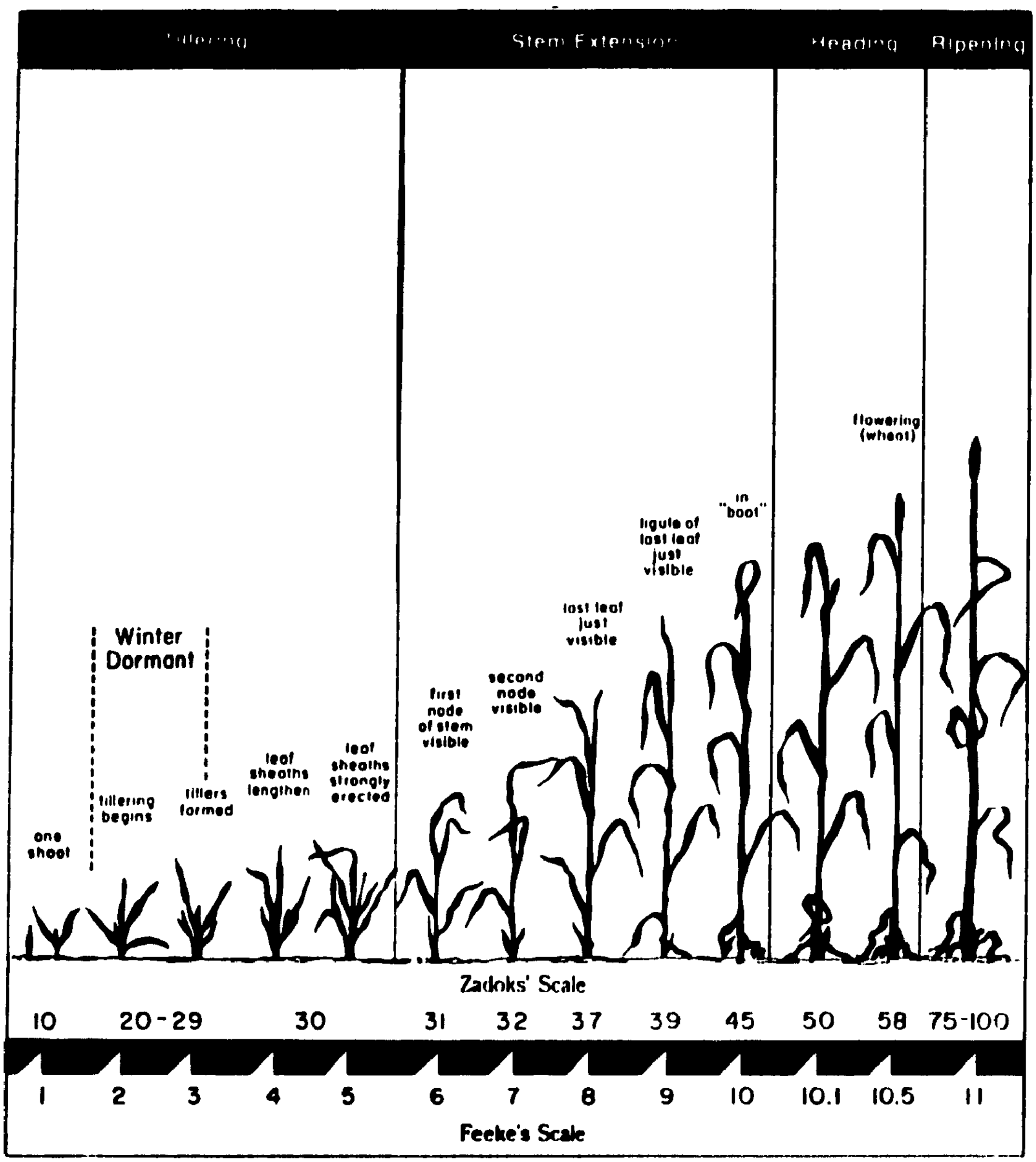
Nova Scotia Winter Grain Marketing Board, Canning, N S (1982-85)	Wheat (MAX, ABSOLVENT, MONOPOL)	Fungs., PGRs
Agricultural Research Institute, Truro, N.S (1985-88)	Spring Barley Spring Wheat Winter Wheat	Fungs., PGRs Nitrogen
New Brunswick Department of Agriculture, Plant Inspection Branch, Fredericton, N B (1979-)	Barley (LEGER, LAURIER) Wheat (LENNOX, MILTON, OPAL)	Fungs , PGRs, Nitrogen
Agriculture Canada, Fredericton Research Station, Fredericton, N B (1985-88)	Variety Evaluation	Fungs., PGRs, Nitrogen
Canada Grains Council and Co-operative Fédérée de Québec, Montréal, Qué (1985-88)	Spring Wheat Winter Wheat	Fungs., PGRs, Nitrogen
Semico Inc , Ste Hyacinthe, Qué (1983-)	Barley (Various) Spring Wheat (Various)	Fungs., PGRs, Nitrogen
Roche Ltée , Montréal, Qué	Spring Wheat Winter Wheat Oats	Fungs., PGRs Nitrogen
Ministère de l'Agriculture, des Pêcheries et de l'Alimentation du Québec (1983-)	Spring Wheat Winter Wheat Oats	Fungs , PCRs, Nitrogen
University of Guelph, N B Dept of Agriculture, Fredericton, N B (1980-81)	Wheat (FREDRICK)	Fungs , PGRs, Nitrogen
Ontario Red Wheat Association, Harriston, Ont (1983-88)	Wheat (ABSOLVENT MONOPOL)	Fungs , PGRs, Nitrogen

W.G. Thompson and Sons Ltd , Blenheim, Ont (1982-83)	Barley (BIRKA, LEGER, PERTH) Wheat (AUGUSTA, FREDRICK, HOUSER)	Fungs., PGRs, Nitrogen
King Agro Ltd , Chatham, Ont (1984-)	Variety Evaluation	
New Liskeard College of Agricultural Technology New Liskeard, Ont. (1968-)	Barley (VARIOUS)	Fungs , PGRs, Nitrogen, Row Spacing, Seeding date/rate
University of Manitoba, Crop Science Department (1981-84)	Wheat (NORSTAR)	Fungs , PGRs, Nitrogen
Canada Grains Council, Winnipeg, Man (1984-88)	Spring Wheat Winter Wheat	Fungs , PGRs, Nitrogen
Ag. Quest, Minto, Man		
Saskatchewan Crop Development Centre, Saskatoon, Sask	Barley	Fungs , PGRs, Nitrogen
Saskatchewan Crop Development Centre, Saskatoon, Sask (1985-89)	Spring Wheat Winter Wheat	Fungs , PGRs Nitrogen
Canada Grains Council, Edmonton, Alta (1984-88)	Spring Wheat Winter Wheat	Fungs , PGRs Nitrogen
Farming For The Future, Alberta Agriculture, Edmonton, Alta (1985-)	Barley Wheat	PGRs
Union Carbide, Calgary, Alta (1985)	Barley Variety Evaluation	
Lacombe Research Station, Lacombe, Alta	Barley	PGRs

Ciba Geigy, Calgary, Alta (1984)	Barley Spring Wheat	Fungs
Saanichton Research Station, Sidney, B.C. (1984-)	Barley	PGRs

APPENDIX TWO: Feekes' and Zadoks' Growth Scales

APPENDIX TWO provides an illustration of the Feekes and the Zadoks growth scales (Source: Oplinger *et al* 1985, 5). For further explanations, refer to: Feekes - Large (1954); Zadoks - Zadoks *et al.* (1974).



APPENDIX THREE: Project Datasets

APPENDIX THREE presents the five datasets generated by the data selection criteria utilized in this project. Each of these datasets is sorted according to inputs:

(NI, CE, CY, TE, BA, DI, TI, SR, RW).

This presentation format makes it easier for the reader to identify different combinations of inputs and the corresponding number of observations for each combination. Note that the regression procedures were not performed on sorted datasets.

ABBREVIATIONS

AGRONOMIC DATA:

OBS	Observation number
NI	Nitrogen
CE	CERONE (Plant Growth Regulator)
CY	CYCOCEL EXTRA (Plant Growth Regulator)
TE	TERPAL (Plant Growth Regulator)
BA	BAYLETON (Fungicide)
DI	DITHANE M-45 (Fungicide)
TI	TILT (Fungicide)
SR	Seeding Rate
RW	Row width
YLD	Yield

APPENDIX THREE

DATASET: B113

OBS	NI	CE	CY	TE	BA	DI	TI	SR	RW	YLD
1	0	0	0	0	140	0	0	450	10	5884
2	0	0	0	0	140	0	0	450	10	5577
3	0	0	0	0	140	0	0	450	10	5875
4	0	0	0	0	140	0	0	450	10	5756
5	0	480	0	0	140	0	0	450	10	6332
6	0	480	0	0	140	0	0	450	10	5268
7	0	480	0	0	140	0	0	450	10	4517
8	0	480	0	0	140	0	0	450	10	5687
9	70	0	0	0	0	0	0	450	20	4538
10	70	0	0	0	0	0	0	450	20	5517
11	70	0	0	0	0	0	0	450	20	5118
12	70	0	0	0	0	0	0	450	20	6509
13	70	0	0	0	0	0	0	450	20	7083
14	70	0	0	0	0	0	0	450	20	6519
15	70	0	0	0	0	0	0	450	20	5654
16	70	0	0	0	0	0	0	450	20	5877
17	70	0	0	0	0	0	0	450	20	7006
18	70	0	0	0	0	0	0	450	20	5196
19	70	0	0	0	0	0	0	450	20	5418
20	70	0	0	0	0	0	0	450	20	5298
21	70	0	0	0	0	0	0	450	20	4749
22	70	0	0	0	0	0	0	450	20	3822
23	70	0	0	0	0	0	0	450	20	4858
24	70	0	0	0	0	0	0	450	20	5820
25	70	0	0	0	0	0	0	450	20	5935
26	70	0	0	0	0	0	0	450	20	5956
27	70	0	0	0	140	0	0	450	10	4544
28	70	0	0	0	140	0	0	450	10	6418
29	70	0	0	0	140	0	0	450	10	5511
30	70	0	0	0	140	0	0	450	10	6675
31	70	0	0	0	140	0	0	450	20	6211
32	70	0	0	0	140	0	0	450	20	6161
33	70	0	0	0	140	0	0	450	20	5892
34	70	0	0	0	140	0	0	450	20	5870
35	70	480	0	0	140	0	0	450	10	4540
36	70	480	0	0	140	0	0	450	10	4560
37	70	480	0	0	140	0	0	450	10	5608
38	70	480	0	0	140	0	0	450	10	5348
39	140	0	0	0	140	0	0	450	10	6539
40	140	0	0	0	140	0	0	450	10	5803
41	140	0	0	0	140	0	0	450	10	6514
42	140	0	0	0	140	0	0	450	10	6200
43	140	480	0	0	0	0	0	450	10	6257
44	140	480	0	0	0	0	0	450	10	4903
45	140	480	0	0	0	0	0	450	10	5402
46	140	480	0	0	0	0	0	450	10	5468
47	140	480	0	0	0	0	0	450	10	6148
48	140	480	0	0	140	0	0	450	10	2914
49	140	480	0	0	140	0	0	450	10	5204
50	140	480	0	0	140	0	0	450	10	5699
51	140	480	0	0	140	0	0	450	10	5732
52	140	480	0	0	140	0	0	450	10	7447
53	140	480	0	0	140	0	0	450	10	575[illegible]
54	140	480	0	0	140	0	0	450	10	7070
55	140	480	0	0	140	0	0	450	10	3929
56	140	480	0	0	140	0	0	450	10	5424
57	140	480	0	0	140	0	0	450	10	5468
58	140	480	0	0	140	0	0	450	10	5761
59	140	480	0	0	140	0	0	450	10	6085
60	[illegible]	480	0	0	140	0	0	450	10	3157
61	[illegible]	480	0	0	140	0	0	450	10	3088
62	140	480	0	0	140	0	0	450	10	2015
63	140	480	0	0	140	0	0	450	10	4157
64	140	480	0	0	140	0	0	450	10	5109
65	140	480	0	0	140	0	0	450	10	6259
66	140	480	0	0	140	0	0	450	10	5922
67	140	480	0	0	140	0	0	450	10	5337
68	140	480	0	0	140	0	0	450	10	5952
69	140	480	0	0	140	0	0	450	10	4785
70	140	480	0	0	140	0	0	450	10	5615
71	140	480	0	0	140	0	0	450	10	4960
72	140	480	0	0	140	0	0	450	10	5991

DATASET: B114

OBS	NI	CE	CY	TE	BA	DI	TI	SR	RW	YLD
1	0	0	0	0	140	0	0	450	10	3031
2	0	0	0	0	140	0	0	450	10	3123
3	0	0	0	0	140	0	0	450	10	4430
4	0	0	0	0	140	0	0	450	10	3630
5	0	480	0	0	140	0	0	450	10	2466
6	0	480	0	0	140	0	0	450	10	3081
7	0	480	0	0	140	0	0	450	10	3560
8	0	480	0	0	140	0	0	450	10	3900
9	70	0	0	0	0	0	0	450	20	2433
10	70	0	0	0	0	0	0	450	20	1497
11	70	0	0	0	0	0	0	450	20	2273
12	70	0	0	0	0	0	0	450	20	4087
13	70	0	0	0	0	0	0	450	20	3557
14	70	0	0	0	0	0	0	450	20	3224
15	70	0	0	0	0	0	0	450	20	2676
16	70	0	0	0	0	0	0	450	20	2570
17	70	0	0	0	0	0	0	450	20	5794
18	70	0	0	0	0	0	0	450	20	3610
19	70	0	0	0	0	0	0	450	20	3740
20	70	0	0	0	0	0	0	450	20	2808
21	70	0	0	0	0	0	0	450	20	1216
22	70	0	0	0	0	0	0	450	20	5247
23	70	0	0	0	0	0	0	450	20	3653
24	70	0	0	0	0	0	0	450	20	4466
25	70	0	0	0	0	0	0	450	20	4829
26	70	0	0	0	0	0	0	450	20	3002
27	70	0	0	0	0	0	0	450	20	3922
28	70	0	0	0	0	0	0	450	20	3043
29	70	0	0	0	0	0	0	450	20	2338
30	70	0	0	0	140	0	0	450	10	3063
31	70	0	0	0	140	0	0	450	10	3030
32	70	0	0	0	140	0	0	450	10	3344
33	70	0	0	0	140	0	0	450	10	3057
34	70	0	0	0	140	0	0	450	10	3935
35	70	0	0	0	140	0	0	450	10	3986
36	70	0	0	0	140	0	0	450	20	2015
37	70	0	0	0	140	0	0	450	20	2065
38	70	0	0	0	140	0	0	450	20	2321
39	70	0	0	0	140	0	0	450	20	1645
40	70	480	0	0	140	0	0	450	10	3235
41	70	480	0	0	140	0	0	450	10	3781
42	70	480	0	0	140	0	0	450	10	3255
43	140	0	0	0	140	0	0	450	10	2768
44	140	0	0	0	140	0	0	450	10	3121
45	140	0	0	0	140	0	0	450	10	3936
46	140	0	0	0	140	0	0	450	10	3642
47	140	480	0	0	0	0	0	450	10	2235
48	140	480	0	0	0	0	0	450	10	1624
49	140	480	0	0	0	0	0	450	10	1769
50	140	480	0	0	0	0	0	450	10	2969
51	140	480	0	0	0	0	0	450	10	2088
52	140	480	0	0	140	0	0	450	10	1764
53	140	480	0	0	140	0	0	450	10	2099
54	140	480	0	0	140	0	0	450	10	2745
55	140	480	0	0	140	0	0	450	10	2075
56	140	480	0	0	140	0	0	450	10	2495
57	140	480	0	0	140	0	0	450	10	3212
58	140	480	0	0	140	0	0	450	10	3775
59	140	480	0	0	140	0	0	450	10	3683
60	140	480	0	0	140	0	0	450	10	3547
61	140	480	0	0	140	0	0	450	10	1667
62	140	480	0	0	140	0	0	450	10	1978
63	140	480	0	0	140	0	0	450	10	2996
64	140	480	0	0	140	0	0	450	10	3228
65	140	480	0	0	140	0	0	450	10	3189
66	140	480	0	0	140	0	0	450	10	3307
67	140	480	0	0	140	0	0	450	10	3418
68	140	480	0	0	140	0	0	450	10	2830
69	140	480	0	0	140	0	0	450	10	4090
70	140	480	0	0	140	0	0	450	10	2609
71	140	480	0	0	140	0	0	450	10	3051
72	140	480	0	0	140	0	0	450	10	2948
73	140	480	0	0	140	0	0	450	10	3202
74	140	480	0	0	140	0	0	450	10	4018
75	140	480	0	0	140	0	0	450	10	2176
76	140	480	0	0	140	0	0	450	10	2688

APPENDIX THREE

DATASET: B115

OBS	NI	CE	CY	TE	BA	DI	TI	SR	RW	YLD
1	0	0	0	0	0	0	0	450	10	4719
2	0	0	0	0	0	0	0	450	10	6084
3	0	0	0	0	0	0	0	450	10	5696
4	0	0	0	0	0	0	0	450	10	7501
5	0	480	0	0	0	0	0	450	10	2689
6	0	480	0	0	0	0	0	450	10	6775
7	0	480	0	0	0	0	0	450	10	4677
8	0	480	0	0	0	0	0	450	10	4467
9	70	0	0	0	0	0	0	450	10	6264
10	70	0	0	0	0	0	0	450	10	7208
11	70	0	0	0	0	0	0	450	10	2611
12	70	0	0	0	0	0	0	450	10	2749
13	70	0	0	0	0	0	0	450	20	6699
14	70	0	0	0	0	0	0	450	20	7090
15	70	0	0	0	0	0	0	450	20	4637
16	70	0	0	0	0	0	0	450	20	4267
17	70	0	0	0	0	0	0	450	20	5339
18	70	0	0	0	0	0	0	450	20	4023
19	70	0	0	0	0	0	0	450	20	5926
20	70	0	0	0	0	0	0	450	20	6008
21	70	0	0	0	0	0	0	450	20	5888
22	70	0	0	0	0	0	0	450	20	4589
23	70	0	0	0	0	0	0	450	20	4621
24	70	0	0	0	0	0	0	450	20	2067
25	70	0	0	0	0	0	0	450	20	6755
26	70	0	0	0	0	0	0	450	20	6781
27	70	0	0	0	0	0	0	450	20	2434
28	70	0	0	0	0	0	0	450	20	5243
29	70	0	0	0	0	0	0	450	20	5546
30	70	0	0	0	0	0	0	450	20	5871
31	70	0	0	0	140	0	0	450	10	3811
32	70	0	0	0	140	0	0	450	10	4062
33	70	0	0	0	140	0	0	450	10	3003
34	70	0	0	0	140	0	0	450	10	2575
35	70	0	0	0	140	0	0	450	10	3908
36	70	0	0	0	140	0	0	450	10	2580
37	70	0	0	0	140	0	0	450	10	3086
38	70	0	0	0	140	0	0	450	10	2787
39	70	0	0	0	140	0	0	450	20	3709
40	70	0	0	0	140	0	0	450	20	3373
41	70	0	0	0	140	0	0	450	20	3246
42	70	0	0	0	140	0	0	450	20	4059
43	70	0	0	0	140	0	0	450	20	3718
44	70	0	0	0	140	0	0	450	20	3882
45	70	0	0	0	140	0	0	450	20	3515
46	70	0	0	0	140	0	0	450	20	3778
47	70	480	0	0	0	0	0	450	10	2738
48	70	480	0	0	0	0	0	450	10	5780
49	70	480	0	0	0	0	0	450	10	5865
50	70	480	0	0	0	0	0	450	10	6037
51	140	0	0	0	0	0	0	450	10	5264
52	140	0	0	0	0	0	0	450	10	4488
53	140	0	0	0	0	0	0	450	10	7861
54	140	0	0	0	0	0	0	450	10	6693
55	140	480	0	0	0	0	0	450	10	2841
56	140	480	0	0	0	0	0	450	10	7433
57	140	480	0	0	0	0	0	450	10	7677
58	140	480	0	0	0	0	0	450	10	7827
59	140	480	0	0	140	0	0	450	10	4309
60	140	480	0	0	140	0	0	450	10	4595
61	140	480	0	0	140	0	0	450	10	2924
62	140	480	0	0	140	0	0	450	10	2576
63	140	480	0	0	140	0	0	450	10	1410
64	140	480	0	0	140	0	0	450	10	4959
65	140	480	0	0	140	0	0	450	10	4165
66	140	480	0	0	140	0	0	450	10	3762
67	140	480	0	0	140	0	0	450	10	3460
68	140	480	0	0	140	0	0	450	10	2883
69	140	480	0	0	140	0	0	450	10	3141
70	140	480	0	0	140	0	0	450	10	2838
71	140	480	0	0	140	0	0	450	10	4532
72	140	480	0	0	140	0	0	450	10	4566
73	140	480	0	0	140	0	0	450	10	4703
74	140	480	0	0	140	0	0	450	10	4608
75	140	480	0	0	140	0	0	450	10	5558
76	140	480	0	0	140	0	0	450	10	5261

DATASET: B125

OBS	NI	CE	CY	TE	BA	DI	TI	SR	RW	YLD
1	0	0	0	0	0	0	0	375	12	835
2	0	0	0	0	0	0	0	375	12	672
3	0	0	0	0	0	0	0	375	12	1984
4	0	0	0	0	0	0	0	375	12	1957
5	0	0	0	0	0	0	0	375	12	430
6	0	0	0	0	0	0	0	375	12	522
7	0	0	0	0	0	0	0	375	12	1473
8	0	0	0	0	0	0	0	375	12	1261
9	0	0	0	0	0	0	0	375	12	1073
10	0	0	0	0	0	0	0	375	12	1261
11	0	0	0	0	0	0	125	375	12	767
12	0	0	0	0	0	0	125	375	12	682
13	0	0	0	0	0	0	125	375	12	895
14	0	0	0	0	0	0	125	375	12	790
15	0	0	0	0	0	0	125	375	12	1219
16	0	0	0	0	0	0	125	375	12	2545
17	0	0	0	0	0	0	125	375	12	1478
18	0	0	0	0	0	0	125	375	12	1790
19	0	0	0	0	0	0	250	375	12	787
20	0	0	0	0	0	0	250	375	12	929
21	0	0	0	0	0	0	250	375	12	2483
22	0	0	0	0	0	0	250	375	12	2113
23	0	240	0	0	0	0	0	375	12	2065
24	0	240	0	0	0	0	0	375	12	1728
25	80	0	0	0	0	0	0	375	12	3122
26	80	0	0	0	0	0	0	375	12	662
27	80	0	0	0	0	0	0	375	12	3106
28	80	0	0	0	0	0	0	375	12	3017
29	80	0	0	0	0	0	0	375	12	1831
30	80	0	0	0	0	0	0	375	12	2797
31	80	0	0	0	0	0	0	375	12	2262
32	80	0	0	0	0	0	0	375	12	1985
33	80	0	0	0	0	0	0	375	12	2835
34	80	0	0	0	0	0	125	375	12	3042
35	80	0	0	0	0	0	125	375	12	3338
36	80	0	0	0	0	0	125	375	12	673
37	80	0	0	0	0	0	125	375	12	1072
38	80	0	0	0	0	0	125	375	12	2824
39	80	0	0	0	0	0	125	375	12	2936
40	80	0	0	0	0	0	125	375	12	2883
41	80	0	0	0	0	0	125	375	12	2880
42	80	0	0	0	0	0	250	375	12	3070
43	80	0	0	0	0	0	250	375	12	2133
44	80	0	0	0	0	0	250	375	12	3073
45	80	0	0	0	0	0	250	375	12	2363
46	80	240	0	0	0	0	0	375	12	2325
47	80	240	0	0	0	0	0	375	12	2265
48	90	0	0	0	0	0	0	350	12	4705
49	120	0	0	0	0	0	0	375	12	2927
50	120	0	0	0	0	0	0	375	12	2964
51	120	0	0	0	0	0	0	375	12	2935
52	120	0	0	0	0	0	0	375	12	3066
53	120	0	0	0	0	0	0	375	12	2152
54	120	0	0	0	0	0	0	375	12	3030
55	120	0	0	0	0	0	0	375	12	2416
56	120	0	0	0	0	0	0	375	12	2809
57	120	0	0	0	0	0	0	375	12	1814
58	120	0	0	0	0	0	0	375	12	2257
59	120	0	0	0	0	0	0	375	12	2914
60	120	0	0	0	0	0	0	375	12	2918
61	120	0	0	0	0	0	125	375	12	3202
62	120	0	0	0	0	0	125	375	12	3240
63	120	0	0	0	0	0	125	375	12	2631
64	120	0	0	0	0	0	125	375	12	3618
65	120	0	0	0	0	0	125	375	12	2120
66	120	0	0	0	0	0	125	375	12	2515
67	120	0	0	0	0	0	125	375	12	2694
68	120	0	0	0	0	0	125	375	12	2157
69	120	0	0	0	0	0	250	375	12	3662
70	120	0	0	0	0	0	250	375	12	3349
71	120	0	0	0	0	0	250	375	12	2711
72	120	0	0	0	0	0	250	375	12	2487
73	150	0	0	0	0	0	0	275	12	3179
74	150	0	0	0	0	0	0	275	12	4120
75	150	0	0	0	0	0	0	275	12	4565
76	150	0	0	0	0	0	0	275	12	3888
77	150	0	0	0	0	0	0	375	12	3039
78	150	0	0	0	0	0	0	375	12	4354
79	150	0	0	0	0	0	0	375	12	4723
80	150	0	0	0	0	0	0	375	12	3925

OBS	NI	CE	CY	TE	BA	DI	TI	SR	RW	YLD
81	150	0	0	0	0	0	0	475	12	2655
82	150	0	0	0	0	0	0	475	12	4018
83	150	0	0	0	0	0	0	475	12	5353
84	150	0	0	0	0	0	0	475	12	4135
85	150	0	0	0	0	0	0	575	12	2806
86	150	0	0	0	0	0	0	575	12	3841
87	150	0	0	0	0	0	0	575	12	5191
88	150	0	0	0	0	0	0	575	12	3365
89	150	0	0	0	0	0	125	450	12	3905
90	160	0	0	0	0	0	0	375	12	2921
91	160	0	0	0	0	0	0	375	12	4171
92	160	0	0	0	0	0	0	375	12	1075
93	160	0	0	0	0	0	0	375	12	2739
94	160	0	0	0	0	0	0	375	12	554
95	160	0	0	0	0	0	0	375	12	3142
96	160	0	0	0	0	0	0	375	12	816
97	160	0	0	0	0	0	0	375	12	2782
98	160	0	0	0	0	0	0	375	12	1737
99	160	0	0	0	0	0	0	375	12	3126
100	160	0	0	0	0	0	125	375	12	4471
101	160	0	0	0	0	0	125	375	12	3254
102	160	0	0	0	0	0	125	375	12	3578
103	160	0	0	0	0	0	125	375	12	3524
104	160	0	0	0	0	0	125	375	12	434
105	160	0	0	0	0	0	125	375	12	429
106	160	0	0	0	0	0	125	375	12	707
107	160	0	0	0	0	0	125	375	12	1945
108	160	0	0	0	0	0	250	375	12	3493
109	160	0	0	0	0	0	250	375	12	3491
110	160	0	0	0	0	0	250	375	12	1962
111	160	0	0	0	0	0	250	375	12	593
112	160	240	0	0	0	0	0	375	12	3044
113	160	240	0	0	0	0	0	375	12	1575

DATASET: W123

OBS	NI	CE	CY	TE	BA	DI	TI	SR	RW	YLD
1	0	360	0	0	0	0	0	500	10	1141
2	0	360	0	0	0	0	0	500	10	1731
3	0	360	0	0	0	0	0	500	10	1128
4	0	360	0	0	0	0	0	500	10	1075
5	0	360	0	0	0	0	250	500	10	1370
6	0	360	0	0	0	0	250	500	10	1407
7	0	360	0	0	0	0	250	500	10	1227
8	0	360	0	0	0	0	250	500	10	1636
9	0	360	0	0	0	2 2	125	500	10	1624
10	0	360	0	0	0	2 2	125	500	10	1738
11	0	360	0	0	0	2 2	125	500	10	1564
12	0	360	0	0	0	2 2	125	500	10	1605
13	0	360	0	0	0	2 2	125	500	10	1788
14	0	360	0	0	0	4 5	0	500	10	1386
15	0	360	0	0	0	4 5	0	500	10	1446
16	0	360	0	0	0	4 5	0	500	10	1780
17	0	360	0	0	0	4 5	0	500	10	1823
18	0	360	0	0	0	6 7	0	500	10	1860
19	0	360	0	0	0	6 7	0	500	10	1142
20	0	360	0	0	0	6 7	0	500	10	1074
21	120	360	0	0	0	0	0	500	10	2994
22	120	360	0	0	0	0	0	500	10	2892
23	120	360	0	0	0	0	0	500	10	3012
24	120	360	0	0	0	0	0	500	10	2662
25	120	360	0	0	0	0	250	500	10	2988
26	120	360	0	0	0	0	250	500	10	2810
27	120	360	0	0	0	0	250	500	10	2857
28	120	360	0	0	0	0	250	500	10	2833
29	120	360	0	0	0	2 2	125	500	10	3263
30	120	360	0	0	0	2 2	125	500	10	3088
31	120	360	0	0	0	2 2	125	500	10	2589
32	120	360	0	0	0	2 2	125	500	10	3114
33	120	360	0	0	0	4 5	0	500	10	3193
34	120	360	0	0	0	4 5	0	500	10	3133
35	120	360	0	0	0	4 5	0	500	10	2533
36	120	360	0	0	0	4 5	0	500	10	3117
37	120	360	0	0	0	6 7	0	500	10	3364
38	120	360	0	0	0	6 7	0	500	10	3410
39	120	360	0	0	0	6 7	0	500	10	2533
40	120	360	0	0	0	6 7	0	500	10	3204
41	150	0	0	0	0	0	250	500	10	3030
42	150	0	0	0	0	0	250	500	10	2684
43	150	0	0	0	0	0	250	500	10	3062
44	150	0	0	345	0	0	250	500	10	2912
45	150	0	0	345	0	0	250	500	10	2906
46	150	0	0	345	0	0	250	500	10	2813
47	150	0	0	345	0	0	250	500	10	2724
48	150	0	C	345	0	0	250	500	10	3058
49	150	0	345	0	0	0	250	500	10	2985
50	150	0	345	0	0	0	250	500	10	3212
51	150	0	345	0	0	0	250	500	10	2821
52	150	360	0	0	0	0	0	500	10	2931
53	150	360	0	0	0	0	0	500	10	3318
54	150	360	0	0	0	0	0	500	10	2845
55	150	360	0	0	0	0	0	500	10	3210
56	150	360	0	0	0	0	250	500	10	2687
57	150	360	0	0	0	0	250	500	10	3105
58	150	360	0	0	0	0	250	500	10	2881
59	150	360	0	0	0	0	250	500	10	2899
60	150	360	0	0	0	0	250	500	10	2788
61	150	360	0	0	0	0	250	500	10	2665
62	150	360	0	0	0	0	250	500	10	3661
63	150	360	0	0	0	0	250	500	10	3216
64	150	360	0	0	0	0	250	500	10	3349
65	150	360	0	0	0	2 2	125	500	10	3036
66	150	360	0	0	0	2.2	125	500	10	3157
67	150	360	0	0	0	2 2	125	500	10	3089
68	150	360	0	0	0	2.2	125	500	10	3135
69	150	360	0	0	0	4 5	0	500	10	2758
70	150	360	0	0	0	4 5	0	500	10	3088
71	150	360	0	0	0	4 5	0	500	10	3025
72	150	360	0	0	0	4 5	0	500	10	3365
73	150	360	0	0	0	6 7	0	500	10	3553
74	150	360	0	0	0	6 7	0	500	10	3252
75	150	360	0	0	0	6 7	0	500	10	2853
76	150	360	0	0	0	6 7	0	500	10	3515
77	180	0	0	0	0	0	250	500	10	2823
78	180	0	0	0	0	0	250	500	10	3391
79	180	0	0	0	0	0	250	500	10	2949
80	180	0	0	0	0	0	250	500	10	2909

OBS	NI	CE	CY	TE	BA	DI	TI	SR	RW	YLD
81	180	0	0	345	0	0	250	500	10	2692
82	180	0	0	345	0	0	250	500	10	2823
83	180	0	0	345	0	0	250	500	10	3141
84	180	0	0	345	0	0	250	500	10	2648
85	180	0	240	0	0	0	0	353	12	3478
86	180	0	240	0	0	0	0	353	12	3103
87	180	0	240	0	0	0	0	353	12	3814
88	180	0	240	0	0	0	0	353	12	3558
89	180	0	240	0	0	0	0	500	12	3232
90	180	0	240	0	0	0	0	500	12	3509
91	180	0	240	0	0	0	0	500	12	3580
92	180	0	240	0	0	0	0	500	12	3351
93	180	0	240	0	0	0	0	647	12	3011
94	180	0	240	0	0	0	0	647	12	3502
95	180	0	240	0	0	0	0	647	12	3498
96	180	0	240	0	0	0	0	647	12	3498
97	180	0	240	0	0	0	0	647	12	3378
98	180	0	240	0	0	0	0	794	12	3216
99	180	0	240	0	0	0	0	794	12	3672
100	180	0	240	0	0	0	0	794	12	3371
101	180	0	240	0	0	0	250	353	12	3383
102	180	0	240	0	0	0	250	353	12	3581
103	180	0	240	0	0	0	250	353	12	3883
104	180	0	240	0	0	0	250	353	12	3773
105	180	0	240	0	0	0	250	500	12	3718
106	180	0	240	0	0	0	250	500	12	3593
107	180	0	240	0	0	0	250	500	12	3951
108	180	0	240	0	0	0	250	500	12	3134
109	180	0	240	0	0	0	250	647	12	3388
110	180	0	240	0	0	0	250	647	12	3885
111	180	0	240	0	0	0	250	647	12	3230
112	180	0	240	0	0	0	250	647	12	4027
113	180	0	240	0	0	0	250	794	12	3768
114	180	0	240	0	0	0	250	794	12	3639
115	180	0	240	0	0	0	250	794	12	3550
116	180	0	240	0	0	0	250	794	12	3784
117	180	0	240	0	0	2 2	125	353	12	3474
118	180	0	240	0	0	2 2	125	353	12	3161
119	180	0	240	0	0	2 2	125	353	12	3775
120	180	0	240	0	0	2 2	125	353	12	3584
121	180	0	240	0	0	2 2	125	500	12	3456
122	180	0	240	0	0	2 2	125	500	12	3633
123	180	0	240	0	0	2 2	125	500	12	4064
124	180	0	240	0	0	2 2	125	500	12	3419
125	180	0	240	0	0	2 2	125	647	12	3521
126	180	0	240	0	0	2 2	125	647	12	3509
127	180	0	240	0	0	2 2	125	647	12	3614
128	180	0	240	0	0	2 2	125	647	12	3634
129	180	0	240	0	0	2 2	125	794	12	3748
130	180	0	240	0	0	2 2	125	794	12	3804
131	180	0	240	0	0	2 2	125	794	12	3602
132	180	0	240	0	0	2 2	125	794	12	3327
133	180	0	240	0	0	4 5	0	353	12	3607
134	180	0	240	0	0	4 5	0	353	12	3644
135	180	0	240	0	0	4 5	0	353	12	3499
136	180	0	240	0	0	4 5	0	353	12	3985
137	180	0	240	0	0	4 5	0	500	12	3738
138	180	0	240	0	0	4 5	0	500	12	3731
139	180	0	240	0	0	4 5	0	500	12	3980
140	180	0	240	0	0	4 5	0	500	12	3136
141	180	0	240	0	0	4 5	0	647	12	3202
142	180	0	240	0	0	4 5	0	647	12	3682
143	180	0	240	0	0	4 5	0	647	12	3803
144	180	0	240	0	0	4 5	0	647	12	3633
145	180	0	240	0	0	4 5	0	794	12	3687
146	180	0	240	0	0	4 5	0	794	12	3704
147	180	0	240	0	0	4 5	0	794	12	3731
148	180	0	240	0	0	4 5	0	794	12	3503
149	180	0	240	0	0	6 7	0	353	12	3603
150	180	0	240	0	0	6 7	0	353	12	3018
151	180	0	240	0	0	6 7	0	353	12	3537
152	180	0	240	0	0	6 7	0	353	12	3875
153	180	0	240	0	0	6 7	0	500	12	3780
154	180	0	240	0	0	6 7	0	500	12	3366
155	180	0	240	0	0	6 7	0	500	12	3763
156	180	0	240	0	0	6 7	0	500	12	3544
157	180	0	240	0	0	6 7	0	647	12	3276
158	180	0	240	0	0	6 7	0	647	12	3614
159	180	0	240	0	0	6 7	0	647	12	3604
160	180	0	240	0	0	6 7	0	647	12	3647

OBS	NI	CE	CY	TE	BA	DI	TI	SR	RW	YLD
161	180	0	240	0	0	6.7	0	647	12	3657
162	180	0	240	0	0	6 7	0	794	12	3567
163	180	0	240	0	0	6 7	0	794	12	3212
164	180	0	240	0	0	6 7	0	794	12	3413
165	180	0	345	0	0	0	250	500	10	2777
166	180	0	345	0	0	0	250	500	10	3057
167	180	0	345	0	0	0	250	500	10	3158
168	180	0	345	0	0	0	250	500	10	3071
169	180	360	0	0	0	0	0	500	10	3051
170	180	360	0	0	0	0	0	500	10	3641
171	180	360	0	0	0	0	0	500	10	3102
172	180	360	0	0	0	0	0	500	10	2466
173	180	360	0	0	0	0	0	500	10	3247
174	180	360	0	0	0	0	0	500	10	3517
175	180	360	0	0	0	0	0	500	10	3437
176	180	360	0	0	0	0	0	500	10	2996
177	180	360	0	0	0	0	250	500	10	2806
178	180	360	0	0	0	0	250	500	10	3228
179	180	360	0	0	0	0	250	500	10	3458
180	180	360	0	0	0	0	250	500	10	2997
181	180	360	0	0	0	0	250	500	10	3962
182	180	360	0	0	0	0	250	500	10	2989
183	180	360	0	0	0	0	250	500	10	3285
184	180	360	0	0	0	0	250	500	10	2762
185	180	360	0	0	0	0	250	500	10	3359
186	180	360	0	0	0	0	250	500	10	3642
187	180	360	[illegible]	0	0	0	250	500	10	3259
188	180	360	[illegible]	0	0	0	250	500	10	3046
189	180	360	0	0	0	2 2	125	500	10	3589
190	180	360	0	0	0	2 2	125	500	10	3211
191	180	360	0	0	0	2 2	125	500	10	3463
192	180	360	0	0	0	2 2	125	500	10	3510
193	180	360	0	0	0	2 2	125	500	10	3063
194	180	360	0	0	0	2 2	125	500	10	3668
195	180	360	0	0	0	2 2	125	500	10	3244
196	180	360	0	0	0	2 2	125	500	10	3300
197	180	360	0	0	0	4 5	0	500	10	3242
198	180	360	0	0	0	4 5	0	500	10	2625
199	180	360	0	0	0	4 5	0	500	10	3161
200	180	360	0	0	0	4 5	0	500	10	2984
201	180	360	0	0	0	4.5	0	500	10	2855
202	180	360	0	0	0	4 5	0	500	10	3600
203	180	360	0	0	0	4 5	0	500	10	3395
204	180	360	0	0	0	4 5	0	500	10	4137
205	180	360	0	0	0	6 7	0	500	10	3470
206	180	360	0	0	0	6 7	0	500	10	2931
207	180	360	0	0	0	6 7	0	500	10	3251
208	180	360	0	0	0	6 7	0	500	10	3099
209	180	360	0	0	0	6 7	0	500	10	3415
210	180	360	0	0	0	6 7	0	500	10	3326
211	180	360	0	0	0	6 7	0	500	10	3031
212	180	360	0	0	0	6 7	0	500	10	3379
213	210	0	0	0	0	0	250	500	10	2961
214	210	0	0	0	0	0	250	500	10	2990
215	210	0	0	0	0	0	250	500	10	3388
216	210	0	0	0	0	0	250	500	10	2656
217	210	0	0	0	0	0	250	500	10	3121
218	210	0	0	345	0	0	250	500	10	2849
219	210	0	0	345	0	0	250	500	10	2934
220	210	0	0	345	0	0	250	500	10	3182
221	210	0	345	0	0	0	250	500	10	2818
222	210	0	345	0	0	0	250	500	10	2703
223	210	0	345	0	0	0	250	500	10	2891
224	210	0	345	0	0	0	250	500	10	2810
225	210	360	0	0	0	0	0	500	10	2746
226	210	360	0	0	0	0	0	500	10	3435
227	210	360	0	0	0	0	0	500	10	2828
228	210	360	0	0	0	0	0	500	10	3569
229	210	360	0	0	0	0	250	500	10	2915
230	210	360	0	0	0	0	250	500	10	2979
231	210	360	0	0	0	0	250	500	10	3450
232	210	360	0	0	0	0	250	500	10	2880
233	210	360	0	0	0	0	250	500	10	3034
234	210	360	0	0	0	0	250	500	10	4033
235	210	360	0	0	0	0	250	500	10	2799
236	210	360	0	0	0	0	250	500	10	3341
237	210	360	0	0	0	2 2	125	500	10	3521
238	210	360	0	0	0	2 2	125	500	10	3573
239	210	360	0	0	0	2 2	125	500	10	2924
240	210	360	0	0	0	2.2	125	500	10	3877

APPENDIX THREE

OBS	NI	CE	CY	TE	BA	DI	TI	SR	RW	YLD
241	210	360	0	0	0	4 5	0	500	10	3277
242	210	360	0	0	0	4 5	0	500	10	3823
243	210	360	0	0	0	4.5	0	500	10	2240
244	210	360	0	0	0	4 5	0	500	10	3406
245	210	360	0	0	0	6 7	0	500	10	3461
246	210	360	0	0	0	6 7	0	500	10	3725
247	210	360	0	0	0	6 7	0	500	10	2892
248	210	360	0	0	0	6 7	0	500	10	2916

APPENDIX FOUR: SAS Procedures

APPENDIX FOUR explains the two PROC REG regression options in SAS which were utilized in this project An example of each option an part of a command file, along with the respective output produced, is presented in APPENDIX SIX (The SAS Institute Inc. 1990)

SAS ... PROC REG (Options)

(a) OPTIONS = NONE ... this is the PROC REG default setting, and provides a fitted model given the terms specified in the MODEL statement. This option would be used to fit any model without reference to any other factor other than the given model variables.

(b) OPTIONS = STEPWISE .. This option allows for the fitted model to be constructed one term (*ie.* variable) at a time The user is prompted to select a significance level (*ie.* SLENTRY = ..) which the F-test statistic of each term must equal or exceed in order to be entered into the model In addition, after a term is added to the model, there are subsequent checks on the significance levels of that term and any others currently in the model. If at any point the significance level of one or more terms falls below the SLSTAY = ... value, those terms are dropped from the model. The process continues until none of the terms outside of the model have an F-statistic significant at the SLENTRY level and all of the terms inside the model are significant at the SLSTAY level The default for both of these, SLENTRY and SLSTAY, is 0.1500.

APPENDIX FIVE: Dataset Adjustments

APPENDIX FIVE provides an explanation of the preparation of the *ADJUSTED DATASET* model. In using this model, one wants to remove the influence of explanatory variables which cannot be accommodated in the equation at hand.[1] The procedure used in this project, as a result of Mitscherlich-Baule equation failures, entailed the following steps:[2]

1 A stepwise regression job was submitted, the results of which determined the terms to be submitted to a Mitscherlich-Baule equation estimation

2. The variable which was not accommodated in the Mitscherlich-Baule estimation was identified for removal from the dataset at hand (*eg* Z)

3 For the variable to be removed, the range of its application rates was determined and a mid-point calculated

4 The stepwise regression model is consulted and the parameter estimates which contain the variable Z are noted

5 For each yield observation which contains the variable Z as an input, the following calculation is carried out

$$\mathbf{YIELD_{adjusted} = YIELD_{actual} + [(Z\ midrange - Z\ input\ level) * Z\ parameter\ estimate]}$$

To remove the influence of Z, the actual yield values would have to be adjusted according to the sign on the Z parameter estimate Following these five steps would remove the influence of the variable Z by decreasing (increasing) the actual yields if the sign on the Z parameter estimate is positive (negative) Given that the above calculation deals with the mid-point of the input application rates, the adjusting procedure is adjusting all yields towards a variable Z-input level equal to the mid-point Hence, if the level of application of Z is above (below) the mid-point, the calculation will produce an adjusted yield value which is less than (greater than) the actual yield value for that observation

---

1 The use of this adjusting procedure is subject to debate as to the appropriateness of such procedures

2 Assume that only one variable, Z, could not be accommodated and will therefore be removed from the dataset

The choice of adjusting the yield values to the mid-point of the range of application is arbitrary: the adjustments could be made to zero or any other rate of application with in the stated range of application for the dataset.

APPENDIX SIX: PROC MODEL/PROC REG SAS Jobs

APPENDIX SIX (A)

APPENDIX SIX (A) illustrates the SAS input commands for a PROC REG (options=NONE) regression and the output that is generated.

INPUT

```
/* The following statements initiate the SAS dataset "MBMODEL TEST"        */
/* These statements also command the SAS program to include an external    */
/*  dataset with the INPUT statement                                       */

        DATA MBMODEL.TEST;
        ;
        INPUT YLD 0-12 NI 13-21 PO 22-30;
        CARDS;
        ;
        DATA TEMPFRA;
            SET MBMODEL.TEST;

/* The next three statements define quadratic and linear regression        */
/*  terms and command the program to keep these new terms, along with      */
/*  the variables supplied by the dataset in a SAS dataset "TEMPFRA"       */

            NISQR=(NI**2) ;
            POSQR=(PO**2) ;
            NIXPO=(NI*PO) ;
            KEEP NI PO
            NISQR POSQR
            NIXPO
            YLD;

/* The following procedure begins a non-stepwise quadratic                 */
/*  regression on the model submitted in the MODEL statement               */
/*  options are specified for tests for autocorrelation and                */
/*  heteroscedasticity                                                     */

          PROC REG DATA=TEMPFRA;
            MODEL YLD=NI PO
            NISQR POSQR NIXPO/DW
            SPEC;
```

OUTPUT

/* The following output is the result of the PROC REG regression job, */
/* listing the analysis of variance and related statistics as well as */
/* the estimated model parameters */

Model: MODEL1
Dependent Variable: YLD

Analysis of Variance

Source	DF	Sum of Squares	Mean Square	F Value	Prob>F
Model	5	201977 60002	40395 52000	107 116	0 0001
Error	108	40728 94629	377 11987		
C Total	113	242706 54632			

Root MSE	19 41957	R-square	0 8322
Dep Mean	86 06842	Adj R-sq	0 8244
C V	22 56295		

Parameter Estimates

Variable	DF	Parameter Estimate	Standard Error	T for H0 Parameter=0	Prob > |T|	Variance Inflation
INTERCEP	1	-7 510288	6 63746715	-1 131	0 2604	0 00000000
NI	1	0 584293	0 06346631	9 206	0 0001	14 62853625
PO	1	0 663809	0 06346631	10 459	0 0001	14 62853625
NISQR	1	-0 001581	0 00017644	-8 962	0 0001	12 58077283
POSQR	1	-0 001797	0 00017644	-10 185	0 0001	12 58077283
NIXPO	1	0 000811	0 00015471	5 244	0 0001	5 53461880

/* Heteroscedasticity test results are determined by the value of the */
/* Prob>Chisq <value> a value greater than 0 1000 is deemed to */
/* indicate the absence of heteroscedasticity */

Test of First and Second Moment Specification
DF 12 Chisq Value 19 2562 Prob>Chisq. 0 0825

/* Autocorrelation test results are determined by the value indicated */
/* in the Durbin-Watson (DW) statement values derived have to */
/* looked-up in DW tables (Wittink, 1988) */

Durbin-Watson (DW) 0 971 (For Number of Obs) 114
1st Order Autocorrelation 0 501

APPENDIX SIX (B)

APPENDIX SIX (B) illustrates the SAS input commands for a PROC MODEL regression job and the output that is generated.

INPUT

```
/* The following statements initiate the SAS dataset "MBMODEL TEST"      */
/* These statements also command the program to include the external     */
/*  dataset with the INPUT statement                                      */

        DATA MBMODEL.TEST;
        ;
        INPUT YLD 0-12 NI 13-21 PO 22-30;
        CARDS;
        ;
        DATA TEMPFRA;
            SET MBMODEL.TEST;

/* The M-B model estimation begins with defining the dependant           */
/*  and independent variables, indicating parameters to be               */
/*  estimated, and, identifying the equation to be fitted, all           */
/*  of which are brought together in a new SAS dataset "TEMPFRA"         */

        PROC MODEL DATA=TEMPFRA;
            ENDOGENOUS YLD;
            EXOGENOUS NI PO;
            PARMS A N1 N2 P1 P2;
            YLD=A*(1-EXP(-N1*(N2+NI)))*
            (1-EXP(-P1*(P2+PO)));

/* Starting values for the non-linear parameter estimation are           */
/*  supplied, with options, to aid the iterative estimation procedure    */

            FIT YLD
            START=(A 127 63 N1 .019 N2 13 36
            P1 .028 P2 5 61)/
            CONVERGE=0.001
            MAXITER=80 MAXSUBITER=80
            METHOD=MARQUARDT DW;
```

OUTPUT

/* The following "NOTE" indicates a successful non-linear regression */
/* convergence given the convergence criteria */

NOTE: At OLS Iteration 2 CONVERGE=0.001 Criteria Met.

/* The following output is the result of the PROC MODEL regression */
/* job, listing a summary of the equation to be estimated as well as */
/* the a summary of the estimated equation and related residual */
/* statistics */

```
                     MODEL Procedure
                      Model Summary

              Model Variables          3
                Endogenous             1
                Exogenous              2
              Parameters               5
              Equations                1

              Number of Statements     1

Model Variables  YLD NI PO

Parameters  A  127 6  N1  0 019  N2  13 36  P1  0.028  P2  5 61

Equations  YLD

                     MODEL Procedure

              The Equation to Estimate is

               YLD = F( A, N1, N2, P1, P2 )

                      OLS Estimation

              Observations Processed
              Read                      114
              Solved                    114

                      OLS Estimation

        Nonlinear OLS Summary of Residual Errors

            DF    DF                                                              Durbin
Equation  Model Error       SSE          MSE    Root MSE  R-Square  Adj R-Sq  Watson

YLD           5   109     18552    170 19977    13 04606    0 9236    0 9208   1 789
               Nonlinear OLS Parameter Estimates

                                          Approx        'T'   Approx
          Parameter      Estimate        Std Err      Ratio  Prob>|T|

          A            127 625045        2 42230      52 69    0 0001
          N1             0 019120      0 0022033       8 68    0 0001
          N2            13 359518        2 57940       5 18    0 0001
          P1             0 027476      0 0032176       8 54    0 0001
          P2             5 599963        1 43493       3 90    0 0002


       Number of Observations       Statistics for System
      Used                  114     Objective      162 7349
      Missing                 0     Objective*N       18552
```

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