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AN EVALUATION OF FARM MANAGEMENT STRATEGIES UNDER DROUGHT CONDITIONS: THE CASE OF DRYLAND GRAIN PRODUCTION ON THE CANADIAN PRAIRIES

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© BERNARD GRANT MONNEY

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Date June 16, 1983

Dedicated

To my dear wife

Stella

To our daughter

Adwoa Amonoa

and

To the memory of my father

J.C.

Abstract

This study employs a simulation approach to trace the impact of drought on farm cash flows, capital accummulation, and equity of a representative grain farm in southwestern Saskatchewan. The objectives of the study are:

1. To develop a methodology for evaluating the impact of drought on the farm business; and
2. To identify and evaluate management strategies that prairie farmers might follow in order to mitigate the impact of drought and to enhance the prospects of the long-run survival of the farm business.

The development of methodology for evaluating drought impacts is achieved by modifying an existing Dryland Crop Simulation Model, considered as the basic model in this study, to make it possible for sets of yield values to be read by the model.

The process of research involves an interview with the case farmer to determine the specifics of his operation and to identify his basic management practice as well as the drought adjustment options available to him. Drought adjustment is part of the farmer's basic strategy, even though he does not carry any crop insurance.

The study identifies fifteen adjustment strategies and evaluates the consequencies of these strategies with consideration to farm growth and business survival. The strategies are therefore evaluated on the basis of the mean-standard deviation efficiency criteria, which are

derived from the expected utility theory and the concepts of stochastic dominance.

For each strategy, the farm business is evaluated for a ten year period of operation, and the ending equity value is selected. This process is repeated ten times using randomly selected yield series to obtain ten ending equity positions from which the expected equity position and its standard deviation are computed.

Four series of simulations are conducted, each representing a different level of debt load, namely debt-free, low debt, medium debt and high debt situations. The case farm is represented by the debt-free situation. The other levels of outstanding liabilities are assumed in order to test results under conditions of debt. The study identifies three essential components of farm management strategy under drought conditions, namely

1. the inclusion of fallow in the crop rotation programme, particularly the 1/2 crop - 1/2 fallow rotation,
2. the purchase of crop insurance coverage, and
3. the postponement of certain cost related activities such as machinery purchase.

The results for consumption behaviour are inconclusive for the case farmer, although it is possible to consider reduction in consumption withdrawals as part of a drought adjustment strategy. The study also reveals that the combined effects of high indebtedness and high rates of interest preclude real business growth and, in the event of severe drought, ensure business failure or bankruptcy.

The study notes that improved knowledge of farm financial management principles will enable farmers to better manage their cash flows and maintain adequate cash reserves and loan requirements in order to reduce the adverse effects of drought.

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1. INTRODUCTION

This study focuses on the economic evaluation of farm management practices in a region characterized by frequent occurrences of drought of varying intensity and duration. In particular, the study attempts to trace the impact of drought at the farm level (or the supply side), with emphasis on its effects on cash flows, capital accummulation, and equity. Present farm level adjustment practices are also identified and evaluated with consideration to farm growth and business survival.

The chapter begins with a general description of the performance of the Canadian agricultural sector, with special reference to the prairie region. The remaining sections elaborate on the study problem and its objectives, and also present the hypotheses and the importance of the study.

1.1 Recent Performance of the Canadian Agricultural Sector

The contribution of the agricultural sector to the economic growth of Canada cannot be disputed, even though its relative importance in the national economy seems to have declined in recent years. Recent figures indicate that the sector's contribution to Canada's GDP[1] is approximately 25% of the total economic activity.[2] In addition, the agricultural sector accounted for 9.3% of Canada's export

[1] GDP represents the Gross Domestic Product, which is the total dollar value of domestic output.
[2] Statistics Canada, *Canada Year Book 1980-81*, Ottawa, p.401.

trade in 1978.[1] Futhermore, the sector has achieved great strides within the past 50 years - a performance mainly attributable to increased efficiency.[2]

Table 1 sheds more light on some of the changes which have taken place in the agricultural sector from 1971 to 1976. During the period, the number of farms and farm population decreased by 7.5% and 15.7% respectively, while the average farm size increased by 3.4%. Farms are therefore getting larger and larger and this is achieved mainly through mergers and new capitalization.[3] Table 1 also shows a large increase in capital value which may explain the trend towards capitalization, as farms get larger and farm population becomes smaller. However, since capital assets were based on their market value, inflation has contributed to much of the large increase.

As noted earlier, the Canadian agricultural sector has become highly productive over the years. Indeed, from 1961 to 1969, the productivity growth rate for the agricultural sector averaged 4.3% per annum on per capita basis which is greater than the corresponding rate of 2.7% achieved by the non-agricultural sector.[4] Peterson and Hayami[5]

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[1] *Ibid.*

[2] G. Lussier, "Current Agricultural Situation in Canada", in Canadian Banker's Assoc., *Proceedings of the Agricultural Credit Conference*, Oct. 22-24, 1979; and S. Zariffa, "Introduction", *Agricultural Credit Conference*, Oct. 22-24, 1979.

[3] Zariffa, "Introduction", *Agricultural Credit Conference*, Oct. 22-24, 1979.

[4] Statistics Canada, *Canada Year Book 1980-81*, Table 23.14, pp. 867-8.

[5] W. Peterson and Y. Hayami, "Technical Change in Agriculture", in Lee R. Martin, ed., *A Survey of*

TABLE 1

Some Agricultural Indicators for Canada (1971,1976)

	1971	1976	% Change*
Number of farms	366128	338578	-7.5
Av. Farm size (ac.)	535	553	3.4
Farm population	1489600	1255800	-15.7
Capital value (m. $)	22.4	57.1	154.9

Source: Agriculture Canada, *Selected agricultural statistics for Canada and the Provinces*, Ottawa (1978,1982).
*My own calculation.

traced the sources of productivity growth in the U.S. agriculture to the following:

1. increase in skills of farm people,
2. increase in quality of non-human capital (e.g. machinery, equipment, buildings),
3. increase in quality of other inputs (i.e. commercial fertilizers with improved nutrient content, new and improved crop varieties, more efficient breeds of livestock and poultry, and new and improved agricultural chemicals),
4. increase in quality of output, and
5. economies of scale.

There is no doubt that these factors have accounted for the observed productivity growth within the Canadian agricultural sector.

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*(cont'd) *Agricultural Economic Literature*, 4 vols. (Minneapolis: University Minnesota Press, 1977-81), 1:497-540.

Even though significant improvement in the development and use of agricultural technology has occured in Canada, it is evident that most of the effort has been directed at improving those factors which are under the control of the farmer. Since farming takes place in an environment which is characterized by the presence of controlled as well as uncontrollable factors,[1] it is also essential that steps be taken to study and fully understand the effects of the uncontrollable factors, which account for the observed instabilities or variations in farm prices and outputs and hence uncertainty in farming.[2] Perhaps nowhere in Canada is the influence of the uncontrollable factors, particularly the weather, more prominent than on the prairies.

The prairie region occupies much of western Canada and stretches southwards into central U.S. to form the Great Plains of North America.[3] The Great Plains region is important for grain and livestock production. The region accounts for 90% of the commodity trade grain crops in North America.[4]

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[1] Uncontrollable factors such as climate, pest, disease etc. are random in nature.

[2] Indeed, the purpose of applied research is to change uncontrollable factors to controllable ones - e.g. the development of fertilizers, herbicides, and improved seed varieties. In this study, major reference is made to the weather which is difficult to control.

[3] Roughly, the Great Plains stretch from Texas and New Mexico (U.S.) north through Saskatchewan and Manitoba (Canada), with the Rocky Mountains defining the western boundary. See N.J.Rosenberg, ed., *Drought In the Great Plains: Research on Impacts and Strategies* (Littleton, Co.: Water Resources Publication, 1979), p. 1. For this study the terms "prairie region" or "the prairies" will be used to refer to the Canadian prairies.

[4] J.E. Newman, "Drought Impacts on American Agricultural

In Canada, the prairie region occurs in the provinces of Manitoba, Saskatchewan and Alberta. Agriculture is the main economic activity of this region, which contains 75% of the farmland in Canada[1] and accounts for 77-100% of the output of the major field crops of Canada.[2] Tables 2 and 3 show wheat to be the most important field crop in terms of total output and as a source of income to prairie farmers. In spite of its agricultural importance, the prairie region is influenced to a large extent by unstable weather and other climatic conditions. A principal climatic phenomenon on the Great Plains is the occurrence of drought,[3] which has been described as the major production problem for western agriculture,[4] as well as the "chief climatic risk" of the region.[5] The *Encyclopaedia Britannica*[6] extended this further when it described drought as the "most serious physical hazard to agriculture in nearly every part of the world". The problem associated with drought on the Canadian prairies is of primary interest to this study and is therefore discussed in detail in later sections.

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[4](cont'd)Productivity", in N.J.Rosenberg, ed., *North American Droughts* (Boulder, Co.: Westview Press, 1978).
[1] Statistics Canada, *Canada Year Book 1980-81*, Ottawa
[2] Computed from Table 2.
[3] There are perhaps as many definitions of drought as there are disciplines interested in the phenomenon. Here we are interested in agricultural drought which may be defined as "a climatic excursion involving a shortage of precipitation sufficient to adversely affect crop production or range productivity". See Rosenberg(1979), p. 2.
[4] G. McKay, "Mitigation of the Effects of Drought With Special Reference to the Canadian Experience", in Rosenberg(1979), p. 168.
[5] Newman, "Drought Impacts on American Agricultural Productivity", in Rosenberg(1978), p. 44.
[6] *Micropaedia*, 15th. Ed., *s.v.* "Drought".

TABLE 2

**Production of Selected Field Crops
Prairie Provinces and Canada, 1981(m. bu.)**

CROP	MANITOBA	SASK	ALBERTA	PRAIRIE TOTAL	CANADA
All Wheat	123	518	222	863	901
Oats	33	55	91	179	232
Barley	107	155	303	565	615
All Rye	8.9	13.0	12.7	34.6	37.9
Flaxseed	10.6	6.0	2.2	18.8	18.8
Rapeseed	15.0	30.0	33.0	78.0	79.2

Source: Statistics Canada, Catalogue No. 22-002.

TABLE 3

**Percentages of Farm Cash Receipts from Farm Operations
Prairie Provinces and Canada (1980)**

CROP	MANITOBA	SASK	ALBERTA	CANADA
Wheat	27	63	38	20
Cattle and Calves	22	16	21	23
Canola	7	7	10	4
Barley	6	5	10	4
Other cash receipts	38	9	21	49
TOTAL	100	100	100	100

Source: Statistics Canada, *Farming facts 1982*, Ottawa.

1.2 The Study Problem and Analysis

Drought has been referred to as a "creeping phenomenon"[1] and a "non-event" since, unlike other natural disasters such as floods, earthquakes or hurricanes, both the onset of a period of prolonged drought and its termination point may not be easily noticeable.[2] Losses associated with the occurrence of drought could be very substantial. For instance, Haas[3] ranks drought as second only to flood and frost in direct loss produced in the U.S. annually.

The effect of drought is felt at various levels of the society - *viz.* the farm level, the regional level, the national level and, in some cases, the international level. Sometimes drought may affect a small locality, even one farm, and may not be felt in the rest of the neighbourhood. The effects of drought at the farm level are of interest to this study since the sector often receives the immediate and adverse impacts of drought. Drought of a brief duration may be confined to the farm level and may not be noticed even at the regional level. Riefler[4] has outlined the areas of impact of certain historic droughts, and notes that because agricultural planners tend to take years of good precipitation to be normal years, and thus plan accordingly,

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[1] J.E. Haas, "Strategy in Event of Drought", in Rosenberg(1978), p. 103.
[2] R.F. Riefler, "Drought: An Economic Perspective" in Rosenberg(1978), p. 63.
[3] Haas, "Strategies in Event of Drought", in Rosenberg(1978), p. 103.
[4] Riefler, "Drought:An Economic Perspective," in Rosenberg(1978), p. 69.

coupled with the increased trend towards capital intensive farming, the individual farmer becomes more susceptible, economically, to prolonged drought.

The prairie region has seen the recurrence of drought conditions ever since agricultural settlement in the area took place in the latter part of the 19th. century.[1] Records, however reveal the occurrences of severe droughts prior to this period. The conditions that existed on the prairies caused many explorers, such as Captain John Palliser, to have an unfavourable view of parts of the region. Captain Palliser was commissioned by the Secretary of State for the Colonies in 1857 "to explore that part of North America which lies between the north branch of the river Saskatchewan and the frontier of the United States, and between the Red River and the Rocky Mountains". He identified, within this region, a "Fertile Belt" and also what he called the "Canadian Desert", which he mistakenly regarded as an extension of the American Desert, and now commonly known as the Palliser Triangle.[2]

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[1] A brief account of the experiences of drought on the prairies is given in Chapter 2.

[2] Palliser's recommendation is contained in a report that he submitted to the Royal Geographical Society and to the Colonial Office in London in 1862. The "Fertile Belt" was was identified as an area that extended northwest from east of Fort Garry, to beyond Fort Edmonton, and from there southward along the the foothills of the Rocky Mountains. The Palliser Triangle is a triangular-shaped region whose base stretches along the 49th. parallel (the border with the U.S.), from longitude 100° to 114° W. and extends north to the 52nd. parallel. It is, however, believed that Palliser's expedition in the Palliser Triangle might have taken place at a time when the region was experiencing one of its recurrent droughts. The expedition, which took place between 1857 and 1860, has been cited by James H. Gray, *Men against*

The Palliser Triangle was identified as an area not capable of supporting viable agriculture, a decision which was to have an impact on settlement in the area. Other pioneers of the prairies, notably the Rt. Hon. Edward Ellice and Sir George Simpson, both former governors of the Hudson's Bay Company, which used to own much of western Canada, had similar opinions of the region.[1]

These negative impressions, notwithstanding, the prairies have emerged as an important agricultural region, producing more than 95% of grains that Canada exports, and there is no doubt that many factors have contributed to this impressive record of the prairie agricultural sector. Furthermore, prairie farmers have without doubt devised means by which they cope with or accommodate the occurrences of drought. In this study an attempt is made to determine how prairie farmers cope with the recurrent drought conditions and also how they adjust to drought of varying intensity and duration.

The problem associated with the prevalence of drought conditions on the prairies may be traced to two main factors: the climatic conditions of the region and the soil

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[2](cont'd)*the desert* (Saskatoon: Western Producer Prairie Books, 1978);John W. G. MacEwan, *Grant MacEwan's illustrated history of western Canada agriculture* (Saskatoon: Western Producer Prairie Books, 1980),Chpt. 6; C.H. Anderson, *A History of Soil Erosion by Wind in the Palliser Triangle of Western Canada*, Agriculture Canada Historical Series No. 8, 1975; H.G.L. Strange, *A Short History of Prairie Agriculture* (Winnipeg: Searle Grain Company Limited, 1954), and J.B. Campbell, *The Swift Current Station,1920-70*, Canada Dept. of Agriculture, Historical Series No. 6, 1971, p. 9.

[1] See Campbell(1971), p. 9.

types. The region is principally semi-arid, which is characterized by low precipitation relative to evaporation and transpiration or (evapotranspiration) and usually uneven distribution of precipitation during the year.[1] The driest part of the region is the south Saskatchewan River Basin along the Alberta-Saskatchewan border, which receives an average annual precipitation of less than 300mm (12in).[2] The level of precipitation increases in the northerly direction to over 410mm (16in) in the wooded parkland belt, and eastward to over 510mm (20in) in Manitoba.[3] The semi-arid region is classified as between the arid zone, where cultivation is not possible without irrigation, and the subhumid zone where precipitation is adequate for continuous cultivation.[4] Climatic conditions of both the subhumid and the arid types are commonly experienced over time in the semi-arid regions, which explains the alternation of favourable and unfavourable cropping conditions. This instability in weather conditions is the principal factor in the unreliability of soil moisture in the semi-arid regions

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[1] A detailed definition is given in H.P. Bailey, "Semi-Arid Climates: Their Definition and Distribution", in A.E Hall, G.H. Cannell, and H.W. Lawton, eds., *Agriculture in Semi-Arid Environments* (Berlin, Heidelberg and New York: Springer-Verlag, 1979), pp. 73-97.
[2] F. Kenneth Hare and Morley K. Thomas, *Climate of Canada* (Toronto: Wiley Publishers of Canada Limited, 1974), p. 113.
[3] *Ibid.*
[4] This is the Thornthwaite classification which has been mentioned in the *Encyclopaedia Britannica*, 15th. ed., *s.v.* "Semi-arid". See also C.W. Thornthwaite, "An approach toward a rational classification of climate", *Geog. Rev.*, 38: 55-94, 1948, and G. Perrin de Brichambaut, "Similarities and Differences in Worldwide Dryland Farming", in W.C. Burrows *et al.*, eds., *International Conference On Mechanized Dryland Farming* (Moline: Deere and Company, 1970), p. 20.

of the world.

There are three main soil zones in the major grain and livestock producing areas of the prairies.[1] These are the brown soil zone to the south, the dark brown soil zone and the black soil zone to the north (Figure 1). The brown soils carry short grass species whereas the dark brown and the black soils carry relatively taller grasses. The black soils also carry some tree cover. Prairie soils also differ very much in terms of texture, organic matter content, and moisture holding capacity, which influence soil productivity and vegetation. The classes of soil texture include sands, loams, clays and various combinations of the three. These combinations may be found in all the three soil zones. However, there are distinct variations in soil organic matter content and soil water holding capacity among the soil zones. The organic matter content of the soil increases from the brown soil zone to the dark brown soils to the black soil zone. For a particular texture, the moisture holding capacity of the soil is lowest in the brown soils, with the black soils having the highest water holding capacity.[2]

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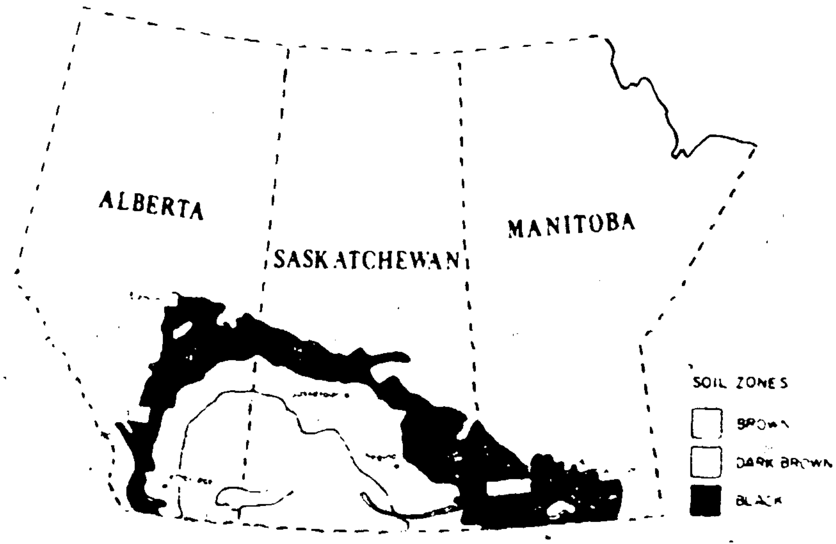
[1] This discussion of prairie soils is based on the following: *Guide to Farm Practice in Saskatchewan 1972*, (Saskatoon: Extension Division of the University of Saskatchewan), pp. 86-87; Anderson, *Soil Erosion in the Palliser Triangle*, 1975; W.M. Drummond and W. Mackenzie, *Progress and Prospects of Canadian Agriculture*, Royal Commission on Canada's Economic Prospects, 1957, pp. 252-260; and K.D. Russell and H.T.M. Colwell, "Economics of short-term energy conservation adjustments on prairie grain farms", *Canadian Farm Economics*, Vol. 16, No. 6 (1981), pp. 1-11.

[2] The ability of soils to hold water is influenced to a large extent by the rate of evapotranspiration. Therefore,

FIGURE 1

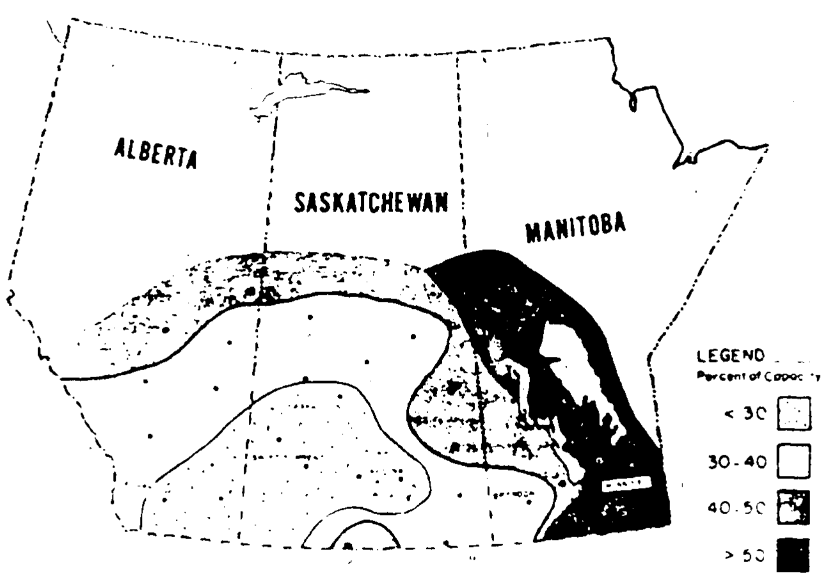
THE BROWN, DARK BROWN, AND BLACK SOIL ZONES OF THE PRAIRIE PROVINCES



Source: K.D. Russell, and H.T.M. Colwell, "Economics of short-term energy conservation adjustments on prairie grain farms", *Can. Farm Econ.*, 16(6): 2, 1981.

FIGURE 2

ESTIMATED NORMAL SOIL MOISTURE RESERVES BY MAY 31 (over 30 years) IN A MEDIUM-TEXTURED SOIL UNDER FORAGE



Source: J.A. Dryer; R.B. Stewart; and D.W. Warner, "A Scheme for Defining Drought Areas", *Can. Farm Econ.*, 16(5): 2, 1981.

This is evident in Figures 1 and 2, which reveal a close relationship between soil zones and soil moisture holding capacity.

All three soil types belong to the class of soils known as the chernozems, which are found in the semi-arid regions of the temperate zone (or the steppes). The chernozems are moderately fertile, well drained, and very rich in such resources as groundwater, coal, and oil.[1] These qualities, which benefit agricultural production and other sectors of the economy, are derived from millions of years of sedimentary deposition.[2] The brown soils of the Canadian prairies are the least fertile and the black soils are the most fertile. The dark brown soils have some characteristics of the brown soils as well as the black soils.

The main type of farming in the Canadian prairies is dryland farming, which is a "consequence of semi-arid climates".[3] Dryland farming depends solely on water available from precipitation and, according to the *Encyclopaedia Britannica*,[4] it "consists of making the best use of limited water supply by storing as much of the moisture in the soil and by selecting crops and growing methods that make the best use of the moisture". This definition emphasizes conservation of soil moisture as

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[2](cont'd)the lower water holding capacity of the brown soils may be due to the higher evapotranspiration rate of the soils.

[1] L. Bowden, "Development of Present Dryland Systems", in Hall, Cannell, and Lawton(1979), pp. 57-65.

[2] *Ibid.*

[3] *Ibid., p. 45.*

[4] *Micropaedia,* 15th. ed., *s.v.* "Dry Farming"

crucial to the success of dryland farming.

The soils of the Palliser Triangle are mainly of the brown and the dark brown types. In this region, the combined effects of the semi-arid conditions and the low moisture holding capacity of the soil imply the existence of a delicate balance between water availability for plant use and plant water requirement. This is even more crucial in view of the dryland farming practice, which as noted earlier, depends solely on water available from precipitation. If favourable conditions prevail, and the supply of soil moisture is not limiting, then a good season results. However, if the reverse situation prevails, as would occur during drought, and soil moisture is not adequate for plant use, then crop failure may occur. The immediate impact of drought on farm production is a decrease in yield (and farm output), which causes the firm's supply curve (and consequently the aggregate supply curve when drought affects a wider area) to contract and in the short-run, when consumer demand for the product has not changed, results in an increase in the price of the product, if drought is widespread.[1] The effect on farm income depends on the extent of the shift and also on the supply and demand elasticities for the product. However, an obvious manifestation is a reduction in farm incomes and decreased

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[1] An exception to this may be traced to the drought of the early 1930's which coincided with the Great Depression and the consequent collapse of the price system. See *Grant MacEwan's Illustrated history of Western Canadian Agriculture*, chpt. 26.

farm growth. Farm growth is depressed because reduced incomes, arising from prolonged drought or succession of poor seasons, cause the farmer to draw upon accummulated wealth or savings, or result in an increase in farm indebtedness and, possibly, farm bankruptcy. Therefore, the result of this delicate balance between soil moisture availability and moisture demand is an alternation of periods of prosperity and depression for the farmer, which leads to instability in farming. Over the years, however, prairie farmers, cognizant of the recurrent nature of prairie droughts, have built drought adjustment measures into their farming practices aimed at reducing instabilities in farm receipts and business growth, and to ensure business survival. This study aims at identifying and evaluating the common drought adjustment strategies with respect to business growth and survival. The question of farm survival in a drought prone region is therefore of prime interest to this study. How this may be achieved is revealed in the objectives presented below. However, it may be observed that any farm practice (or combination of practices) which tends to reduce the fluctuations in crop yields and/or farm incomes over time or leads to increased farm incomes or farm growth might well be found to be an acceptable strategy.

1.3 Objectives of the Study

The objectives of the study are twofold:

1. To develop a methodology for evaluating the impact of drought on the farm business; and
2. To identify and evaluate management strategies that prairie farmers might follow in order to mitigate the impact of drought and to enhance the prospects of the long-run survival of the farm business.

The first objective recognizes present weaknesses in methodology for determining impact of drought at the farm level and seeks to rectify this problem, and the second objective focuses on survival of farming operation under drought conditions, and acknowledges inadequacies of present management practices in this regard.

1.4 Hypotheses of the Study

The hypotheses formulated took into consideration the fact that farmers, when faced with threat of drought, take certain actions aimed at ensuring the survival of the farm business, as observed above. These may involve adjustments to production, marketing and financial management practices, particularly in their cultural practices, inventory levels, resource use, and financial obligations. Some of these actions do not necessarily ensure farm business survival and this study attempts to test some of the options available to the farmer with consideration to the following hypotheses:

1. That the crop rotation programme selected is an

important criterion to farm business survival in moisture deficient areas of the prairies;

2. That the purchase of crop insurance is beneficial to farmers in drought prone areas and, therefore, a strategy which includes the crop insurance programme will normally be selected over one which excludes crop insurance;
3. That in times of drought, reduction in consumption withdrawals and postponement or reduction in cost related activities will be a preferred strategy; and
4. That farmers' vulnerability to drought increases with their debt obligations.

1.5 Assumptions of the Study

The following basic assumptions are relevant to the study:

1. That crop yields are the prime indicator of drought;[1]
2. That outputs such as equity values and net farm incomes belong to populations which are normally distributed. This assumption permits the output values to be analysed on the basis of their means and standard deviations (or variances);
3. That farmers, in general, are risk averse in the sense that they will not accept a fair gamble and that they maximize the utility of payoff. With this assumption, it

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[1] This is a justifiable assumption since, in the region under study, drought and its attendant insect and pest attacks are mainly responsible for recorded crop failures.

is possible to analyse the derived drought adjustment strategies using the stochastic dominance approach discussed in Chapter 3;

4. That effects of inflation and fixed assets appreciation are ignored for the purpose of this study. Thus product and input prices and asset values are kept at their 1981 levels so that effects of changes in the yield values are not masked out.

Additional assumptions are introduced later while some are relaxed to permit further analysis.

1.6 The Delimitations of the Study

The area of research was restricted to the southwestern portion of Saskatchewan, since the region is drought prone and since farming is the dominant economic activity of the area. Futhermore, Saskatchewan was selected since this study forms part of the Saskatchewan Drought Proofing Studies, currently in progress.[1] The area of interest lies wholly in the brown soil zone. One case operation - a typical dryland grain farm - was considered, in view of the importance of grain production to the region.

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[1] See Marv Anderson, "Draft Outline of the Proposed Saskatchewan Drought Proofing Studies", Regina, Sask., April 1981 (Revised), *s.v.* "Study Element 4: Drought Adjustment Patterns".

1.7 Importance of the Study

As noted earlier, drought is a recurrent phenomenon on the prairies and when it does occur losses could be substantial. Drought curtails the supply of economic resources and, given demand, results in higher prices and diminished economic activity.[1] As observed earlier, drought impact is usually felt adversely at the farm level. Particular reference was also made to its contribution to reduced farm output, reduced farm incomes, increased farmer indebtedness, and possible farm bankruptcy. These effects of drought tend to bring hardships on the farmer, hence the importance of drought to economists. On a wider scale, reduction in farm outputs may cause a reduction in the supply of farm products thereby affecting the society as a whole. Regional impacts of drought tend to worsen the situation at the farm level, since there is now competition with the non-agricultural sectors for resources necessary for mitigating the effects of drought. The measurement of the economic impact of drought becomes difficult once drought reaches the regional level, even though the economy's ability to adjust to drought may have increased.[2]

Many measures have been taken to offset the adverse effects of drought but the problem is that they are usually not sustained over a long period of time. Remedial plans are often dropped with the first good rains, and since no two

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[1] Riefler, "Drought: An Economic Perspective", in Rosenberg(1978), p. 64.
[2] *Ibid.*, p. 65.

droughts are alike in their physical dimensions and impacts, earlier measures may not necessarily be appropriate.[1] These measures are often short-term in nature and there is therefore the need to focus attention on developing farming practices which have the long-term effects of introducing stability in farming in a drought prone region or reducing potential losses from drought. When drought mitigation measures are built into farming practices, the danger of abandoning the measures when conditions become favourable is removed.

The effects of drought on agricultural production are reasonably well understood but only quantitatively,[2] and it is generally agreed that there is paucity in the knowledge of drought, its impacts and its predictability, hence the growing concern for research in this area.[3] This study is important since it traces drought impacts at the farm level, and adds to present knowledge of drought by revealing the positive as well as the normative approaches to adjusting to drought of varying intensity and duration. The study is also important because of the possibility that it will benefit farmers, in other parts of the world, who are confronted with similar problems. Of particular interest is the case of

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[1] G. McKay, "Mitigation of the Effects of Drought With Special Reference to the Canadian Experience", in Rosenberg(1979), p. 173.

[2] Rosenberg(1979), p. 6.

[3] See Rosenberg(1978); Rosenberg(1979); and V. Yevjevich, W.A. Hall and J.S. Salas, eds., "Drought Research Needs", *Proceedings of the Conference on Drought Needs*, Colorado State Univ., Fort Collins, Co., Dec. 12-15 (Fort Collins: Water Resources Publication, 1977).

farmers in the savanna region of Ghana, where experiences with drought conditions are becoming increasingly common in recent years.[1] The remaining portions of this chapter elaborate on the nature of the drought problem in the savanna region of Ghana.

The savanna region of Ghana is part of the Guinea and the Sudan savanna (or grassland) zones of West Africa. In Ghana, the savanna region covers an area of 58,785 sq. miles, or about 64% of the country, and comprises the coastal grassland to the south (about 935 sq. miles) and the interior savanna zone, which stretches from the central part of Ghana northwards.[2] The region resembles the prairies in many respects, particularly in terms of topography and vegetation. Savanna soils are light in texture and low in [illegible] matter content,[3] and unlike the temperate semi-arid [illegible] of the world, including the Canadian prairies, where [illegible]derlying rocks are mainly composed of sedimentary [illegible]sitions, the savanna soils of Ghana and other parts of [illegible]t Africa are formed over crystalline rocks of [illegible]-Cambrian origin.[4] Severe leaching due to humid con[illegible]tions and weathering, caused by the combined effects of [illegible]igh temperatures and relatively high moisture conditions,

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[1] It is hoped that the methodology developed for this study will form the basis for a similar investigation in the author's own country of Ghana.
[2] See D.A. Lane, "The Forest Vegetation", in J. Brian Wills, ed., *Agriculture and Land Use in Ghana* (London, Accra and New York: Oxford University Press, 1962) p. 160.
[3] P.H. Nye and D. Stevens, "Soil Fertility", in Wills(1962), pp. 127-143.
[4] D.A. Bates, "Geology", in Wills(1962), p. 52.

have produced soils of very low fertility.[1]

In contrast to the prairies, the savanna region of Ghana is relatively humid and, as a result, the region is not classified as semi-arid. Nevertheless, atmospheric factors often create conditions similar to those experienced in semi-arid as well as arid tropics. The driest parts of the savanna - along the south-eastern coastline and the extreme north-east portion of the country - receive from 500mm to 1000mm (20-30in) of rainfall anually.[2] Much of the rainfall, however, drains away due to the light soil texture and high evapotranspiration rate and therefore becomes unavailable for plant use for the most part of the year. The problem is more pronounced in the interior savanna zone, where the rainfall distribution is single peaked. The rainy season usually begins in April and ends in August or September, after which there is usually a long and severe dry season. During the dry season, the prevailing winds of the region (or the harmattan) originate from the Sahara desert, blow across the Sahel region,[3] and are therefore very deficient in moisture. The harmattan winds are responsible for the severe dry season experienced in the region.

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[1] Bowden, "Development of Present Dryland Farming Systems", in A.E. Hall *et al*.(1979).
[2] H.G. Baker, "The Ecological Study of Vegetation in Ghana", in Wills(1962), pp. 151-159.
[3] The Sahel region stretches across the central part of West Africa. The region is well known for its severe droughts - a situation which is of worldwide concern.

The interior savanna region is very important to agricultural production and accounts for much of Ghana's grain (e.g. millet, sorghum, and rice), yam, and livestock production. Crop failures resulting from drought are becoming a common feature to the region. A recent experience was the severe drought of 1975 to 1977, which was blamed on the southward movement of the Sahara desert.[1] The emergence of Sahelian conditions in parts of northern Ghana is commonly attributed to changing climatic conditions and human actions. However, human actions (such as burning, continuous cropping, and overgrazing by livestock) are likely to be the main cause of the changing conditions, since the region, like most of Africa, has not experienced any major climatic changes over the last 2,000 years.[2] In comparison, human action is largely blamed for the serious soil erosion and virtual desertification of major parts of the prairies in the 1930's,[3] and it demanded human actions and ingenuity in order to reverse the situation into an agricultural success. Ghana therefore stands to benefit from the experiences of the prairies. However, techniques developed on the prairies would require substantial modifications, with consideration to social, cultural and environmental factors of the region, if they are to be

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[1] Central Bureau of Statistics, *Economic Survey 1977-80*, Accra (December 1981), p. 33.
[2] A.T. Grove, "Desertification in the African Environment", in David Dalby, R.J. Harrison Church and Fatima Bezzaz, eds., *Drought in Africa*, African Environment Special Report 6, International African Institute, London, 1977.
[3] Gray, *Men against the desert*, pp. 53-65. See also Chapter 2 of this report.

successful.

2. DROUGHT EXPERIENCES ON THE CANADIAN PRAIRIES

The frequent occurrences of drought on the Canadian prairies and its association with lack of adequate precipitation and/or soil moisture deficits in the region has been noted in Chapter 1. The present chapter carries this discussion further and presents a brief account of the occurrences of major droughts on the prairies, with reference to their periodicity and areas of impact. In addition, the experience of droughts of the 1930's and steps which were taken towards drought mitigation on the prairies are discussed in some detail.

2.1 Historical Account of Prairie Droughts

The incidence of major droughts on the prairies and their impacts on agricultural production have mainly been revealed by means of historical data on precipitation, estimates of soil moisture levels, and crop yield values.[1] The first of the prairie droughts since the region was settled is often traced to the year 1883,[2] although there is evidence of periods of drought prior to settlement.[3] Prairie droughts have not occurred in any regular fashion, and attempts at linking the incidence of drought to the sun-spot

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[1] A.J. Connor, "Droughts in Western Canada", *The Canada Year Book 1933*, Ottawa, pp. 47-59; J.H. Ellis, W.H. Shafer and O.G. Caldwell, "The Recent Drought Situation in Southwestern Manitoba", *Scientific Agriculture*, Vol. XVI (May 1936): pp. 478-488; Strange (1954); and A.H. Laycock, "Drought Patterns in the Canadian Prairies", *Int. Assoc. Scientific Hydrology*, Publication No. 51, 1960.

[2] Strange(1954), p. 26.

[3] Ellis, Shafer and Caldwell(1936), p. 478.

frequency, for example, did not reveal any strong relationship between the two.[1]

Using precipitation data for the Southwestern Manitoba, Ellis *et al.*[2] observed that for the 50 year period covering 1885 to 1934, there were 29 years with conditions drier than average and 21 years where the rainfall values were above average for the area and concluded that the "combating of drought must always be of vital importance to this area". Strange[3] extended this analysis to cover the whole of the prairies and for the period 1885 to 1953, and observed that for the first 32 years (i.e. 1885 to 1916) there were five "semi-drought" years - namely 1886, 1889, 1900, 1907 and 1910 - where the recorded annual rainfall was less than 10 inches. Similarly, there were ten "semi-drought" years - i.e 1918, 1919, 1924, 1929, 1930, 1931, 1936, 1937, 1945 and 1949 - for the next 37 years (or from 1917 to 1953), which would indicate an increase in drought incidence over the later years.[4] Other periods of drought incidence on the prairies worth noting include the drought years of 1960-61[5] and of 1976-77.[6]

There have been significant variations in drought intensity and regional patterns from one year to another on

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[1] Connor(1933), p. 50-51.
[2] Ellis, Shafer and Caldwell(1936), p. 481.
[3] Strange(1954), p. 63.
[4] *Ibid.*
[5] G.D.V. Williams, "Prairie Droughts: The Sixties compared with Thirties", *Agric. Inst. Rev.*, 17 (Jan/Feb 1962): 16-18.
[6] McKay, "Mitigation of the Effects of Drought With Special Reference to the Canadian Experience", in Rosenberg(1979), p. 170.

the prairies.[1] On the basis of the expectation of rainless and rainy periods, Hopkins[2] observed that "under prairie weather conditions the maximum duration of rainy periods is much less than that of rainless ones", which confirms the observation regarding the higher likelihood of dry periods on the prairies. Variations in regional patterns of drought or in the areas of impact have contributed to the unpredictability of prairie droughts. For instance, the drought of 1927 affected most of the northern prairies, particularly northern Saskatchewan and the Peace River district of Alberta, whereas the traditional dry areas to the south were relatively moist.[3] The reverse situation occurred for the 1936-37 drought years and in 1950 the drought was most severe in western Alberta.[4] A comparison of the droughts of the sixties with those of the thirties showed a more severe drought impact to the northeast in 1960-61 than in 1936-37.[5] Furthermore, the drought of the sixties affected a much wider area, which made it one of the worse droughts of the prairies.[6] The droughts of the thirties have, however, received much attention because they were accompanied by other disasters which contributed to making the thirties one of the worst periods in history. These events are discussed

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[1] Laycock(1960), p. 35.
[2] J.W. Hopkins, "Agricultural Meteorology: seasonal incidence of rainless and rainy periods at Winnipeg, Swift Current and Edmonton", *Can. J. Research*, C, 19 (August 1941): 267-277.
[3] Laycock(1960), p. 35.
[4] *Ibid.*
[5] Williams(1962).
[6] *Ibid.*; and J. Woronuik, "Saskatchewan Drought", *Canadian Cattlemen*, 27 (August 1964): 25.

in some detail in the following section.

2.2 The Experiences of the Thirties

The events of 1930's had serious impacts on the lives and activities of prairie settlers and emphasized the need to examine in detail measures relevant to the improvement of agricultural production in the region and the general welfare of the settlers. Among the events of the period were the incidence of severe droughts and serious soil erosion, effects of the depression, and destruction of crops by grasshoppers, rust, and sawflies.

The drought was most severe in the Palliser Triangle. Southern Saskatchewan, for example, was hit by two sets of three year drought - from 1929 to 1931 and from 1936 to 1938 - during the period.[1] Other parts of the prairies also experienced long drought periods. The drought was accompanied by serious soil erosion and soil drifting caused by high winds and inadequate cultivation practices.[2] The resulting dust storms aggravated the effects of the drought by also causing losses in crops and livestock, and of property. The wind erosion was by no means restricted to the Canadian prairies but also large areas of the U.S. prairies were affected. The dust storm, which at some point covered most of the North American continent, was estimated to

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[1] Strange(1954), p. 64.
[2] The winds were felt in many areas, including Edmonton where a 50 m.p.h wind carried with it so many soil particles that midday seemed like night on June 2, 1937. See MacEwan(1980), p. 152.

contain not less than 300 million tons of top soil.[1] Human actions may have contributed to the severe soil erosion and the consequent dust storms. The successful harvest of 1915 attracted many people to the prairies and also encouraged farm investment such that it was possible for more land, (including submarginal land) to be brought under cultivation.[2] Increased tillage operations that resulted from increased cultivation exposed the soil surface to prairie winds, and with subsequent dry and wet years, created conditions which were conducive to wind erosion. The erosion problem was so serious that by the summer of 1937, much of the Palliser Triangle had virtually become a desert.[3]

The prairies did not escape the effects of the events which caused panic at the New York stock exchange on October 18, 1929 and which signalled the beginning of the Great Depression.[4] As a result of the depression, farm prices collapsed between 1930 and 1933, such that wheat prices fell from around $1.30 a bushel to about $0.40 a bushel.[5] The combined effects of reduced output and low farm prices resulted in low farm incomes and increased farm bankruptcies.[6] The problems of prairie farmers were further

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[1] Gray(1978), p. 23.
[2] Açcording to Gray, yields of 30 to 40 bushels per acre were obtained in the Palliser Triangle and, in addition, the prairie provinces produced around 360 million bushels of wheat from just under 14 million acres in 1915. *Ibid.*, p. 12.
[3] *Ibid.*, p. 2; and MacEwan(1980), p. 152.
[4] See MacEwan(1980), p. 151.
[5] See Gray(1978), pp. 3, 54-55.
[6] In the Palliser Triangle, about 50,000 farmers went bankrupt and had to live on relief throughout the period. *Ibid.*, p. VIII.

accentuated by grasshopper invasion which became serious in 1933 and caused more than $30 million worth of damage to crops that year.[1] By 1939, Alberta and Saskatchewan had a total area of about 160,000 square miles infested.[2] Farming conditions improved a little when the region received adequate rainfall in 1934-35. However, the high amounts of moisture resulting from the precipitation created conditions that suited the growth of the stem rust fungus. Thus in 1935, over 3 million acres of crops were destroyed by rust in the southeast corner of the Palliser Triangle, including between 50 and 60 million bushels of wheat.[3] In addition, the thirties brought along sawfly attacks and some of the most extreme temperatures recorded on the prairies. It is not difficult to see that farming in the prairies, and particularly in the Palliser Triangle, was greatly impaired by these unfavourable events. Many farms were therefore abandoned and in most cases the farmers moved northwards where conditions were better and where the crops were more stable.[4]

The experiences of the thirties created an awareness of the severity of the problems facing prairie farmers and also the realization that steps be taken to reverse the situation if agricultural settlement was to succeed in the region. Much of the credit for the present success of the region may be due to the hard work and dedication of many individuals

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[1] *Ibid.*, p. 41.
[2] *Ibid.*, p. 36.
[3] *Ibid.*, pp. 43,55.
[4] See *Ibid.*, p. 131; and Anderson(1975), p. 10.

and government agencies, as the following words of J.H. Gray would reveal:[1]

> "The dust bowl of the thirties didn't just disappear of its own accord when the rains returned. Many dedicated Canadians working in agriculture mounted a massive campaign to prevent the western farmland from deteriorating into a windblown wasteland of sand dunes, buckbrush and pasture sage."

Some of the measures that were taken to combat the situation and to help the farmers survive subsequent droughts and crop infestations are discussed in the next section.

2.3 Drought Mitigation on the Canadian Prairies

The role of various government agencies and many individuals in developing farming techniques suitable to the prairies has already been noted. In general, the various techniques which have been developed to help farmers adjust to drought take the following forms:[2]

1. conservation of water,
2. water augmentation (i.e. irrigation),
3. altering agricultural practices, especially by changing crop or livestock types, and by using drought resistant varieties and specially designed cultivating equipment,
4. spreading or sharing of drought related costs such as purchasing insurance policy, or maintaining crop or cash reserves.

It is not surprising that farmers were the first to develop cultural practices and farm implements that were relevant to

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[1] Gray(1978), see the backcover.
[2] Riefler, "Drought: An Economic Perspective", in Rosenberg(1978), pp. 70-71.

dryland farming. The farmers were aided in their quest for improved farming techniques by scientists from the agricultural research stations, which were established on the prairies to find solutions to problems of agriculture peculiar to the region.

The first two of the prairie research stations were established at Brandon (Manitoba) and Indian Head (Saskatchewan) in 1888 as the Dominion Experimental Farms.[1] Other experimental farms to be established later included the Lethbridge station (in 1906) and the Swift Current station (in 1920), which are both located in the Palliser Triangle.[2] The experimental farms, which have now become the Agriculture Canada Research Stations, have made important contributions to the success of farming in the prairie region and the roles played by them will be made clear later in the section.

2.3.1 The Role of the PFRA

The drive to halt the soil drifting and erosion of the thirties and to develop drought mitigation techniques for the prairies was championed by the Prairie Farm Rehabilitation Administration (PFRA), which was established by an act passed by the Government of Canada on April 17, 1935.[3] Under the act, the PFRA was to assist in the rehabilitation

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[1] See Strange(1954), p. 27.
[2] See Campbell(1971), p. 11.
[3] H.M. Hill, "Drought Mitigation in Canada's Prairie Provinces", in *Hydrological Aspects of Drought*, Indian National Committee for International Hydrological Programme, Proceedings, Vol. 1 (3-7 December 1979):571.

of agricultural land seriously affected by drought and soil drifting.[1] Its main objectives were water conservation, community pasture development and soil erosion control.[2] The PFRA was very successful in achieving its goals and this is mainly due to its close co-operation with the Experimental Farms Service,[3] the farmers, and scientists from the prairie universities.

The water conservation measures were taken to ensure reliable supply of water to farms, industries, and municipalities during drought periods. Since its inception, the PFRA has sponsored some 150,000 water development projects, including 31,000 wells, 100,000 dugouts and 12,000 small on-farm dams.[4] It has also played an important role in the development of several irrigation projects (about 200,000 hectares or 500,000 acres), with the South Saskatchewan river as the main source of water supply, and also the development of large multi-purpose water storage reservoirs the largest of which, the Lake Diefenbaker in Saskatchewan, contains more than 9 million cubic decametres (318,000 cubic feet) of water.[5]

The community pastures were established on lands which had been abandoned because they suffered severe wind erosion and whose ownership had been turned over to the

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[1] *Prairie Farm Policy Guide 1977-78* (Saskatoon: The Western Producer, 1977)
[2] Campbell(1971), p. 29.
[3] Indeed the Experimental Farms Service was supported by PFRA funds and personnel. Anderson(1975), p. 11.
[4] Hill(1979), p. 573.
[5] *Ibid.*; and Anderson(1975), p. 15.

municipalities to pay the back taxes.[1] The PFRA developed these lands into good pastures by first controlling the soil drifting and then seeding the land to perennial grasses, like the crested wheatgrass, which had been tested and found suitable to the area. The community pastures soon grew in size and popularity - from about 330,000 hectares (or 825,000 acres) in 1939 to over 1 million hectares (i.e. 2.5 million acres) in 1979, and now provide summer grazing facilities for some 250,000 cattle.[2]

The control of wind erosion and soil drifting was achieved with the help of the experimental farms and the Agricultural Improvements Associations (AIA's), whose purpose was to bring farmers together into organized groups to exchange ideas, to inform the PFRA and provincial agencies of conditions needing attention, and to act as an exchange through which special activities could function and assistance given.[3] The activities of the AIA's included organizing field days and inviting speakers to demonstrate farming practices and types of farm equipment which aided in bringing the land back to productivity.[4] The PFRA also undertook to plant trees to provide shelterbelts to protect crops from winds in order to reduce soil drifting. Distribution of the trees was made possible through the AIA's, whose members were supplied with 909,000 trees for the shelterbelt plantations in 1938 and by 1939 about 1,277,700

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[1] *Ibid.*, p. 14.
[2] See *Ibid.*, pp. 14-15; and Hill(1979), p. 573.
[3] Anderson(1975), p. 572.
[4] Hill(1979), p. 572.

trees had been distributed.[1] The trees for the shelterbelt plan[illegible] were produced at the experimental farms. The AIA[illegible]lped in distributing special implements for emer[illegible]trol of excessive soil drifting.[2]

[illegible]ctivities of the PFRA involved a drive towards [illegible]e d[illegible]sification of the prairie economy to include [illegible]oug[illegible] tolerant activities and the establishment of govern- m[illegible]ergency programmes such as the crop insurance and o[illegible] financial programmes, and the supply of water and ca[illegible]e feed to farmers.[3] It is obvious that, the individuals and[illegible]gencies involved with the control of the wind erosion and [illegible]e protection of farmers from the full impact of prai[illegible]e droughts were successful in achieving some of their aims. However it has been realized that some of the measures were i[illegible]dequate against some recent droughts (eg. the 1976-[illegible]drought), and as a result attempts are being made to strengthen the present measures.[4]

2.3.2 Moisture Conservation Measures

The conservation of soil moisture is crucial to dryland farming. The measure is aimed at reducing soil moisture loss and includes the following cultural practices: summerfallow, stubble mulching or trash conservation, and minimum

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[1] Anderson(1975), p. 16.
[2] *Ibid.*, p. 13.
[3] Hill(1979), p. 573.
[4] McKay, "Mitigation of the Effects of Drought With Special Reference to the Canadian Experience", in Rosenberg(1979), p. 173.

tillage.[1] Maintenance of high soil moisture level is essential if fertiliser application is to be beneficial.

The practice of summerfallow is an integral part of dryland farming all over the world.[2] The practice was "discovered" or verified in Canada in 1886 at Indian Head,[3] although it has been practised around the Mediterranean and in other parts of the world for centuries.[4] The discovery of summerfallowing brought hopes to the settlers, some of whom had been severely affected by previous droughts and had started to move out of the region. After testing the new technique, the Indian Head Experimental Farm advised farmers as follows:[5]

> "Our season points to only one way in which we can in all years expect to reap something. It is quite

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[1] See Haas, "Strategies in the Event of Drought", in Rosenberg(1978), pp. 103-122; and Rosenberg, "Technological Options for Crop Production in Drought", in Rosenberg(1978), pp. 123-142.

[2] Summerfallow is the practice by which a plot of land is allowed to lie idle for one crop season or more. The land is therefore able to store much of the precipitation it received while it was idle and, as a result, has a relatively high moisture level hence the popularity of summerfallowing in dryland farming.

[3] The discovery of summerfallowing was purely accidental. It is reported that in 1885, when horses were required to carry military supplies to the scene of the Northwest Rebellion, the British army leased many horses from various farms with the promise to return them in time to cultivate the land in spring of that year. Most of the horses were from a large wheat farm operated by Bell, and by the time the horses were returned, it was late for seeding the crop therefore, the land was left idle. When the land was cultivated the following year, it produced a good crop, although 1886 was a bad drought year which resulted in an almost complete crop failure on stubble land. See Strange(1954), pp. 26-27; Gray(1978), p. 7.; and MacEwan(1980), pp. 68-69.

[4] Bowden, "Development of Present Dryland Farming Systems", in Hall, Cannell and Lawton(1979), p. 60.

[5] See Strange(1954), p. 27.

> within the bounds of probabilities that some other and perhaps more successful method may be found, but at present . . . fallowing the land is the best preparation to ensure a crop."

In Western Canada, the proportion of acreage under fallow increased from 29.7% of the improved acreage to 39.7% between 1931 and 1961.[1] During the same period the land devoted to annual crops and fallow increased by 25.7%.[2] The growth of summerfallowing was encouraged in 1970 by the federal government under the LIFT programme.[3]

In addition to increasing soil moisture levels of the land, fallowing also increases nutrient levels from the breakdown of soil organic materials, minimizes losses from insects and diseases, controls weeds, and contributes to a more uniform distribution of labour and machinery requirements.[4] In general, crop yields are higher and more stable after fallow than under continuous cropping,[5] and on the

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[1] R.A. Hedlin, "The Place of Summerfallow in Agriculture on the Canadian Prairies", in *Prairie Production Symposium: Soils and Land Resources*, (Saskatoon: The Univ. of Saskatchewan, Oct. 29-31, 1980).
[2] *Ibid.*
[3] The Lower Inventory For Tomorrow programme was introduced when it was feared that large grain inventories, resulting from very successful seasons, would result in depressed grain prices. Consequently, farmers were paid $6.00 per acre for extra land that was left under summerfallow and $10.00 per acre for the extra land put under perennial forage. See Marv Anderson, "Factors Affecting Summerfallow Acreage in Alberta" (Edmonton: Environment of Alberta, August 1981), pp. 32, 49.
[4] W.H. Isom and G.F. Worker, "Crop Management in Semi-Arid Environments", in Hall, Cannell and Lawton(1979), p. 202; and E.S. Molberg *et al.*, "Minimum Tillage Reqiurements for Summer Fallow in Western Canada", *Can. J. Soil Science* 47: 211-216, 1967.
[5] H.M. Austenson and S.R. Khari, "Relative Yields of Wheat, Barley, and Oat Cultivars on Summer Fallow and Stubble Land", *Can. J. Plant Science* 52: 891-896, 1972.

brown and the dark brown soils of the prairies, rotations that include summerfallow are perceived to produce the highest expected incomes, a more uniformly distributed labour use, and the lowest income variability.[1] It is therefore not surprising that a larger proportion of improved land is under fallow in the brown and the dark brown soil zones - about 43% and 39% respectively - than in the black soil zone, where only about 22% of the land is under fallow.[2] The reasons for adopting summerfallowing differ with the soil zones. In the brown soil zone, where soil moisture is very defficient, moisture conservation appears to be the main reason for adopting the technique, whereas in much of the dark brown and the black soil zones, weed control seems to be the prime objective.[3] In spite of its merits, summerfallowing has been found to increase the rate of organic oxidation in the soil leading to lower yields in the long run,[4] to contribute to water and wind erosion by exposing soil surface,[5] and to catalyse the development of saline seep areas.[6]

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[1] R.P. Zentner *et al.*, "An Economic Assessment of Dryland Cropping Programs in the Prairie Provinces: Expected Net Incomes and Resource Requirements", *Can. Farm Economics*, Vol. 14, No. 4, pp. 8-19, 1979; and *Idem*, "An Economic Assessment of Dryland Cropping in the Prairie Provinces: Income Variability", *Can. Farm Economics*, Vol. 14, No. 6, pp. 9-19, 1979.
[2] See Russell and Colwell(1981), p. 3.
[3] Marv Anderson(1981), p. 116.
[4] J.J. Lehane, F.G. Warder and W.J. Staple, "Decline of Wheat Yields and Depletion of Some Nutrients on a Loam Soil During a 36-Year Period", *Can. J. Soil Science*, 44: 50-55, 1964.
[5] D.T. Anderson, "Surface Trash Conservation With Tillage Machines", *Can. J. Soil Science*,41: 99-114, 1961.
[6] R.A. Milne and E. Rapp, *Soil Salinity and Drainage*

In trash conservation, the straw that remains after the grain has been harvested is left on the soil surface. This increases the capacity of the soil to store moisture, since evaporation is reduced. Scientists have developed suitable machines and combination of implements that will help conserve as much of the trash as possible during harvesting. For example, it has been observed that maximum trash is conserved when the disker is operated at a speed of 5 to 6 km/h and a depth of 8 to 10 cm and with a narrow pan angle setting for the widest possible cut.[1]

Minimum tillage has received much attention in recent times. At the moment, it is believed that 20% of the U.S. crop production is based on the technique, and it has been predicted that by the year 2010, about 95% of U.S. crop will be by minimum tillage systems and 55% of that will be under no-tillage system.[2] The importance of this technique is expected to rise as energy and labour costs continue to increase.[3] This has been confirmed by Zentner and Lindwall,[4] who also observed substantial savings in labour, fuel and oil, machine repairs, and overhead costs, and also improvement in moisture conservation, grain yield and

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[a](cont'd)*Problems*, Agriculture Canada, Publication No. 1314, Ottawa, 1968.

[1] D.T. Anderson, "Some factors affecting trash conservation with disk-type implements", *Can. Agric. Eng.*, 6: 11-13, 19, 1964.

[2] H.E. Dregne, "Report of the Task Group on Technology", in Rosenberg(1979), p. 25.

[3] *Ibid.*, p. 26.

[4] R.P. Zentner and C.W. Lindwall, "Economic Assessment of Zero Tillage in Wheat-Fallow Rotations in Southern Alberta", *Canadian Farm Economics*, Vol. 13, No. 6, pp. 1-6, 1978.

erosion resistance with zero tillage. A problem with minimum tillage is that its repeated use may involve heavy reliance on herbicides to control weeds, which might cause environmental problems.[1]

2.3.3 Other Measures Taken

The measures which were taken against the drought would not have produced useful results without the attendant control of the pests and diseases which destroyed crops during the thirties. The research stations were instrumental in the fight to control the grasshopper plague and the diseases caused by the stem rust and the sawfly, and also to reduce the vunerability of crops to frosts. In the thirties, the grasshopper attacks were successfully controlled by means of poisons developed by entomologists, the most effective being the standard sodium siloco flouride, mixed with sawdust or bran.[2]

The plant diseases and the frosts were mainly controlled by developing resistant crop varieties. Wheat has received much attention because of its importance to Canada and also because it is very susceptible to the attacks. The first wheat variety to be introduced to the prairies, *Red Fife* in 1870, was moderately resistant to drought.[3] In developing later varieties, scientists concentrated on improving resistance to drought, frosts, and the plant diseases common

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[1] Dregne, "Report of the Task Group on Technology", in Rosenberg(1979), p. 26.
[2] Gray(1978), p. 39.
[3] Strange(1954), p. 33.

to the prairies, as well as obtaining higher yields. The first wheat variety resistant to rust, *Thatcher*, was introduced into Canada from the U.S. in 1935.[1] Later, other wheat varieties superior to *Thatcher* were developed at the Dominion Rust Research Laboratory at Winnipeg and the University of Saskatchewan at Saskatoon.[2] In 1946, the Dominion Experimental Farm at Ottawa introduced *Rescue*, the first wheat variety resistant to the sawfly, and in 1954 *Selkirk* wheat, resistant to strain 15-B rust, was introduced.[3] Many other wheat varieties were introduced. Among them, *Neepawa*, which was licensed in 1969, was found to be high yielding, early maturing and thereby not destroyed by frosts, and resistant to common rusts, and the sawfly.[4]

It is important to note the roles played by institutions in the success of agricultural settlement on the prairies. For example, the Canadian Pacific Railway Company, which has had a long relationship with prairie farmers and also was prominent in the settlement drive, is said to have cancelled all interest on farm loans for 1931 to help the farmers who had been hit by drought and depressed prices.[5] The federal and provincial governments also established many institutions to help farmers. These include the federally funded Farm Credit Corporation, which was established in 1959 to make long-term mortgage loans to assist farmers in

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[1] *Ibid.*, p. 34.
[2] *Ibid.*
[3] *Ibid.*
[4] *Prairie Farm Policy Guide 1977-78*, p. 50.
[5] Gray(1978), p. 21.

developing viable farm business, and also the introduction, in 1959, of the crop insurance programme as a joint federal-provincial venture to provide wide range of insurance based on individual farmer's soil productivity and long-term acreage in his area.[1] Private banks have also played an increasing role in farm assistance programmes. This is evidenced by the fact that, in 1976 the value of loans offered to farmers by the eleven chartered banks amounted to $3339.4 million (or 6.15% of total loans).[2] This amount increased by 16.4% to $3888.2 million in 1977, and by a further 25.8% to $4892.7 million in 1978 - a yearly average of 21.1% over the period.[3] In comparison, the growth of total loans offered by the banks averaged 11.8% per annum over the same period.[4]

2.4 Summary

This chapter has focused on drought experiences on the prairies and some of the measures which were undertaken to make farmers cope better with the drought situation and introduce stability in farming. The measures which were discussed in the chapter may be grouped into into three broad classes:[5]

1. Cultural practices such as the various cropping

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[1] *Prairie Farm Policy Guide 1977-78*, p. 49.
[2] Statistics Canada, *Canada Year Book 1980-81*, Table 21.11, p. 785.
[3] *Ibid.*
[4] *Ibid.*
[5] A fourth class, business management practices, was implicit in the discussion above although it is of interest to this study.

patterns, stubble mulching, and minimum tillage. These have mainly been developed by the farmers (and backed by research) in an attempt to conserve as much of the soil moisture as possible.

2. Technological contribution resulting in the development of specially adapted farm machinery, suitable crop varieties and breeds of livestock, and farm inputs such as fertilizer, herbicides, and insecticides.
3. Institutional factors such as the banking system to make credit available to the farmer and to encourage farm investments, and the crop insurance programmes, which have been introduced to reduce the risk of losses from drought, hail, frost, and other environmental hazards.

The following chapter presents a review of the theory underlying the criteria for evaluating drought adjustment techniques developed by the farmers, and Chapter 4 discusses the development of methodology that will permit such analysis.

3. SELECTION OF FARM PRODUCTION STRATEGIES UNDER UNCERTAINTY

The frequent but irregular occurrences of drought on the prairies create an imperfect environment within which agricultural production must take place. As a result, output variables, such as crop yields, net incomes, and equity positions cannot be determined with certainty, and this presents a decision problem because the prairie farmer has to select from among a number of alternatives without *a priori* knowledge of the outcome of his selection. The economic performance of the farm business depends to a large extent on the management decisions that the farmer makes. Decision making is therefore an integral part of farming operation, and the present chapter begins with a review of the principles of decision making. The chapter also focuses on theoretical foundations of rational choice under imperfect conditions.

3.1 Some Aspects of the Decision Making Process

Farm level decision making in a market economy is principally the responsibility of the individual farmer. The farmer decides on how to produce, what to produce, how much to produce, his marketing strategy, his resource requirements, etc., and the market system operates to ensure that resources are used efficiently to achieve certain normative goals. Steps in the decision making process that a farmer goes through are generally described as follows:[1]

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[1] See L. Bauer, "Managing Risk", Paper presented at the Regional Farm Management Seminar, Wainwright, Alberta,

1. establishing *goals and objectives*;
2. measuring performance against goals to detect *problems and opportunities*;
3. analysing and specifying possible *ways of solving the problem*;
4. choosing a particular *solution and implementing* it; and
5. accepting the *result* and evaluating the *consequencies* of the actions.

Figure 3 presents an illustration of components of the decision making process and how they are interrelated. The decision maker begins the process with establishing goals and objectives. Goals are specific to the individual and are influenced by a number of factors, including the farmer's time preference which determines the degree to which the farmer is averse to risk, or whether the farmer is concerned with building equity or satisfying present needs.

The performance of the farm business is measured against the farmer's goals to detect problems. A problem exists if there is a discrepancy between the actual and the desired state. The process of resolving a problem presents two possibilities - either there are several ways of tackling the problem or there is no choice. In the case of the latter, the farmer is forced to take action. If there are a number of alternatives for resolving the problem, then the farmer has to determine if he has adequate information for making the choice. When more information is required, a

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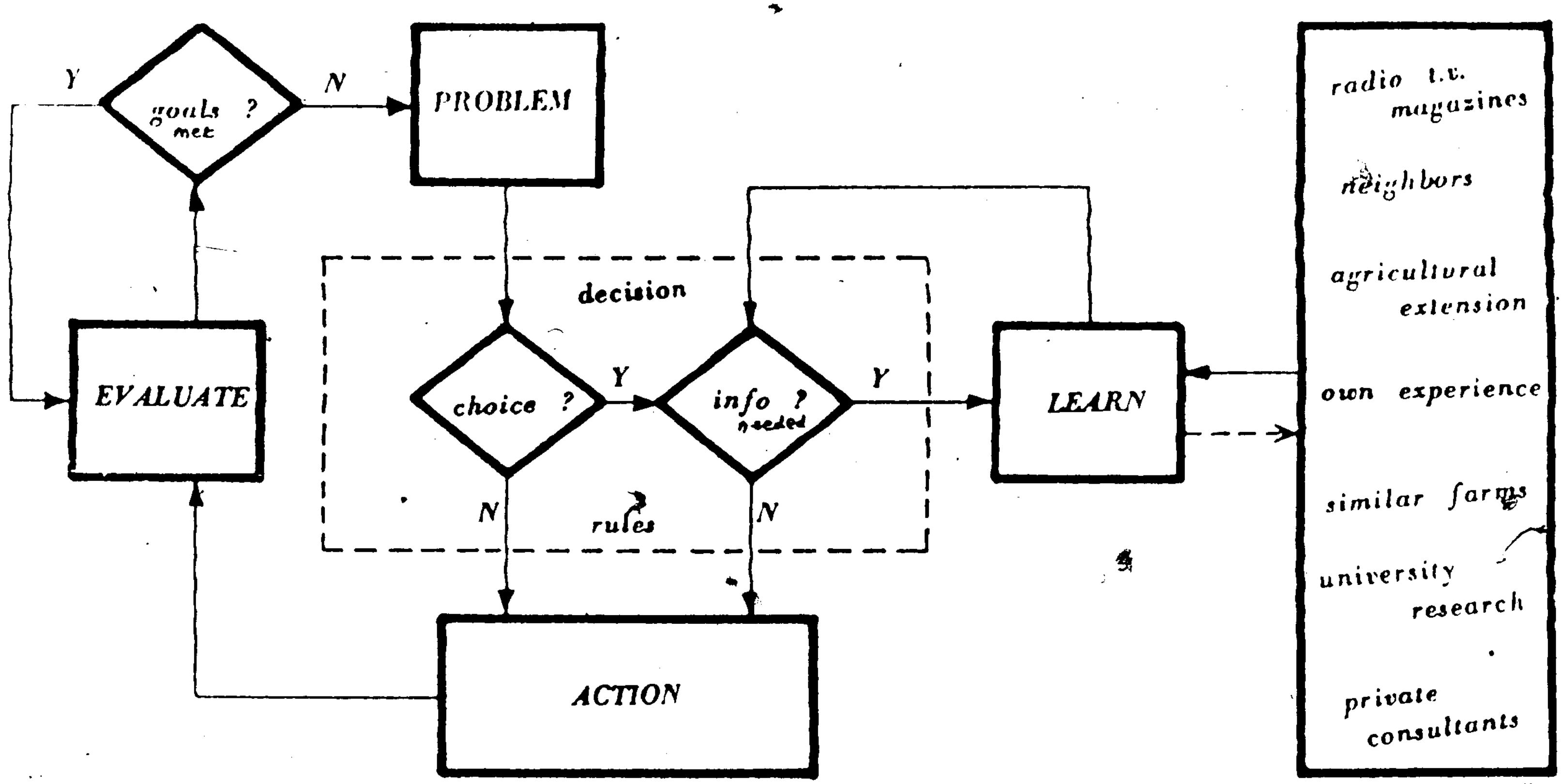
'(cont'd)Canada, Nov. 22-23, 1982.

FIGURE 3: THE DECISION MAKING PROCESS



Source: L. Bauer, "Managing Risk", Paper presented at the Regional Farm Management Seminar, Wainwright, Alberta, Nov. 22-23, 1982.

process of information gathering aimed at enhancing the farmer's confidence in making the decision ensues. The farmer goes through a learning process as more information becomes available. The information required is obtained from a number of sources, including the farmer's personal experience and historical observations. For instance, on the basis of historical observations, the case farmer assumes drought to be the normal condition and plans his farming operations with this in mind.

The information gathering process may be costly and time consuming. The amount of information obtained is important, since a decision based on insufficient information may likely be erroneous. Extra information improves the accuracy of the decision although cost of information rises as well. Therefore, a farmer must compare the extra benefits of additional information to the extra costs entailed in obtaining the information before deciding to obtain more information. When the farmer is satisfied with the information available to him, he goes into action by selecting a particular solution and implementing it. He then evaluates the consequencies of his action to determine whether his goals have been realised. If the goals have not been met then he goes back to the problem and repeats the process until satisfactory results are obtained.

The process of establishing goals and objectives is central to decision making. From the farmer's point of view, this may involve weighing production gains against losses.

The best situation occurs when net gains are maximized, e.g. maximizing profits (or net returns) or maximizing business growth. Under perfect or deterministic conditions, such goals are not difficult to achieve. However the real situation is characterized by imperfect conditions, especially since the planning period stretches into the future and returns from farming operation may be difficult or impossible to predict. In this case the question of risk[1] needs to be taken into consideration. On the prairies, the imminence of droughts is generally not known and farmers' goals become difficult to achieve, since the objective of maximizing net gains may have to take into consideration the minimization of the adverse effects of risk (or drought). A decision problem therefore exists, when uncertainty is taken into consideration. The remaining sections elaborate on the decision problem and introduce the concept of utility, which is central to decision making under uncertainty and provides means by which preferences may be measured, and the concepts of stochastic dominance, which provide alternative means of ranking risky prospects.

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[1] In classical literature, a risky prospect is one with known probability distribution and an uncertain prospect is one whose probability distribution is unknown. This thesis, however, follows the more recent approach of using both terms interchangeably.

3.2 Elements of a Decision Problem

A simple decision problem may comprise the following basic components:[1]

1. *Acts* or *choices* facing the decision maker, commonly represented by $A = \{a_j, j=1,...,J\}$. In decision analysis, acts are defined to be mutually exclusive as well as exhaustive. The prairie farmer may be faced with several choices, including that of selecting crop(s) to be grown, selecting a particular rotation, or between purchasing and not purchasing crop insurance.
2. The possible *states of nature*, represented by $\theta = \{\theta_i; i=1,...,I\}$, upon which the decision maker has no control or advance knowledge of which state, θ_i, will occur, e.g. the dryland farmer has no control over whether sufficient or insufficient amount of soil moisture will prevail at the time of planting.
3. Due to the uncertain nature of θ, there exists a *set of probabilities*, $\{p(\theta_i), i=1,...,I\}$, each of which reflects the decision maker's subjective evaluation of the frequency of occurrence of the corresponding state of nature. The probabilities are constrained such that $\sum_{i=1}^{I} p(\theta_i) = 1$;
4. *Consequences* - reflecting the outcome(s) of an act (j)

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[1] See A.N. Halter, and G.W. Dean, *Decisions under Uncertainty with Research Applications*, (Cincinnati: South-Western Publishing Co., 1971), pp. 1-13; J.R. Anderson, J.L. Dillon, and J.B. Hardaker, *Agricultural* [illegible] *Analysis*, (Ames: The Iowa State University Press, [illegible]d John D. Hey, *Uncertainty in Microeconomics*, [illegible]artin Robertson, 1979), pp. 38-41.

when a particular state of nature (i) prevails, e.g. the outcome of a decision not to purchase crop insurance and the occurrence of drought conditions. Consequences are commonly measured in terms of utility, and can be represented as $\{U_{ij}, i=1,...I, j=1,...,J\}$; and

5. *Choice criterion* (e.g. maximizing expected utility) involving the determination of an objective function which enables the decision maker to select the most preferred alternative. Under imperfect conditions, conventional static production theory gives way to utility theory as a better way of describing farmers' behaviour.[1]

3.3 The Concept of Expected Utility

Modern utility theory is often traced to the work of von Neumann and Morgenstern,[2] although it was derived from a principle suggested by Nicolas Bernoulli in the 18th. century.[3] The theory is based on certain basic axioms which explain rational choice and also provide the basis for deriving the decision maker's utility function. For the

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[1] See William W. Lin, G.W. Dean, and C.V. Moore, "An Empirical Test of Utility vs. Profit Maximization in Agricultural Production", *Am. J. Agric. Econ.*, 56: 497-508, 1974.

[2] von Neumann, J., and O. Morgenstern, *Theory of Games and Economic Behavior* (Princeton: Princeton University Press, 1947).

[3] The principle, sometimes referred to as *St. Petersburg paradox*, is associated with the Bernoulli family and was first published in Latin. See Daniel Bernoulli, "Exposition of a new theory on the measurement of risk", trans. Louise Sommer, *Econometrica*, 22 (1): 23-36, 1954; and cited by H.A. John Green, *Consumer Theory* (Penguin Books, 1971; revised ed., London: The Macmillan Press Ltd., 1979), p. 214.

unidimensional case, the following axioms are sufficient for its derivation:[1]

1. *Ordering.* For a pair of risky prospects belonging to the ordered set (q_1, q_2), there exists a relation, $q_1 R q_2$, such that either q_1 is preferred to q_2, or q_2 is preferred to q_1, or there is indifference between them.
2. *Transitivity.* This is an extension of Axiom 1 which implies that if there are three risky prospects (q_1, q_2, q_3), and the decision maker prefers q_1 to q_2 (or is indifferent between them) and prefers q_2 to q_3 (or is indifferent between them), then he will prefer q_1 to q_3 (or be indifferent between the two). Axioms 1 and 2 permit the ranking of risky prospects to conform with the decision maker's preferences.
3. *Continuity.* If a person has the preference relation, $q_1 R q_2 R q_3$, then there exists a unique subjective probability, $\{p(q_1) | 0 < p(q_1) < 1\}$, such that he is indifferent between q_2 and a lottery yielding q_1 and q_3 with probabilities of $p(q_1)$ and $1-p(q_1)$ respectively. This assumption implies that if the decision maker is faced with a risky prospect involving favourable and unfavourable outcomes, he will take the risk if the probability of the unfavourable outcome is low enough.
4. *Independence.* If the decision maker prefers risky prospect q_1 to q_2, and there is a third prospect q_3,

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[1] See Anderson, Dillon, and Hardaker(1977), p. 67; and John L. Dillon, *The Analysis of Response in Crop and Livestock Production*, 2nd. ed., (Oxford: Pergamon Press, 1977), pp. 107-108.

then he will prefer a lottery with outcomes q_1 and q_3 to a lottery with outcomes q_2 and q_3 if $p(q_1) = p(q_2)$ - i.e. the decision maker's preferences are unaffected by q_3.

These axioms give rise to the expected utility theorem, which is commonly referred to as Bernoulli's principle. According to the principle, as long as the decision maker's preferences do not violate the axioms of ordering, transitivity, continuity, and independence of preferences, there exists:[1]

1. a unique subjective probability distribution for the set of outcomes associated with any risky choice alternative that he faces; and
2. a function $U(q)$, called a *Utility function*, which gives a single-valued index for each of the risky alternatives that he faces. This utility function $U(q)$ has the following properties:
   a. if q_1 is preferred to q_2, then $U(q_1) > U(q_2)$. The reverse is also true;
   b. if q_1 and q_2 have probability distributions of p and $1-p$, respectively, then expected utility is defined as,

   $$E[U(q)] = pU(q_1) + (1-p)U(q_2), \text{ and}$$
   $$U(q) = E[U(q)];$$

   c. the utility function is bounded such that

   $$-\infty < U(q) < +\infty;$$

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[1] *Ibid.*, p. 108; Anderson, Dillon, and Hardaker(1977), p. 68; and Halter and Dean(1971), p. 50.

d. the utility function is continuous and monotone increasing, which implies the existence of a positive and continuous first derivative;

e. the utility function is unique up to a positive linear transformation. Therefore its structure and properties are not affected by such transformations.

Important conclusions which may be derived from the Bernoulli principle and the properties outlined above are;

1. the decision maker's preferences may be represented by the utility function, with the higher preferences showing higher utility values, and
2. a rational person, when faced with risky choice, acts so as to maximize his expected utility.

Algebraically, the utility function may be expressed as:

$$U = U(q), \tag{3.1}$$

where:

q = random variable representing payoffs, such as net returns and equity,

$U'(q) = dU/dq \geq 0$, and

$U''(q) = d^2U/dq^2 > = < 0$.

The sign of the second derivative of the utility function $U''(q)$ determines the curvature of the function as well as the decision maker's attitude toward risky prospects. Three types of behaviour can be derived:

1. if $U''(q) > 0$, then the marginal utility of the payoff is increasing (i.e. the utility function has convex curvature) and this characterizes an individual who

prefers risk;

2. if $U''(q) = 0$, then the utility funtion is linear, which describes a risk neutral person; and

3. if $U''(q) < 0$, then the marginal utility function is decreasing (or the utility function is concave), and the individual is described as risk averse.

Individuals vary considerably in their attitudes towards risk. However, risk aversion is given much attention in the thesis, since it is most consistent with farmers' behaviour. The utility functions for the three types of behaviour to risk are illustrated in Figure 4.

3.4 Mean-Variance (E-V) Analysis

As noted above, the expected utility function is expressed as the sum of the utility of the payoff, $U(q)$, weighted by its probability distribution, or

$$E[U(q)] = \sum_{i=1}^{I} p_i U_i(q), \text{ where } \sum_{i=1}^{I} p_i = 1 \qquad (3.2)$$

This is simpler and more convenient when there are only a few outcomes under consideration. For more complex problems, the expected utility can be derived by means of a Taylor series expansion of the utility function $U(q)$ about the mean (or expected) value of the outcome, $E(q)$. According to Taylor's theorem, for any q^* and every $q \neq q^*$, there exists a point $\emptyset$ interior to the interval joining q and q^* such that[1]

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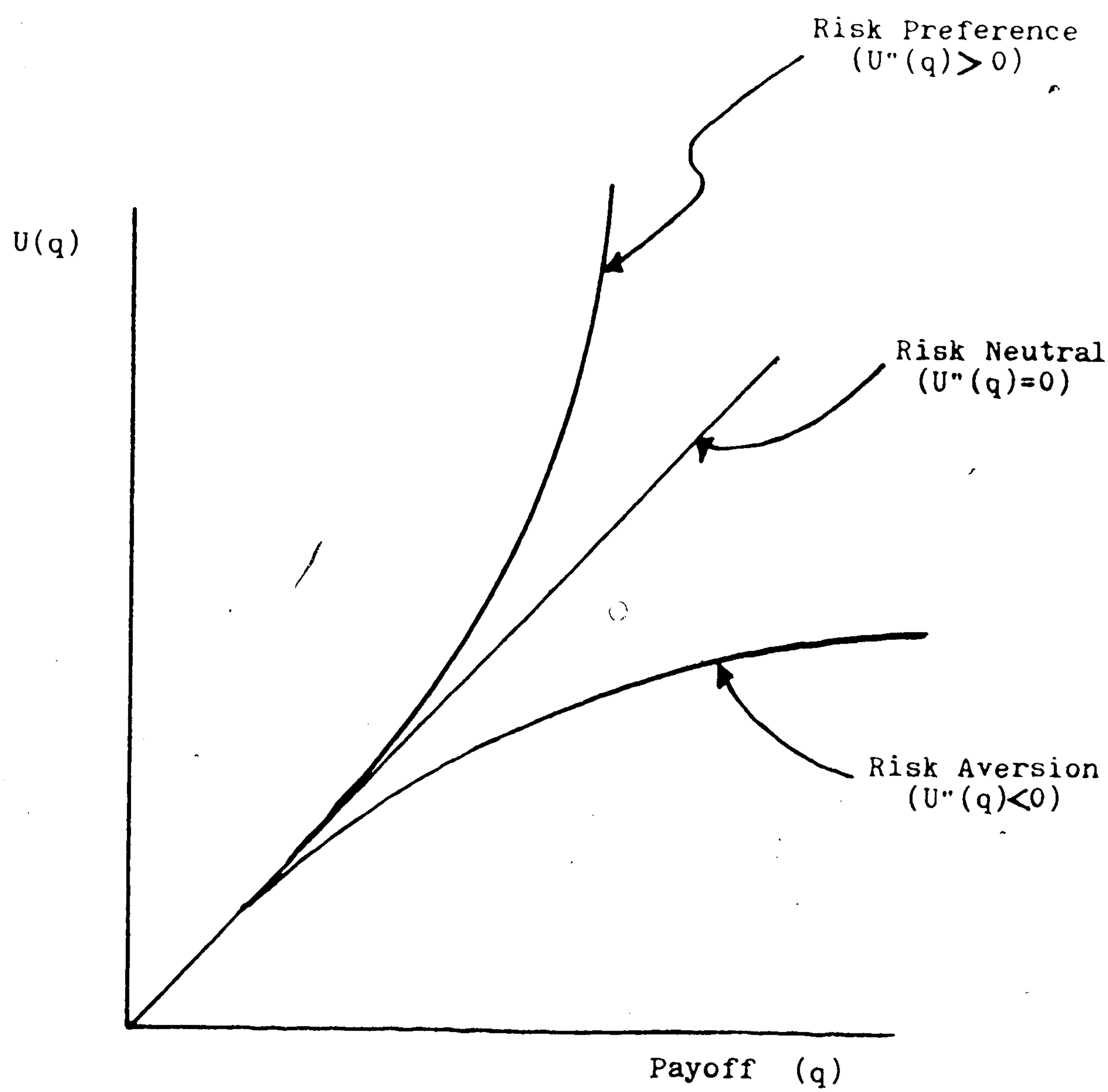
[1] Only discrete analysis involving the utility function is considered here, although the technique is applicable to the continuous case and also for all functional relations. For a discussion of Taylor's theorem, see Wayne A. Skrapek; Bob M.

FIGURE 4

Utility Functions Characterising Behaviour under Risk



$$U(q) = U(q^{\cdot}) + \sum_{K=1}^{n-1}[U_K(q^{\cdot})(q-q^{\cdot})^K/k!] + R_n(q,q^{\cdot}) \quad (3.3)$$

Equation (3.3) is a polynomial of degree n, where $R_n(q,q^{\cdot})$ is known as the *remainder term*, and is defined as

$$R_n(q,q^{\cdot}) = U_n(\emptyset)(q-q^{\cdot})^n/n!, \qquad q^{\cdot} \le \emptyset \le q, \text{ and}$$

U_K represents the kth. derivative of the utility function. For many functions, $R_n(q,q^{\cdot})$ is convergent, therefore $R_n(q,q^{\cdot}) \rightarrow 0$, as $n \rightarrow \infty$, and equation (3.3) becomes;

$$U(q) = U(q^{\cdot}) + \sum_{K=1}^{n-1}[U_K(q^{\cdot})(q-q^{\cdot})^K/k!] \quad (3.4)$$

If $q^{\cdot}$ is fixed such that $E(q) = q^{\cdot}$, then by taking expectation of each side of equation (3.4), the expected utility function is obtained, or

$$E[U(q)] = UE(q) + \sum_{K=1}^{n-1} U_K E(q) E[q-E(q)]^K/k! \quad (3.5)$$

i.e. the utility of q can be expressed in terms of its mean value, and higher moments about the mean.' By expansion, equation (3.5) becomes;

$$\begin{aligned} EU(q) &= UE(q) + U_1E(q)E[q-E(q)] + U_2E(q)E[q-E(q)]^2/2 \\ &\quad + \sum_{K=3}^{\infty} U_K E(q)E[q-E(q)]^K/k! \\ &\doteq UE(q) + U_2E(q)V/2 \end{aligned} \quad (3.6)$$

since $E[q-E(q)] = 0$, $E[q-E(q)]^2 = V$ (i.e. variance) and, with strong convergence,

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'(cont'd)Korkie; and Terrence E. Daniel, *Mathematical Dictionary for Economic and Business Administration*, (Boston, Mass.: Allyn and Bacon, Inc., 1976) *s.v.* Taylor's theorem

' In theory there are infinite number of moments about the mean. However, the only first two moments (*mean* and *variance*) are commonly used in analyses. The variance, and its positive square root (*the standard deviation*) are used as measures of risk, with higher values representing higher risk. The third and fourth moments are often met in complex analyses and they respectively measure the skewness and the *kurtosis* (peakedness) of a distribution. Higher moments are often ignored on the assumption that their values are close to zero.

$$\sum_{k=3}^{\infty} U_k E(q) E[q-E(q)]^k / k! \doteq 0,$$

Therefore, the expected utility may be expressed in terms of its mean value and variance as:

$$EU(q) = U(q) = U(E,V) \qquad (3.7)$$

where:

E = expected (or mean) value of q, and

V = variance of q

Utility funtions may be represented in an E-V space for specific utility values. The mathematical form is of the nature;

$$V = g(E;U^{\cdot}) \qquad (3.8)$$

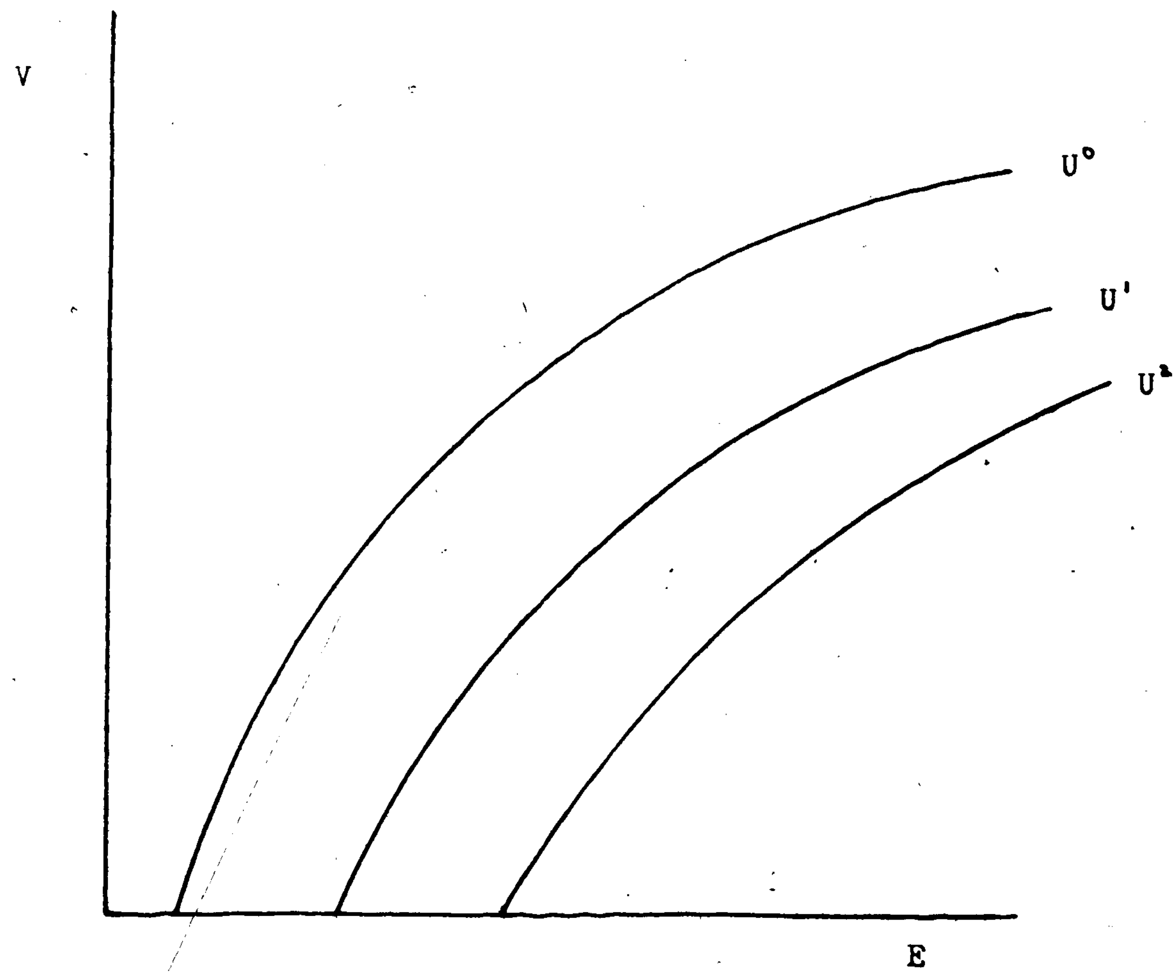
When $U^{\cdot}$ is assigned different values, a set of isoutility (or indifference) curves, is obtained. Indifference curves for the risk averse individual are presented in Figure 5. Along each indifference curve, utility is constant (hence the term isoutility), whereas utility increases such that $U^2 > U^1 > U^0$ (Figure 5). The maximization of expected utility assumption implies a movement towards the highest possible indifference curve and, from Figure 5, this may be achieved by minimizing variance (and therefore minimizing risk) for a fixed expected payoff, or by achieving higher payoff, given some level of risk.

3.5 Risk Aversion and Forms of Utility Function

Many forms of the utility function have been proposed and tested by researchers. Among them include the polynomial, the Cobb-Douglas, the semilog, the exponential, and

FIGURE 5

Typical Indifference Curves for the Risk Averse Individual



the constant elasticity of substitution (CES) functions. Lin and Chang[1] tested alternative forms of the utility function, and observed that proper specification of the functional form is essential if the Bernoullian utility maximization hypothesis is to predict actual behaviour of farmers with reasonable accuracy. Therefore it is possible for certain functional specifications to wrongly represent the farmer's attitude to risk.

The polynomial function (and especially its quadratic form) has received much attention because it is simple and easily amenable to mathematical programming techniques. However, the function has been found to be too restrictive.[2] In particular, the polynomial function has been criticized on the basis that it exhibits increasing risk aversion,[3]

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[1] William W. Lin and Hui S. Chang, "Specification of Bernoullian Utility Function in Decision Analysis", *Agric. Econ. Res.*, 30 (1): 30-36, 1978.

[2] *Ibid.*, p. 35.

[3] The degree of risk aversion is measured by means of the Arrow-Pratt coefficient of absolute risk aversion; $Ra(q) = -U''(q)/U'(q)$; where U' and U'' are as defined above. This is, however, a local measure of risk aversion. For the risk averse person, $Ra > 0$, since $U' > 0$ and $U'' < 0$. An alternative measure is the Arrow-Pratt coefficient of relative risk aversion, $Rr(q) = qRa(q) = -qU''(q)/U'(q)$, which is dimensionless and therefore is unaffected by choice of units of q. The coefficients were independently proposed by Pratt and Arrow. See J.W. Pratt, "Risk Aversion in the Small and in the Large", *Econometrica*, 32 (1-2): 122-136, 1964; and K.J. Arrow, "The Theory of Risk Aversion", in *Essays in the Theory of Risk-Bearing* (Amsterdam: North Holland, 1971). To illustrate increasing risk aversion among polynomial functions, consider the quadratic function;

$U = a + bq - cq^2$, $a,b > 0$, then

$U' = b - 2cq$,

$U'' = -2c$, and

$Ra(q) = -U''/U' = 2c/(b-2cq)$

Therefore as q increases (and the individual becomes more whereas the farmer has been observed to be less risk averse as his wealth increases.[1] The functions which have been found to be more satisfactory, as far as decreasing absolute risk aversion is concerned, include the semilog functions, the negative exponential function, or $U(q) = K[1-exp(-\alpha q)]$, $K,\alpha > 0$, the family of CES utility functions, $[1/(1-\alpha)]q^{1-\alpha}$, $\alpha > 0$.[2] Strict adherence to the polynomial utility function may not be necessary, since non-polynomials can be converted into polynomial utility functions by Taylor series expansion provided they are continuous and have derivatives.[3]

Apart from the problem with specifying the utility function, there is also the problem of determining and measuring the individual's utility.[4] As a result, many other techniques have been devised for ranking risky prospects by circumventing the problems mentioned above. Among the techniques is the stochastic dominance concept which was developed by Quirk and Saposnik and elaborated further by Hadar and Russell, and Whitmore.[5]

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[3](cont'd)and more wealthy), $Ra(q)$ increases as well.

[1] See Lin and Chang(1978).

[2] Ibid.; S.C. Tsiang, "The Rationale of the Mean-Standard Deviation Analysis, Skewness Preference, and the Demand for Money", *Am. Econ. Rev.*, 62 (3): 354-371, 1972; and Steven T. Buccola and Ben C. French, "Estimating Exponential Utility Functions", *Agric. Econ. Res.*, 30 (1): 37-43, 1978.

[3] See Tsiang(1972), p. 356.

[4] The determination of utility function has been discussed in Halter and Dean(1971), chpt. 3; and Anderson, Dillon and Hardaker(1977), chpt. 4.

[5] J.P. Quirk and R. Saposnik, "Admissibility and Measurable Utility Functions", *Rev. Econ. Stud.*, 29 (2): 140-46, 1962; Josef Hadar and William R. Russell, "Rules for Ordering Uncertain Prospects", *Am. Econ. Rev.*, 59 (1): 25-34,1969; and G.A. Whitmore, "Third-Degree Stochastic Dominance", *Am.*

3.6 The Concepts of Stochastic Dominance

The stochastic dominance technique uses efficiency criteria to provide partial ordering of risky prospects and, in the process, the "pursuit of an optimal decision" is sacrificed.[1] Instead, decisions are classified (on the basis of efficiency) as dominated (i.e. inferior, inefficient) or undominated (i.e. superior, efficient). The undominated decisions are then considered as admissible or acceptable. This ordering process is made possible because of a close relationship between stochastic dominance and preference among uncertain prospects, which may be expressed as the following two propositions:[2]

1. Given any two prospects P and P', if P is stochastically larger than P', then P is preferred to P', regardless of the specification of the utility function; and
2. Given any two prospects P and P', if P is preferred to P' for all utility functions, then P is stochastically larger than P'.

Each proposition is the reverse of the other.

Risky prospects are evaluated on the basis of their probability density functions (*PDF*) and cumulative distribution functions (*CDF*),[3] The evaluation criteria are the first-degree (*FSD*), the second-degree (*SSD*), the

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[5](cont'd)*Econ. Rev.*, 60: 457-59, 1970.
[1] Anderson, Dillon and Hardaker(1977), p. 281.
[2] Adapted from Hadar and Russell(1969), p. 27.
[3] If $f(q)$ is the probability density function of payoff q, then its corresponding CDF is defined as $F(q_i) = \int_{-\infty}^{I} f(q_i)dq$ for the continuous case and $F(q_i) = \sum_{i=1}^{I} f(q_i)$ for the discrete case. Subsequent analyses are made with reference to the continuous case only.

third-degree (*TSD*), etc., stochastic dominance. In this report, attention is focussed on the first and second degree stochastic dominance, which are described in the next two sections.[1]

3.6.1 First-Degree Stochastic Dominance

The first-degree stochastic dominance is based on the assumption that given the range $R \in [a,b]$, the decision maker's utility function is monotone increasing, i.e. $U' > 0$. Therefore, for a given variance, a higher expected payoff is preferred to a lower expected payoff. According to the *FSD*, a risky prospect q_1 with *CDF*, $F_1(R)$, defined over the domain $[a,b]$ is said to dominate another risky prospect q_2, with *CDF*, $G_1(R)$, in the sense of *FSD* if $F_1(R) \leq G_1(R)$ for all possible R in the range $[a,b]$ with at least one strong inequality. The distribution F_1 is then said to be stochastically efficient, or alternatively, G_1 is stochastically inefficient. The *FSD* has been illustrated in Figure 6, which shows F_1 and G_1 with the same variance, but F_1 dominates G_1 because it has a greater expected payoff. Therefore, the dominant curve lies wholly to the right of the dominated curve. Under FSD, two curves may touch each other, but they should not intersect if one is to dominate the other.

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[1] The discussion of the *FSD* and the *SSD* is mainly based on Hadar and Russell(1969); J.R. Anderson, "Risk Efficiency in the Interpretation of Agricultural Production Research", *Rev. Mktg. Agric. Econ.*, 42 (3):131-84, 1971; and Anderson, Dillon and Hardaker(1977),chpt. 9.

3.6.2 Second-Degree Stochastic Dominance

The second-degree stochastic dominance (*SSD*), introduces additional restriction which makes further selection among *FSD* efficient set possible. Under the *SSD* the utility function is assumed to be monotone increasing over the domain $[a,b]$ as well as being strictly concave. Therefore, the *SSD* assumes the decision maker to be risk averse. In the case of the *SSD*, distribution F dominates G if $F_2(R) \leq G_2(R)$ for all possible R in the range $[a,b]$ with at least one strong inequality, where $F_2(R) = \int_a^R F_1(q)dq$.[1] An illustration of *SSD* is given in Figure 7, where Figure 7A reveals that two *CDFs* may cross each other, but F_1 dominates G_1 iff the area under F_1 is less than the area under G_1 - i.e. F_1 and G_1 have the same expected payoff but F_1 dominates G_1 because it has a smaller variance. However, like the case of the *FSD*, the *SSD* cumulative distributions, F_2 and G_2, must not cross each other if one is to dominate the other. F_2 dominates G_2 if it lies wholly to the right of G_2 (Figure 7B). Higher degree stochastic dominance analyses are performed in a similar fashion and involve the progressive introduction of restrictions on the nature of the decision maker's utility function.

3.6.3 Stochastic Dominance and E-V Efficiency

The stochastic dominance concepts discussed in the preceeding sections can be applied to *E-V* analysis if the

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[1] In general, $F_n(R) = \int_a^R F_{n-1}(q)dq$.

FIGURE 6

Illustration of the First-degree Stochastic Dominance

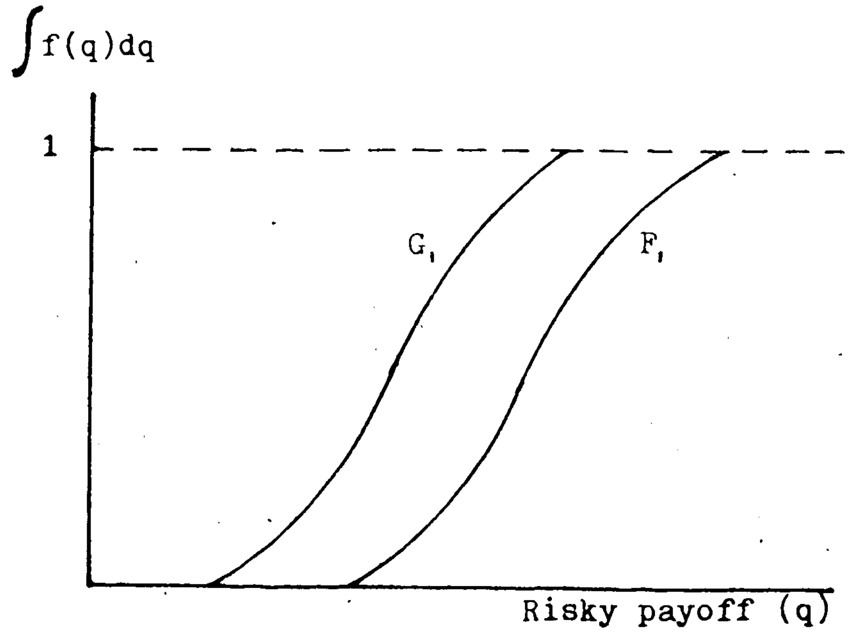
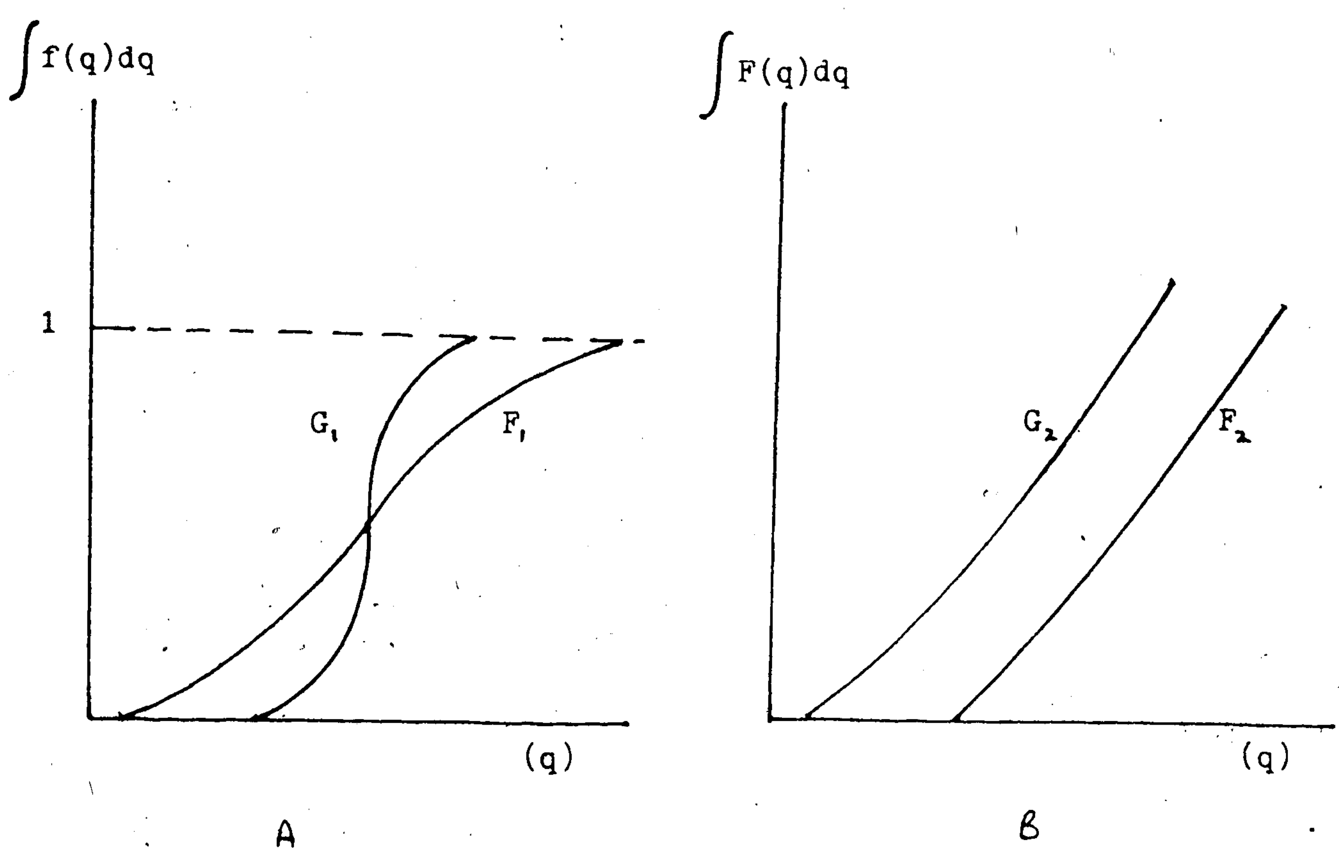


FIGURE 7

Illustration of the Second-degree Stochastic Dominance



payoffs $(q_i; i=1,...,I)$ are assumed to be normally distributed and, in this case, F is said to dominate G in the sense of FSD if $E_F(q) \geq E_G(q)$, with at least one strong inequality. This means that the decision maker prefers more of the payoff to less. In general, FSD cannot be applied under E-V analysis, since in normally distributed functions, the range of values, R, belong to the infinite interval $(-\infty, +\infty)$, and therefore the *CDFs* are likely to intersect, unless there exists within this range, two *CDFs* with the same variance.[1]

In addition, F is said to dominate G in the sense of SSD if $E_F(q) \geq E_G(q)$ and $V_F(q) \leq V_G(q)$ with at least one strong inequality.[2] Thus, other things being equal, the decision maker will prefer lower variance of the payoff to higher one. This is depicted in Figure 8, where, in general, a strategy will dominate other strategies which lie to the north and west of it. For example, S_0 dominates S_1 and S_2, but does not dominate S_3. Therefore, S_0 and S_3 belong to the same efficient set, but S_3 is attained with a higher payoff and at a higher risk than S_0. Selection between S_0 and S_3 depends on the decision maker's degree of risk aversion. If he is less risk averse, he will select S_3, otherwise S_0 will be selected.

The E-V efficient approach has been criticized on two fronts:

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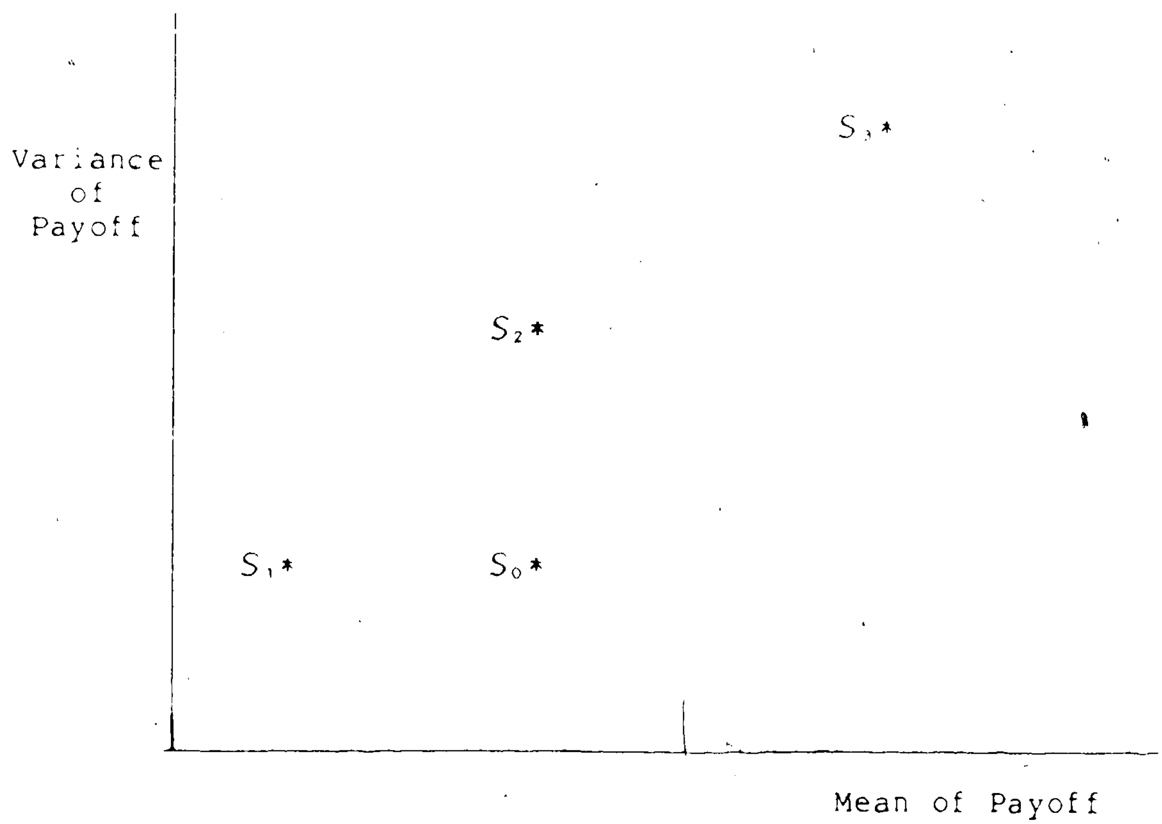
[1] See Anderson, Dillon and Hardaker(1977), p.287.
[2] This conclusion is also applicable to the case in which V is replaced by its standard deviation $(V^{.5})$

FIGURE 8

Stochastic Dominance in the E-V Space



1. that it is doubtful whether the variance of a distribution can be used as a measure of risk; and
2. that the assumption of normally distributed random variables is inappropriate. This assumption is indeed a consequence of the above assumption.

The objection with variance as a measure of risk led to the development of efficiency criteria based on *CDFs*.[1] Tsiang has defended the mean-variance approach and has shown (by means of the Taylor series expansion) that the assumption of normality is not necessary for satisfactory results to be obtained.[2] He further showed the mean-standard deviation analysis to be good approximation of expected utility, if risk is small *relative* to the total wealth of the individual.[3]

Further proof of the reliability of *E-V* analysis was provided by Porter and Gaumnitz, who compared *E-V* efficiency with *SSD* and observed that, in general, *E-V* and *SSD* results were similar, except for the case of low return and low variance range, where some *E-V* efficient portfolios were excluded by *SSD*.[4] It was therefore concluded that the choice

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[1] See G. Hanoch and C. Levy, "Efficiency Analysis of Choice Involving Risk", *Rev. Econ. Stud.*, 36: 335-46, 1969; and M. Rothschild and J.E. Stiglitz, "Increasing Risk I: A Definition", *J. Econ. Theory*, 2: 225-43, 1970.
[2] Tsiang actually used the mean-standard (*E-S*) approach which is derived from mean-variance analysis. See Tsiang(1972), p. 356.
[3] *Ibid.*, pp. 356-357.
[4] R. Burr Porter and Jack E. Gaumnitz, "Stochastic Dominance vs. Mean-Variance Portfolio Analysis: An Empirical Evaluation," *Am. Econ. Rev.*, 62 (3): 438-446, 1972. See also R. Burr Porter, "Semivariance and Stochastic Dominance: A Comparison", *Am. Econ. Rev.*, 64 (1): 200-204, 1974.

between the mean-variance model and the stochastic dominance model is not critical, except for the highly risk-averse investor.

3.6.4 Recent Extensions of the Stochastic Dominance Approach

As may be recalled, the concept of second-degree stochastic dominance proposed by Hadar and Russell[1] is very useful for ranking risky alternatives without the need to specify the utility function of the decision maker. Instead, it is based on the assumptions that the utility function is increasing as well as exhibiting risk aversion. Alternative risky prospects are ranked on the basis that risk averse decision makers are unanimous in preferring some alternatives to others. However, the main problem with this approach is with the presence of a large number of risky prospects, such as S_0 and S_1 in Figure 8, which cannot be ranked and this may be attributed to the fact that the relevant utility function is not specified. Since the utility function is not strictly unique, any new function, obtained as a result of positive linear transformation of the basic utility function could produce *SSD* results similar to those obtained for the basic function.

Meyer recently used generalized procedures in an attempt to resolve this problem and to increase the flexibility and the discriminating power of stochastic dominance.[2]

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[1] Hadar and Russell(1969).
[2] Jack Meyer, "Choice among Distributions", *J. Econ. Theory*,

His technique is also expected to pave the way for applying stochastic dominance to empirical research. The first generalized approach involves the prediction of a decision maker's choice between pairs of alternatives with reference to a lower and an upper bound on his measure of risk aversion.[1] The range is given by $R(q) \in [R_1(q), R_2(q)]$, for all q, where $R(q) = -U''/U'(q)$ = the Arrow-Pratt coefficient of absolute risk aversion which, unlike utility functions, gives a unique representation of the decision maker's preferences.[2] Meyer's approach therefore attempts at representing preferences uniquely. The interval $R(q)$ is not fixed and may be varied to allow for further tests, depending on the interests of the researcher. This prediction process is then extended over a group (or class) of agents[3] in order to determine whether or not they are unanimous in selecting one risky prospect over the other.

The problem considered required the determination of the necessary and sufficient conditions on cumulative distributions $F(q)$ and $G(q)$, for $F(q)$ to be preferred to or be indifferent to $G(q)$ by all agents in the class, $U[R_1(q), R_2(q)]$, given any two functions $R_1(q)$ and $R_2(q)$.[4]

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[2](cont'd) 14: 326-336, 1977a.; and *Idem*, "Second Degree Stochastic Dominance with respect to a function", *Int. Econ. Rev.*, 18 (2):477-487, 1977b.

[1] Meyer(1977a).

[2] Pratt(1964).

[3] The groups of agents are described with the utility relation $U[R_1(q), R_2(q)]$, whose preferences are represented by $R(q)$ satisfying the condition, $R_1(q) \leq R(q) \leq R_2(q)$ for all q and for given functions $R_1(q)$ and $R_2(q)$. Meyer(1977a), p. 327.

[4] A parallel is drawn with the Hadar-Russell approach, where the *FSD* is defined such that $R(q) \in [-\infty, +\infty]$ and in the *SSD*,

Specifically, the problem may be stated as involving the minimization of the function,

$$\int_0^1 [G(q)-F(q)]U'(q)dq$$

subject to

$$R_1(q) \leq -U''(q)/U'(q) \leq R_2(q), \text{ for all } q \in [0,1]$$

An additional restriction may be introduced, without loss of generality, by equating $U'(0)=1$.[1] The selection criteria are as follows:

1. If the minimum of the objective function ≥ 0, then the set of agents unanimously prefer $F(q)$ to $G(q)$, or are indifferent between them; and alternatively
2. If the minimum ≤ 0, then the agents are not unanimous in selecting $F(q)$ over $G(q)$.

Therefore, this technique seeks to ensure that the number of risky prospects that cannot be ranked is reduced.

The second generalization of the stochastic dominance theory is indeed a special form of the Meyer approach just discussed, and applies to second-degree stochastic dominance.[2] In this case, a utility function, $k(q)$, is defined, where $k(q)$ is twice differentiable and arbitrarily increasing,[3] and also belongs to the set of all $U(q)$ such that $U(q) = v(k(q))$, where $v(\cdot)$ is concave and increasing.

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[*](cont'd)the range is defined as $R(q) \in [0,+\infty]$.
[1] This assumption is necessary for a minimum to exist. Recall that $U(q)$ is unique up to a positive linear transformation, therefore when $U'(0)=1$, the possibility of having zero as a multiple is eliminated.
[2] This approach is referred to as the second degree stochastic with respect to a function. See Meyer(1977b).
[3] The latter characteristic ensures that the results obtained are very general.

The procedure followed in the analysis is similar to that described for the first generalized approach, except that in this case the analysis was performed in two stages:

1. where preferences were evaluated with respect to a lower bound only, i.e. $U(q) \in U(-k''(q)/k'(q), +\infty)$; and
2. where preferences were evaluated with respect to an upper bound only, i.e. $U(q) \in U(-\infty, -k''(q)/k'(q))$.

From the results of the analysis, utility functions were grouped into the following three subsets;

1. a subset containing utility functions which ensure that F is preferred to G;
2. a subset containing utility functions for which G is preferred to F; and
3. a subset in which no unanimous preferences exist.

Subsets (1) and (2) are classified depending on whether or not all agents are more risk averse (i.e. $F \geq G$) or less risk averse (i.e. $F \leq G$) than $U(q)$, which serves as a boundary function.

The main advantages of the Meyer techniques may be traced to the fact that they give consideration to increased discrimination of preference determination and, unlike the single-valued utility functions, they are not likely to eliminate a preferred choice from consideration.[1] Possible practical applications of the techniques are mentioned in Meyer, and in King and Robison.[2]

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[1] See Robert P. King and Lindon J. Robison, "A[illegible]al Approach to Measuring Decision Maker Preferences,[illegible] J. *Agric. Econ.*, 63 (3), 1981, p. 519.
[2] Meyer(1977a); and King and Robison(1981).

3.7 Concluding Remarks

The second-degree stochastic dominance approach reviewed in this chapter is appropriate to the evaluation of the drought adjustment strategies obtained from the case farmers. In the present study, equity (i.e. net worth) values at the end of the simulated 10 year period of operation for the various strategies were compared on the basis of their means and variances. Therefore, the *E-V* dominance approach was followed instead of the Hadar-Russell technique, since the former method is simpler. Futhermore, the two approaches were not expected to yield significantly different results since, as a result of high farm investments and high yield variability on the prairies, the mean equity values and their variances were expected to be high enough to rule out the possibility of *E-V* analysis including some strategies which would otherwise be excluded from the *SSD* efficient set.[1]

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[1] Compare with the observation made by Porter and Gaumnitz(1972).

4. DEVELOPMENT OF RESEARCH METHODOLOGY

The complex nature of the prairie agricultural environment and the strong influence of such factors as weather conditions, outbreak of diseases, and pest attacks, have been noted in earlier chapters. Since this study aims at developing a methodology for evaluating the prairie farmer's drought management strategies, an effective way of conducting such an investigation is by studying the system within which farming takes place rather than looking at the problem in isolation. This approach involves the concept of systems analysis.[1]

The systems approach takes into consideration factors which are under the control of the farm operator as well as the uncontrollable (or stochastic) factors which, as has been noted in Chapter 1, account for the uncertainty in farming. Morley[2] believes that a study which is not based on a systems approach risks being no more than a generator of irrelevant data, because it may overlook critical feedback from some parts of the system. Many quantitative techniques have been developed for systems studies. One method which has received much attention, and which has been widely found

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[1] A system may be broadly defined as a collection of interrelated components or elements with a purpose. The study of systems is referred to as *Systems analysis*. See S.R. Johnson and Gordon C. Rausser, "Systems Analysis and Simulation: A Survey of Applications in Agricultural and Resource Economics", in Lee R. Martin, ed., *A Survey of Agricultural Economics Literature*, 4 vols. (Minneapolis: University of Minnesota Press, 1977-81), 2: 161.

[2] F.H.W. Morley, "A Systems approach to Animal Production: What is it about?", *Proc. Aust. Soc. Anim. Prod.*, Vol. IX, 1, 1972.

useful for tackling problems involving uncertainty is the technique of simulation.[1] The present chapter outlines steps followed in the study from the point of view of simulation methodology.

4.1 The Concept of Simulation

Simulation is the method of studying the behaviour of a system over time and involves setting up a model of the real situation (or system) and then performing experiments on it.[2] Therefore simulation involves two processes: modelling and experimentation.

Simulation techniques are useful since they can be adapted to incorporate dynamic as well as stochastic elements of the system. In addition, they are flexible and can accommodate almost any type of model, including regression models, mathematical programming models, identities, and the Monte Carlo (or probability sampling) procedure. The main problem with simulation involves the construction of the model. If the model over-simplifies the real system, it may become trivial and if it carries too many features from the real system, it may become

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[1] See E.M. Babb and C.E. French, "Use of Simulation Procedures", *J. Farm Econ.*, 45 (1963): 876-877; J.B. Dent and J.R. Anderson, eds., *Systems Analysis in Agricultural Management* (Sydney: John Wiley and Sons Australiasia Ltd., 1971); and A.N. Halter and G.W. Dean, "Use of Simulation in Evaluating Management Policies Under Uncertainty: Application to a Large Scale Ranch", *J. Farm Econ.*, 47: 557-573, 1965.

[2] P.J. Charlton and S.C. Thompson, "Simulation of Agricultural Systems", *J. Agric. Econ.*, 21 (1970): 373-384; and T.H. Naylor *et al.*, *Computer Simulation Techniques* (New York: John Wiley, 1966).

intractable and prohibitively clumsy.[1]

Models represent the real system in several forms. A model may be a miniature form of the real system, such as the model of a plane, a bridge, or a building. Alternatively, a model may represent the enlarged form of the system. These include models of chemical compounds and complex molecules like carbohydrates and the DNA. Still, a model may be an abstract representation of the real system in the form of a set of mathematical equations, which is the form relevant to the present study. Whichever form models take, they are useful for studying the performance of the real situation under varied conditions.

Halter, Hayenga and Manetsch[2] have described simulation models as having three components:

1. a difference equation of the system model describing the state of the system and subsequent performance at discrete points in time;
2. an equation which allows a comparison of the performance of the model with the real situation; and
3. an equation relevant to the experimentation stage of the simulation process. This enables the researcher to observe the performance of the system over time and under several policy alternatives.

Specifically, such a system may be represented

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[1] J. Harling, "Simulation Techniques in Operations Research - A Review", *Operations Research* (May-June 1958), pp. 307-319.

[2] A.N. Halter, M.L. Hayenga, and T.J. Manetsch, "Simulating a Developing Agricultural Economy: Methodology and Planning Capability", *Am. J. Agric. Econ.*, 52 (2), 275, 1970.

mathematically as:[1]

$$\Psi(t+1) = F[\Psi(t), \alpha(t), \beta(t), \gamma(t)]$$

$$\theta(t) = H[\Psi(t), \Psi_r(t), \alpha(t), \beta(t), \gamma(t)]$$

$$\Pi(t) = G[\Psi(t), \alpha(t), \beta(t), \gamma(t)]$$

where:

Ψ = vector of variables defining the state of the simulated system at any given time, e.g. amount of land put under cultivation, levels of technology, prices, etc.

Ψ_r = vector of variables describing the state of the system in the real world.

$\alpha(t)$ = set of parameters defining the structure of the system, such as technical coefficients, some of which may be varied within the model.

$\beta(t)$ = set of exogenous or uncontrolled variables that influence the behaviour of the system, e.g. product prices, weather, etc.

$\gamma(t)$ = set of decision or controlled variables that can be modified to alter the system's performance in various directions, e.g., grain quotas, investment alternatives, tax policies, etc.

$\theta(t)$ = set of intermediate output variables that measure how well the model of the system $\Psi(t)$ corresponds to reality $\Psi_r(t)$, e.g. the various statistics such as F, t, and R^2.

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[1] *Ibid.*

$\Pi(t)$ = set of output variables measuring the system's simulated performance, e.g. net farm income, equity values, and rates of growth.

According to Wright[1] the methodology of simulation may include the following:

1. Specification of the problem and objectives;
2. Learning about the system;
3. Formulation of initial system model;
4. Data collection;
5. Specification of detailed model;
6. Programming for computer operation;
7. Validation of model;
8. Experimentation; and
9. Analysis of results.

In this study, one of the existing prairie farm simulation models[2] was used as the basic model, from which methodology

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[1] A. Wright, "Farming Systems, Models and Simulation", in Dent and Anderson(1971), p. 24.

[2] There are four models which have been developed by Agriculture Canada for simulating farming conditions in the Canadian prairies. These are the Dryland Crop Enterprise Model, the Beef-Forage-Grain Production model, the Hog-Grain Model and the Dairy-Forage-Grain Model. The Dryland Crop Enterprise Model is the model selected as the basic model for this study and is simply referred to as the *grain model* in this thesis. The grain model has been described in R.P. Zentner, B.H. Sonntag and G.E. Lee, "Simulation Model for Dryland Crop Production in the Canadian Prairies", *Agricultural Systems*, (3) (1978): 241-251; Zentner, "Prairie Agricultural Farm Simulators (PAFS): A Documentation of the Dryland Crop Enterprise Model", Agriculture Canada Research Station, Swift Current, mimeographed, 1981; and Zentner and R.M. Koroluk, "Introduction to a Whole Farm Computer Model of Dryland Grain Production for Western Canada", Agricultural Canada Research Station, Swift Current, (mimeographed), 1982. The model is updated periodically, as further research data become available to the developers. For the latest version see Zentner and Koroluk(1982).

for evaluating the farmer's drought management strategies was developed. The procedures followed in this study is shown in Figure 9. Seven main steps were followed, beginning with the specification of the problem and objectives of the study which were discussed in Chapter 1. The next section presents a review of the basic simulation model used for the study.[1] Other steps involved in the study are discussed in later sections and subsequent chapters.

4.2 General Features of the Grain Model

The grain model is made up of three main parts:

1. a computer programme in the Fortran IV language, which contains the skeletal relationships and interrelationships of the biological, physical and economic processes involved in grain and oilseed production;
2. a base data file containing a listing of the production alternatives and production (or default) coefficients for average farms in the region. The base data have been developed from biological and agricultural engineering experimentation done in various western Agriculture Canada research stations.
3. a control data file containing data and parameter values specific to the particular farm under consideration. The information required in the control file is obtained by means of an input form, which is also the means by which

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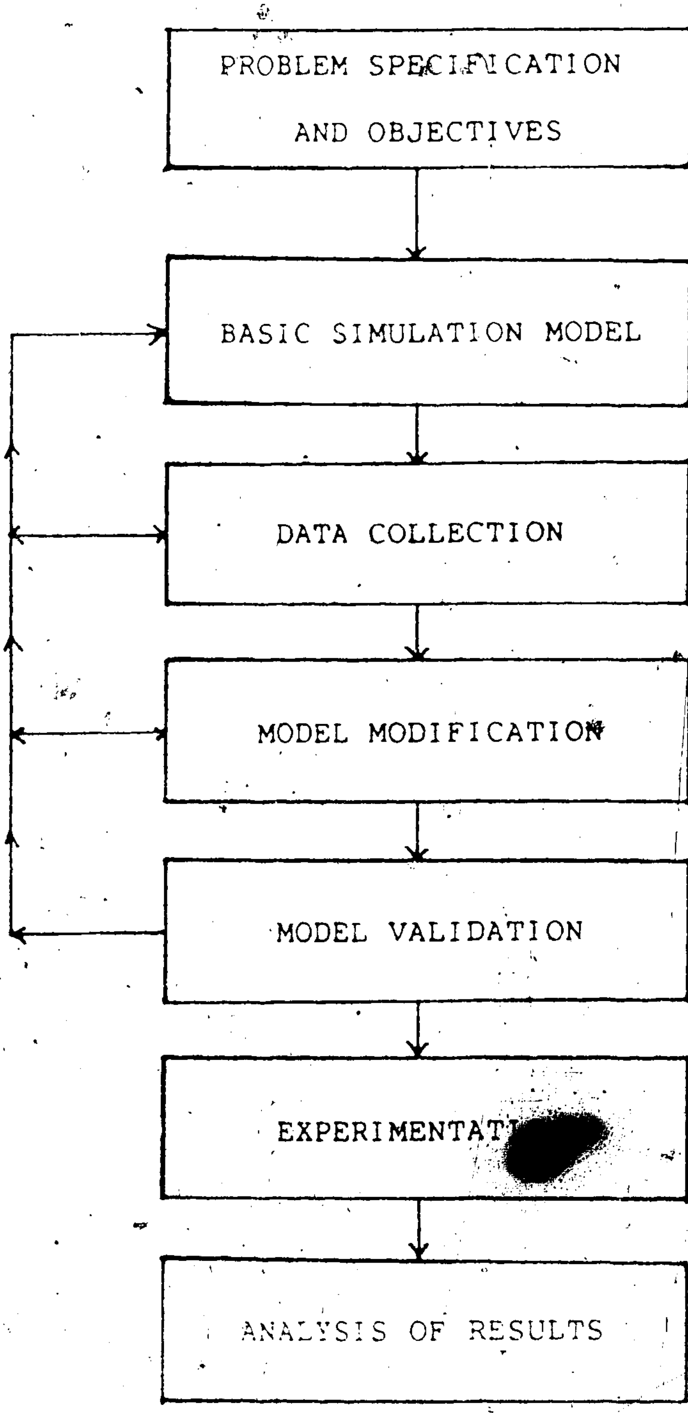
[1] This review of the grain model is based on Zentner(1981); Zentner and Koroluk(1982); Zentner, Sonntag, and Lee(1978); and also on personal experience with the model.

FIGURE 9

Outline of Simulation Methodology



the user communicates with the model.

The model simulates the annual net income and the equity positions of a farm business following selected production and marketing activities. The Monte Carlo simulation procedure is used to randomly select the production pattern (or plan) from several alternatives. The production or "best" plan is selected from among the number generated through consideration of three main objectives of

1. maximizing terminal net worth (or equity) subject to an upper limit on income variance,
2. minimizing labour input subject to some minimum income level, and
3. maximizing physical output.

The "best" plan is selected on the basis of its closeness to optimality and does not necessarily imply optimality.

The model breaks each year down into 26 bi-weekly periods, so that decisions relating to activities can be made at a detailed level and resource flows can be calculated accurately and observed during the year. Simulations can be performed for a production period of up to 10 years in length. This is accomplished through a recursive process where the ending position of one year becomes the starting position of the next. The model is also capable of simulating farming conditions in each of the three soil zones of the prairies, and can be operated in a "budget" mode or in an "optimization mode". The main difference between the two is that farm size is specified by the model user when the model is used in a budget mode, whereas in the optimization mode, farm size is endogenous, and expressed as a function of the resources available on the farm. The major steps in the operation of the grain model are shown in Figure 10.

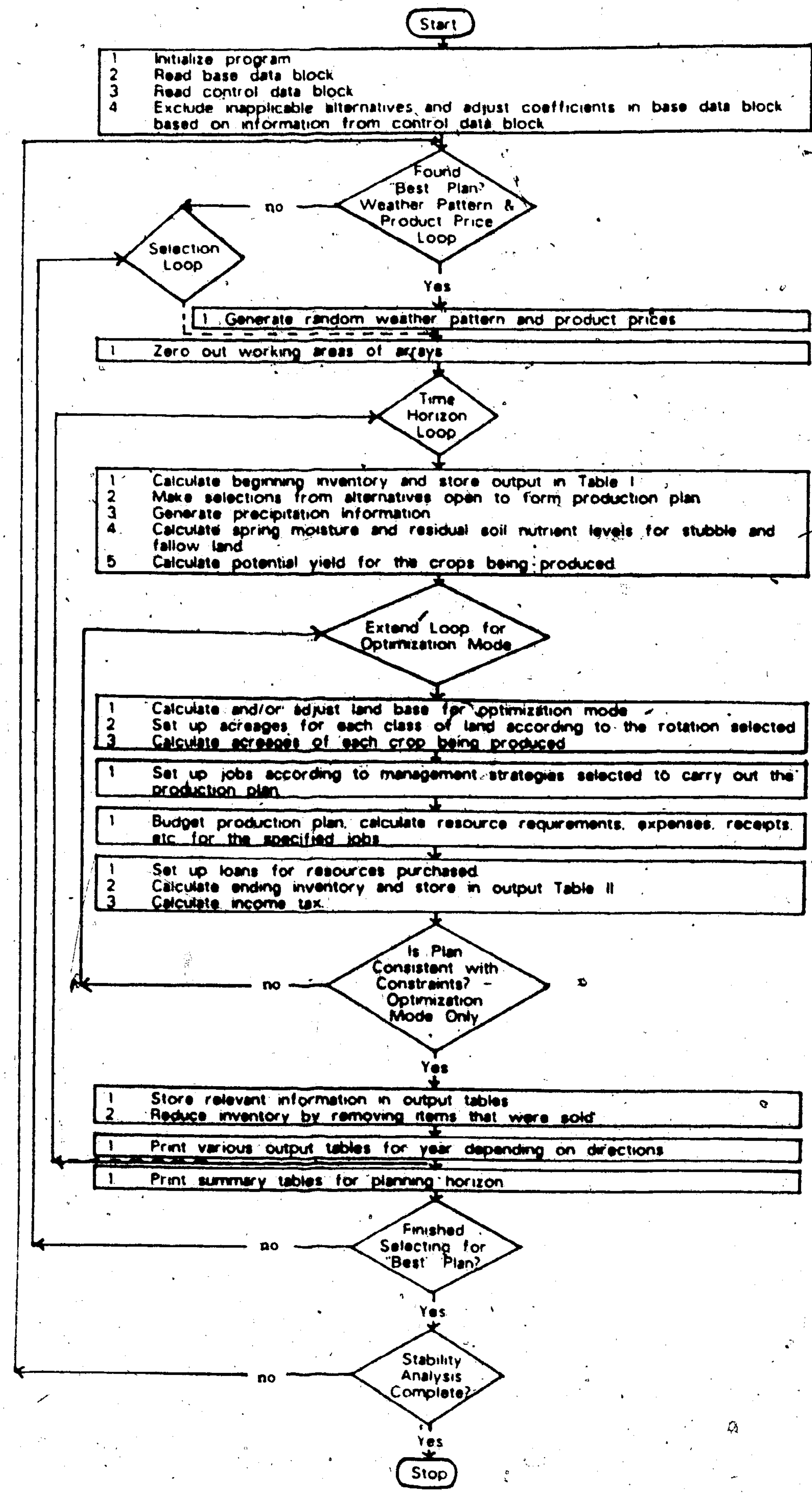
The model can handle six crops simultaneously and one of seven crop rotations. The crops which may be included in the programme are winter wheat, rapeseed, flaxseed, spring wheat, barley and oats. The available rotations are 1/2 summerfallow - 1/2 crop, 1/3 summerfallow - 2/3 crop, 1/3 summerfallow - 2/3 crop "IF", 1/4 summerfallow - 3/4 crop, 1/4 summerfallow - 3/4 crop "IF", continuous cropping and continuous cropping "IF". The "IF" rotations enable the user to bring more stubble land under cultivation if the spring moisture conditions are favourable (i.e. ≥3 inches).[1] The various production alternatives and management strategies for the grain model are illustrated in Figure 11. Other aspects of the grain model are mentioned later in the thesis.

4.3 Data Requirements and Collection

The data collection process began with the selection of the case farm operation and an interview with the operator in order to determine the specifics of his operations. The interview, which took place in August of 1982, was conducted in two stages:

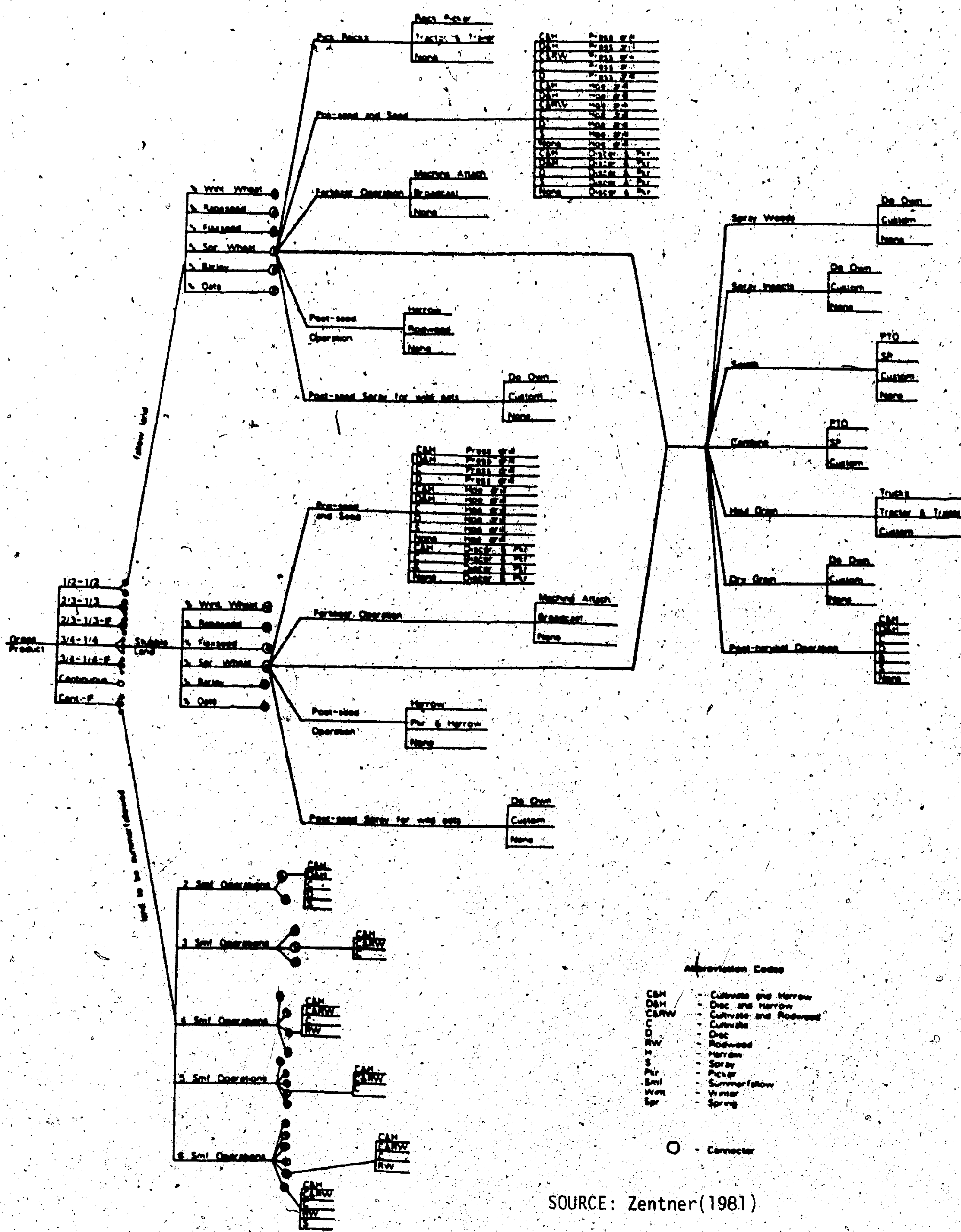
[1] These rotations were not considered in this study since attention is mainly focused on drought conditions.

FIGURE 10: Flow Diagram for the Crop Simulation Model



Source: R.P. Zentner, "Prairie Agricultural Farm Simulators (PAFS)", Swift Current.

FIGURE 11: Decision Tree Diagram for the Crop Model



SOURCE: Zentner(1981)

1. an input form for the grain model was used to obtain the information necessary for simulating the most recent year of the farmer's operations (i.e. 1981), and to calibrate and establish the validity of the model; and
2. the farmer's drought management strategies were determined by means of a questionnaire, which was designed to reveal the farmer's ability to predict drought, based upon conditions in five periods during the crop year, namely, the previous autumn, the previous winter, the early spring, the late spring, and the summer; and also to obtain information on adjustments made to production, marketing and financial management practices once a drought has been predicted.

A copy of the questionnaire is provided in Appendix I, and the case farm is described in some detail in Chapter 5.

The specific information obtained with the input form included the following:

1. resources available on the farm, e.g. types, sizes and ages of machines and equipment, land by area and tenure, seasonal and permanent labour supplies, capital, storage facilities by size, type, and age, and grain and oilseed inventories;
2. production and management alternatives to be considered, e.g. types of crops to be produced, crop rotations, alternative machine and tillage sequences to be used in production, machine replacement policy, input purchase policies, crop insurance policies, and incidence and

extent of chemical application;

3. prices and technical coefficients such as product and input prices, and physical transformation rates such as crop yields;
4. personal and financial data, e.g. living expenses, income, off-farm investment, tax exemptions, debt positions, cash balance, and credit limits; and
5. other items such as expected delivery quotas, and management proficiency indices.

Yield data required for running the model were obtained primarily from the grain farmer, and then supplemented by the Agriculture Canada Research Station at Swift Current (Saskatchewan), and Statistics Canada, Ottawa.

The case grain farm had a record of wheat yields on summerfallow over the 35 year period of from 1947 to 1981. These yield values were used for running the simulation on the grain model. Yields on stubble land were not available on the farm and, as a result, average stubble yields for the Saskatchewan Crop District 4B, in which the farm is situated, were used. Missing values were replaced with reasonable estimates generated by regression analysis. The yield data used for the study are shown in Appendix II.

4.4 Model Modification and Validation

The grain model has in-built crop yield relationships, which enable it to compute crop yields based on the values of certain independent factors. The yield functions for spring wheat on fallow and stubble in the brown soil zone are dependent on the soil texture category, stored soil moisture (in inches), the levels of nitrogen and phosphorus available to the plant (i.e. residual soil nutrient plus applied fertilizer), and the amount of precipitation received in each the growing months of May, June and July. Changes were made to the grain model to make it possible for sets of yield values to be read by the model. The modifications entailed the by-pass of the subroutine for computing crop yields and the introduction of statements permitting the model to read in up to ten yield values at a time. Relevant changes were also made to the base data and the control data files.

The changes made were important because they allowed the model user to have control over the yield data that the model reads, thereby permitting yields reflecting the preferences of the model user to be incorporated into the model. The yield values may include values obtained from statistical records, or the farm under investigation, or even generated from production relationships outside the model. The modifications facilitated the imposition of drought conditions on the case farm. A computer programme was written to permit the random selection of ten series of ten year yields from 35 years of yield data. The selected series were then added to the data in the control file before the model was run. Another programme was developed for selecting the farm's equity position at the end of ten years of operation for each data series, and from which expected value of ending equity position and its standard deviation were computed. Both programmes are presented in Appendix III.

The modified model was then tested to determine how well it represented the real situation. The process of evaluating simulation models in relation to reality is referred to as calibration or validation. The present model was calibrated by simulating the farmer's most recent year of operation for which information on the business was available. The results of the simulation were compared with actual business performance for the simulated period, and further changes made until outputs from the simulation were close to the actual values. The acceptable form of the model was then used for experimentation.

4.5 Experimentation

The process of experimentation involves, *inter alia*, the formulation and testing of hypotheses, and also the manipulation of data to achieve results. The hypotheses formulated and the assumptions of the study are discussed in Chapter 1. The main steps taken in the treatment of data collected are discussed in this section.

The study identified specific strategies employed by the case farmer and tested out the consequencies of these strategies, therefore the model was used in the budget mode only. The experimentation process also involved the identification of the farmer's basic strategy together with several drought adjustment options. Simulation of ten years of operation following the basic and other identified strategies was performed under ten series of randomly selected crop yields to establish the payoff and riskiness of each strategy. Chapter 6 reviews this stage further.

4.6 Analysis of Results

The strategies derived from the results of the interview with the farmer were evaluated with respect to two criteria, namely business growth and business survival. Business growth was measured by the expected equity position at the end of a simulated 10 year period of operation, and results from re-investment of annual net income less living costs and income taxes. Business survival, an important consideration of farm operations (especially in regions subjected to drought), is measured by variance or the standard deviation of the equity positions at the end of the 10 year period as derived under the randomly selected series of crop yields. Once the expected payoffs and standard deviations are calculated, strategies can be classified according to the following rules.

1. In the case where two strategies are equally risky but one has a higher payoff than the other, farmers would be expected to choose the strategy with the greater payoff. The lower payoff strategy is said to be inferior.
2. In the case where two strategies have equal payoffs, farmers would choose the strategy with the lower risk to

ensure business survival. The higher risk strategy is said to be inferior.

3. In the case where one strategy has a higher payoff and is also more risky than another, no direct conclusion can be drawn as to which strategy would be chosen. In this case neither strategy dominates the other and both are said to be efficient. The choice between the two depends upon how important the survival objective is to the particular farm operator.

Each strategy was evaluated within this framework in order to identify those which could be eliminated as being inferior because of dominance. This evaluation technique was discussed in Chapter 3, and the strategies considered to be of relevance to risk averse farm operators, are examined in greater detail in Chapters 5 and 6. Also, the performance of the farmer's net farm income was tracked for the years simulated using two sets of yield series representing the worst and the best decades. The results of the study are discussed in Chapter 6 and Chapter 7 deals with summary, conclusions and recommendations.

5. THE CASE GRAIN FARM OPERATION

This chapter presents a description of the case grain farm with emphasis on its management practices and available resources, and also on the identification of the farmer's basic and other adjustment strategies.

The case grain farm was selected with two main factors in mind:

1. That the case farm must be representative of the dryland grain farms of southwestern Saskatchewan in terms of size and crops grown; and
2. That the case farm must have well kept records.

The dryland grain farm selected for study is situated near Leader, Saskatchewan (Figure 12). It is an 11 quarter section farm,[1] of which nine quarter sections or approximately 1440 acres are owned by the farmer and the remaining half section or 320 acres is cash rented.[2] The farm is situated in the brown soil zone. Spring wheat and durum are the major crops grown, both on fallow. Crops like flax, oats and barley have been grown on occasion but have not formed an important part of the farming programme. They were not grown in 1981, the year under study. This farm business has been in operation since the mid 1940's and the farmer has kept excellent records of income and expenses and

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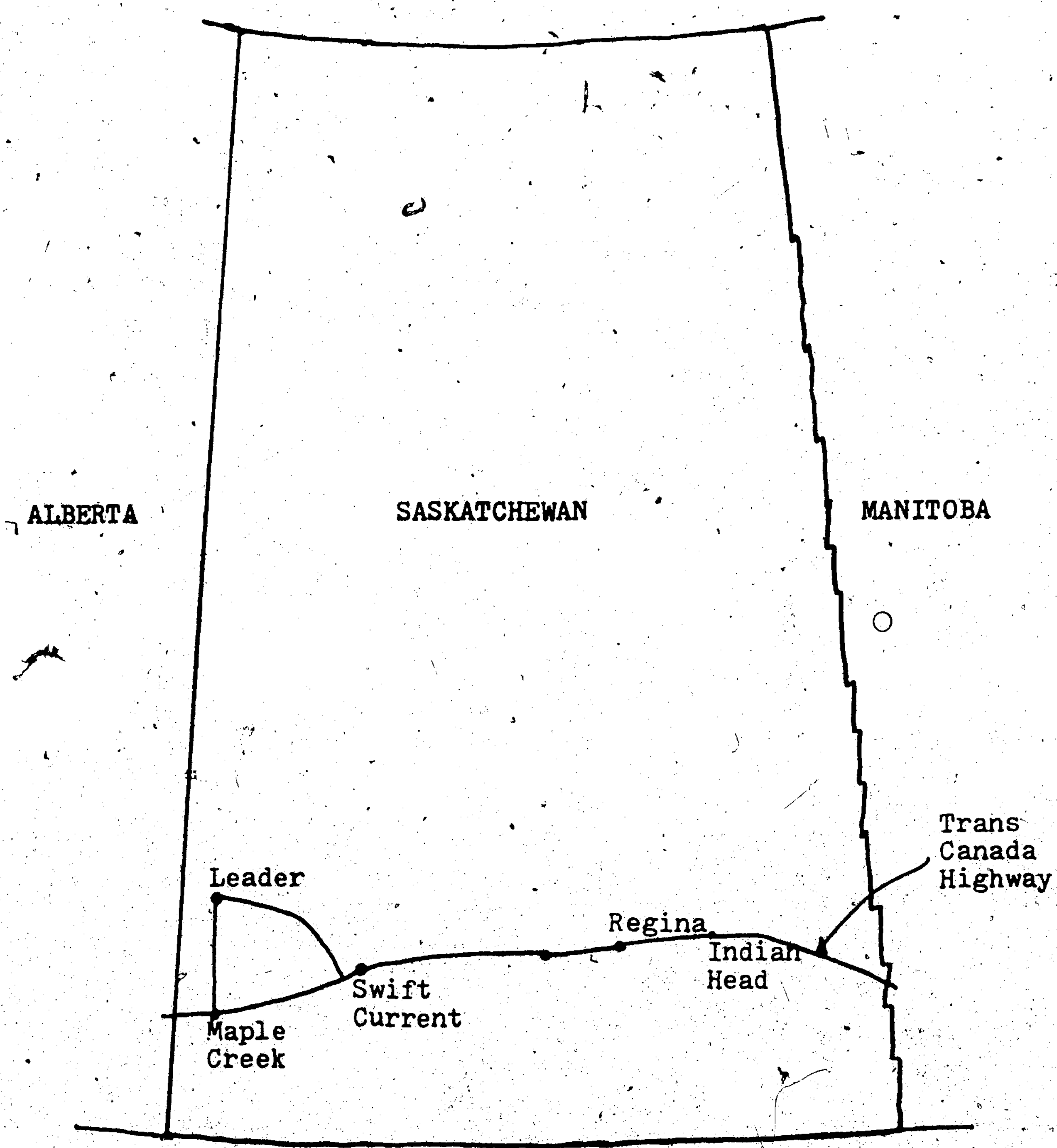
[1] In western Canada and parts of the U.S., farm lands are commonly measured in *sections*, where a section is equivalent to 640 acres.

[2] This farm compares favourably with case farms used in a number of studies conducted in the region. For example, Zentner and Lindwall(1978) used a 600 ha (1500 ac) farm as a representative farm, and Russell and Colwell(1981) assumed a 518 ha or 1295 ac farm for their study.

FIGURE 12

Map of Saskatchewan showing location of the Case Grain Farm



of crop yields since that time.

5.1 Management Practices

The usual starting date of spring operation falls between April 23 and May 6th. The cropping program followed is the 1/2 fallow - 1/2 crop rotation, and no fertilizer is applied. There is also no pre-seed tillage operation. Planting is done by the discer and a post-seed tillage operation on fallow is performed using the harrow. Pre-emergence wild oat control is done in fall on fallow land using granular weed control and there is no post-seed wild oat control. Operations such as spraying broadleaf weeds, spraying insects, swathing, harvesting and hauling grain are performed by the farmer himself.

Four tillage operations are involved in the preparation of summerfallow. The first and second operations are done using the discer and the cultivator, respectively, and the last two operations are performed by means of the rod weeder. All seeds used are home grown and they are applied at the rate of 80 lbs/ac. No crop insurance is purchased but contributions are made towards the Western Grain Stabilization Plan. Sale of grains is strictly through the Canadian Wheat Board.

5.2 Resources Available

The farmer owns all the implements required for his farm operations. Swathing and combining are performed by means of power-take off (PTO) machines. Labour is provided principally by the farmer although extra help is hired when required. This is a well established farm business and as a result there are no outstanding debts. To test results under conditions of debt, three levels of outstanding liabilities were assumed for this resource base. The three levels of debt were established under the assumption that four of the nine quarters had been bought at prevailing prices in 1971, 1976 or 1981 and that all funds for the purchase had been borrowed at the prevailing interest rate at that time. Specifically, the situations were

1. low debt where four quarter sections were purchased for $50,000 at 7.5% in 1971,
2. medium debt where four quarter sections were purchased for $80,000 at 9.75% in 1976,
3. high debt where four quarter sections were purchased for $260,000 at 16% in 1981.

Table 4 provides a statement of assets, liabilities and owners equity for the case farm, in the debt-free situation and also for the three assumed debt levels. Table 5 provides detail of fixed assets available. Assets are recorded on the balance sheet at their market value as of January 1, 1982. Subsequent calculations are made in real terms using 1982 constant dollars.

TABLE 4

Statement of Assets, Liabilities and Owner's Equity for the Case Grain Farm as at Jan 1, 1982

	DEBT FREE	LOW DEBT	MED. DEBT	HIGH DEBT
ASSETS				
Cash	10000	10000	10000	10000
Grain Inventory	24671	24671	24671	24671
Total Current Assets	34671	34671	34671	34671
Land	585000	585000	585000	585000
Buildings	24480	24480	24480	24480
Machinery	57804	57804	57804	57804
Total Fixed Assets	667824	667824	667824	667824
Other Assets	23250	23250	23250	23250
Total Assets	725201	725201	725201	725201
LIABILITIES				
Current Liabilities	0	0	0	0
Term Liabilities	0	43159	76903	260000
Total Liabilities	0	43159	76903	260000
EQUITY				
Beginning Equity	725201	682042	648298	465201
Total Liab and Equity	725201	725201	725201	725201

TABLE 5

Beginning Schedule of Fixed Assets

ASSETS	SIZE	YEAR PURCHASED	PRESENT VALUE($)
Owned Land	1440 ac		585000
Buildings			
3 Granaries	1000 bu		2433
3 Granaries	1500 bu		2904
3 Granaries	2000 bu		3612
5 Granaries	2500 bu		7205
4 Granaries	3000 bu		6764
1 Granary	4000 bu		1562
Sub Total			24480
Machinery			
Cultivator	20 ft	1958	264
Disc	16 ft	1976	4234
Rod Weeder	36 ft	1980	4197
Harrow	44 ft	1977	1741
Packers	44 ft	1971	2436
Discer	24 ft	1971	2987
Press Drill	12 ft	1974	2506
Sprayer	40 ft	1970	483
Granular Applicator	36 ft	1975	1712
PTO Swather	20 ft	1974	1579
PTO Combine	45 in	1975	10615
Truck	1/2 ton	1975	5242
Truck	3 ton	1959	2838
Auger	30 ft	1975	546
Auger	40 ft	1968	305
Tractor	90 hp	1974	16119
Sub Total			57804
Total Fixed Assets			667824

A typical farm business summary for a simulated 10 year period of operation is presented in Table 6.

5.3 Alternative Adjustment Strategies

The interview with the crop farmer revealed that he does not believe it is possible to predict the occurrence of drought, based upon conditions in the early part of the crop season. He assumes drought to be the normal condition and farms accordingly. The basic strategy followed (S_0) is to plant one half the farm to wheat, with the remaining one half being in summerfallow which, he believes, leads to a reduction of soil moisture loss. His usual husbandry practices regarding weed tillage operations, fertilization, etc., described above, form part of this basic strategy, as does his policy not to use crop insurance.

The farmer does not attempt to predict the occurrence of drought. However, in the event of unusually low precipitation in the autumn, winter or spring, which often signals the imminence of drought conditions, certain adjustments are followed, which may include:

1. No fall, winter or early spring cultivation as a water conservation measure;
2. Practice of post seed packing in late spring, using subsurface packers and spike tooth harrows, which leaves a blanket of loose soil on top to prevent soil moisture loss;
3. Increased use of insecticide and herbicide in the

TABLE 6

Farm Business Summary for the Debt-Free Situation

A. Farm Income Statement At End of Year

	1982	1983	1984	1985	1986	1987	1988	1989	1990	1991
REVENUE										
Wheat Sales	38085	45653	59491	84773	73703	53956	84773	63231	65924	73179
Final Grain Payment	28694	25599	10809	13864	18398	28254	6176	26283	16427	17018
Total Revenue	66779	71252	70299	98637	92101	82210	90949	89514	82351	90197
Wheat Inventory Change	2930	6956	10322	22440	-50265	45778	-22440	1346	2020	7854
Gross Income	69709	78208	80621	121077	41836	127988	68509	90860	84371	98051
EXPENSES										
Seed	5761	5761	5761	5761	5761	5761	5761	5761	5761	5761
Chemicals	9944	9944	9944	9944	9944	9944	9944	9944	9944	9944
Fuel and Oil	6449	6470	6510	6583	6551	6494	6583	6521	6529	6549
Machine Repair	10202	10749	11342	12046	12350	12544	13279	13419	13821	14268
Building Repair	979	979	979	979	979	979	979	979	979	979
WGSA Contributions	762	913	1190	1500	1474	1079	1500	1265	1318	1464
Other Supplies/Services	11701	11702	11701	11702	11702	11702	11701	11702	11702	11702
Labour	669	678	692	721	676	715	700	688	690	700
Depreciation	8248	7649	7113	6634	6205	5822	5479	5171	4896	4649
Total Expenses	54715	54845	55232	55870	55642	55040	55926	55450	55640	56016
Net Farm Income	14994	23363	25389	65207	-13806	72948	12583	35410	28731	42035
Other Income [1]	416	1910	2767	6395	12036	15703	17767	25564	30387	37160
Total Net Income	15410	25273	28156	71602	-1770	88651	30350	60974	59118	79195
Wheat Acreage	880	880	880	880	880	880	880	880	880	880
Yield (bu/ac)	12.3	15.4	20.0	30.0	7.6	28.0	18.0	18.6	19.5	23.0
Wheat Produced (bu)	10824	13552	17600	26400	6688	24640	15840	16368	17160	20240
Wheat Sold (bu)	8961	10742	13998	19947	17342	12695	19947	14878	15511	17219
Wheat Carryover (bu)	6494	8131	10560	15840	4013	14784	9504	9821	10296	12144

[1] Primarily from interest earned on cash balances

TABLE 6: Continued

B. Balance Sheet At End of Year

	1982	1983	1984	1985	1986	1987	1988	1989	1990	1991
ASSETS										
Cash on Hand	18387	31781	41421	84093	97727	138500	142059	196232	223747	275941
Wheat Inventory	27601	34558	44880	67320	17054	62832	40392	41738	43758	51612
Total Current Assets	45988	66339	86301	151413	114781	201332	182450	237969	267506	327553
Land	585000	585000	585000	585000	585000	585000	585000	585000	585000	585000
Buildings	22028	19580	17133	14685	12238	9792	7342	4895	2446	0
Machinery	52002	46801	42137	37948	34192	30817	27787	25064	22619	20416
Total Fixed Assets	659036	651381	644270	637633	631430	625609	620129	614959	610065	605416
Other Assets [1]	23250	23250	23250	23250	23250	23250	23250	23250	23250	23250
Total Assets	728268	740970	753821	812296	769461	850191	825830	876179	900820	956219
LIABILITIES										
Tax Payable	0	1373	1665	14533	0	21355	0	11406	7105	15315
Term Liabilities	0	0	0	0	0	0	0	0	0	0
Total Liabilities	0	1373	1665	14533	0	21355	0	11406	7105	15315
Beginning Equity	725199	728268	739597	752156	797763	769461	828836	825830	864773	893715
+ Total Net Income	15410	25273	28156	71602	-1770	88651	30351	60973	59117	79196
– Living Costs	12341	13259	13395	17067	12000	18597	12000	16327	15216	17243
– Income Tax	0	685	2202	8928	14532	10679	21357	5703	14959	14764
Ending Equity	728268	739597	752156	797763	769461	828836	825830	864773	893715	940904
Total Liab + End Equity	728268	740970	753821	812296	769461	850191	825830	876179	900820	956219
Growth in Equity (% p.a.)	.42	1.56	1.70	6.06	-3.55	7.72	-.36	4.72	3.35	5.28

[1] Include parts and supplies, other buildings, improvement, and equipment.

summer;

4. Reduction in the amount of grain sold, and thereby keeping surplus grain in inventory;
5. Postponing equipment purchase or repair old equipment; and
6. Reduction in level of consumption withdrawals.

Adjustment practices (1), (2), and (3) are husbandry practices which affect wheat yields. Since recorded yields are being used, these practices are already embodied in the yields obtained and, therefore, no attempt is made to evaluate them. The fourth adjustment practice may be more of a tax management strategy than a drought adjustment practice and is not considered in this analysis. Adjustment practices 5 and 6 are relevant to this study. However, the grain model was only partially successful in simulating these situations. The study focuses major attention on crop rotations and on levels of crop insurance coverage.

The following options and their levels were considered.

1. Rotations
   a. 1/2 summerfallow - 1/2 crop
   b. 1/3 summerfallow - 2/3 crop
   c. 1/4 summerfallow - 3/4 crop
   d. continuous cropping
2. Machinery purchase
   a. low replacement - machinery replaced when 13% of useful life remains,
   b. high replacement - machinery replaced when 50% of

useful life remains,

3. Crop insurance coverage
   a. no coverage
   b. 60% of long run average yield
   c. 70% of long run average yield
4. Consumption behaviour
   a. unadjusted - requiring $12,000 basic withdrawal plus 10% of net income, and
   b. adjusted - requiring $10,000 basic withdrawal plus 30% of net income.

The dryland crop enterprise model is capable of directly handling options (1) and (3) outlined above. The nature of the model is such that machinery replacement policies (option 2) and consumption behaviour (option 4) must be predetermined by the model user and these are then not responsive to particular crop yields during the run.[1] Nonetheless, 15 adjustment strategies were derived from the options for the evaluation process, and these are listed in Table 7.

The basic strategy, S_0, is that followed by the farmer presently. This includes the 1/2 summerfallow - 1/2 crop rotation, postponed machinery purchase or low machinery replacement during times of drought, no insurance purchase, and the normal consumption level (adjusted during hard times). Strategies S_1, S_2, S_3 are used to evaluate other available crop rotations against the 1/2 summerfallow - 1/2

[1] This point is discussed further in Chapter 7.

TABLE 7

List of Strategies Evaluated

STRATEGY	COMPONENTS	DESCRIPTION
S_0	1(a)-2(a)-3(a)-4(a)	1/2 fallow; low machinery repl.; no insurance; normal cons.
S_1	1(b)-2(a)-3(a)-4(a)	1/3 fallow; low machinery repl.; no insurance; normal cons.
S_2	1(c)-2(a)-3(a)-4(a)	1/4 fallow; low machinery repl.; no insurance; normal cons.
S_3	1(d)-2(a)-3(a)-4(a)	no fallow; low machinery repl.; no insurance; normal cons.
S_4	1(a)-2(b)-3(a)-4(a)	1/2 fallow; high machinery repl.; no insurance; normal cons.
S_5	1(a)-2(a)-3(b)-4(a)	1/2 fallow; low machinery repl.; 60% insurance; normal cons.
S_6	1(a)-2(a)-3(c)-4(a)	1/2 fallow; low machinery repl.; 70% insurance; normal cons.
S_7	1(a)-2(a)-3(a)-4(b)	1/2 fallow; low machinery repl.; no insurance; adjusted cons.
S_8	1(b)-2(a)-3(b)-4(a)	1/3 fallow; low machinery repl.; 60% insurance; normal cons.
S_9	1(b)-2(a)-3(c)-4(a)	1/3 fallow; low machinery repl.; 70% insurance; normal cons.
S_{10}	1(c)-2(a)-3(b)-4(a)	1/4 fallow; low machinery repl.; 60% insurance; normal cons.
S_{11}	1(c)-2(a)-3(c)-4(a)	1/4 fallow; low machinery repl.; 70% insurance; normal cons.
S_{12}	1(d)-2(a)-3(b)-4(a)	no fallow; low machinery repl.; 60% insurance; normal cons.
S_{13}	1(d)-2(a)-3(c)-4(a)	no fallow; low machinery repl.; 70% insurance; normal cons.
S_{14}	1(a)-2(a)-3(c)-4(b)	1/2 fallow; low machinery repl.; 70% insurance; adjusted cons.

crop rotation which has been adopted by the farmer. Strategy S_4, examines the effect of machinery purchase and strategies S_5 and S_6 compare the effect of purchasing 60% and 70% of crop insurance coverage respectively. Strategy S_7 evaluates the impact of reduced level of consumption on the equity situation. Strategies S_1 to S_7 arise directly as adjustments to the basic strategy (S_0). The effect of levels of crop insurance coverage on the other rotations are revealed in strategies S_8 to S_{13} and in strategy S_{14} the basic crop rotation and machinery policy are assumed but the extreme case of insurance coverage (i.e. 70% level) and the adjusted level of consumption behaviour are also considered. The analyses of the strategies are presented in Chapter 6.

6. SIMULATED RESULTS AND ANALYSES

The adjustment strategies identified in Chapter 5 were evaluated in two stages:

1. the farmer's net farm income was tracked over a simulated 10 year production period for selected strategies and yields; and
2. an E-V analysis was employed to group the identified strategies into dominated and undominated strategies. The ending equity values for each run were used as the risky prospect (q) with the assumption that $q \in [0,+\infty]$; and for all generated $q < 0$, $q = 0$ - i.e. the generated equity values are made nonnegative by assigning zero values to those with negative values.[1]

6.1 Net Farm Income Analysis

In order to determine the impact of different yield series on the farmer's net farm income over the length of the simulation run (i.e. 10 years), two yield series were used - the 49 series (or the worst situation), representing yield values from 1949 to 1958, a decade of low yield values; and the '71 series (or the best situation), which refers to the period 1971 to 1980, a decade of favourable climatic conditions and hence favourable yield values.[2] With these yield series, simulation runs were made on the

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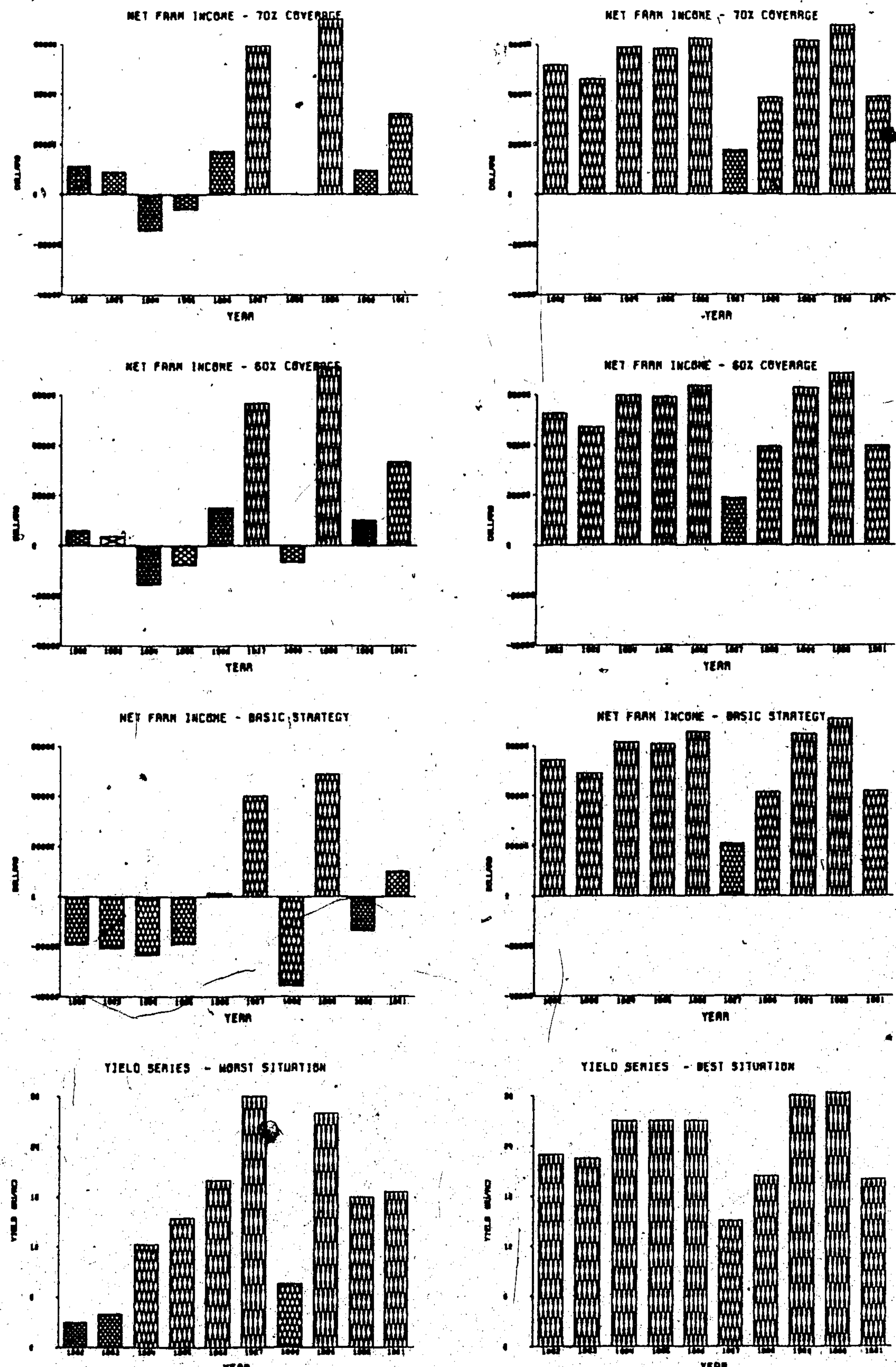
[1] This assumption is necessary since in reality, banks would not allow a business to operate beyond the point of bankruptcy. The assumption therefore ensures that the farming operation is terminated when the farm goes bankrupt.
[2] See Appendix Tables II and IV.

debt-free situation and also for the basic strategy (S_0), strategy S_5 (60% coverage), and strategy S_6 (70% coverage). The results obtained are shown in Appendix IV and Figure 13. In Figure 13, the yield series for the worst and the best decades are shown in the bottom diagrams. Plots of net farm incomes for the basic strategy, strategy S_5, and strategy S_6 are shown directly above their respective yield diagrams. The strong interrelationship between crop yields and net farm income is evident in the diagrams and this is more pronounced for the best situation, where the generated net farm incomes for the three strategies followed similar patterns as the yield values used. Under drought conditions, some amount of crop insurance coverage is advantageous, since the net farm incomes for years with very low yields are improved by the indemnity paid to the farmer (Figure 13A and Appendix IV), whereas under favourable conditions the net farm income is reduced by the amount of insurance premium paid (Figure 13B and Appendix IV). Comparing the two extreme conditions, one may be tempted to be indifferent to purchasing and not purchasing crop insurance. But it is not difficult to see the long-run benefits which may be derived from carrying crop insurance as long as the area under study is drought prone. This observation is further clarified in the mean-standard deviation analysis which follows.

FIGURE 13

Diagrams of Net Farm Incomes and Corresponding Yield Series



A B

6.2 Mean-Standard Deviation Analysis

The procedure for evaluating the adjustment strategies on the basis of mean-standard deviation efficiency can be represented in the form of a box of dimensions 10 x 10 x 15. For each strategy, the farm business was evaluated for the projected 10 year period, 1982-91, and the equity position at the end of 1991 was selected. This was replicated 10 times using 10 sets of randomly selected yield series to obtain 10 ending equity positions. From these, expected (or mean) equity value and its standard deviation[1] were computed. This process was first performed on the debt-free situation and for all fifteen strategies, and then repeated for the other levels of debt situation, namely the low debt situation, the medium debt situation and the high debt situation. Four experiments were conducted, each for a different debt load. The detailed results for the basic strategy (S_0) are given in Table 8. The figures in column 1 (yield series) relate to the yield values selected for the run. For instance yield series 55 would mean that the yield values used for the run were from 1955 to 1964, and so on.

The high debt situation, under the basic strategy, resulted in bankruptcy in seven of the ten replications and in a real decline in equity in the remaining three. The debt

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[1] For this analysis, the standard deviation (or the square root of the variance) is used since it is a simpler concept and also because of the size of the variances involved. As was observed earlier, both the variance and the standard deviation measure the level of risk in a particular operation. The greater the variance (or the standard deviation), the greater the risk.

TABLE 8

Simulated Equity Positions after 10 Years Operation for the Case Farm (Basic Strategy)

YIELD SERIES	DEBT-FREE	LOW DEBT	MED. DEBT	HIGH DEBT[1]
55	967082	876794	788009	0 (91)
49	767651	662121	541278	0 (87)
60	862857	760181	649446	0 (88)
50	940904	848740	757560	0 (90)
71	1205414	1125834	1051406	436049
63	1167730	1087157	1011169	318248
55	967082	876794	788009	0 (91)
48	555186	421775	283140	0 (86)
52	957040	868397	780366	0 (91)
64	1178264	1097564	1020890	330652
Exp. Equity	956921	862536	767127	108495
Stand. Dev.	190185	205076	224723	168238
Beg. Equity	725199	682040	648297	465199
Exp. Growth Rate[2] (%)	2.8	2.4	1.7	n.a.

[1]Equity values of zero indicate bankruptcy has occured. The year of bankruptcy within the current run is indicated in parenthesis.

[2]For any particular year, growth rate is measured as the change in equity (i.e. ending equity less beginning equity) expressed as a percentage of the beginning equity. Over a ten year period, % growth rate is the average annual compound rate.

load was so overwhelming that net income was generally insufficient to provide for family living and debt servicing.[1]

The generated mean and standard deviation values for all the strategies and the four debt situations are are provided in Tables 9 and 10. The corresponding coefficients of variation are presented in columns 4 and 7 of each table. The coefficient of variation is the ratio of standard deviation to its mean. It is a relative measure of risk, with the less risky strategies having low coefficients of variation, and the more risky strategies with high coefficients. The coefficient of variation is useful for ranking risky prospects but it cannot be used for separating between dominated and undominated strategies. This can be achieved by plotting the strategies in a mean-standard deviation space as shown in Figures 14 to 17. In the figures, the coefficient of variation of a particular strategy is measured as the gradient of a line which passes through the origin and the coordinates of the strategy. By comparison, the arrangement of the strategies is similar in Figures 14, 15, and 16. From the three diagrams it may be observed that as the debt load is increased, the strategies move in the north westerly direction. This situation arises from the fact that equity is defined as the difference between assets and debt. Therefore as the debt increases,

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[1] Actually, the decline in equity would have been smaller, and the cases of bankruptcy would have been fewer, if inflation of prices and costs had been considered.

TABLE 9

Generated Means, Standard Deviations (S.D.) and Coefficients of Variation (C.V.) of Ending Equity Values (Debt-Free and Low Debt Situations)

	DEBT-FREE			LOW DEBT		
STRAT	MEAN	S. D.	C.V.	MEAN	S.D.	C.V.
S_0	956921	190185	.20	862536	205076	.24
S_1	944097	203956	.22	848886	219465	.26
S_2	935333	211433	.23	839275	227476	.27
S_3	665715	319952	.48	563391	313943	.56
S_4	575407	289855	.50	466416	285287	.61
S_5	977667	141185	.14	885441	152081	.17
S_6	981994	128848	.13	890429	138516	.16
S_7	890036	143652	.16	807306	158267	.20
S_8	965822	151339	.16	872324	163359	.19
S_9	968729	139435	.14	876212	149797	.17
S_{10}	957363	157157	.16	862906	169846	.20
S_{11}	959728	145135	.15	866302	156221	.18
S_{12}	689343	250873	.36	571269	274373	.48
S_{13}	689484	236027	.34	570762	259451	.45
S_{14}	914718	91909	.10	836151	99829	.12

TABLE 10

Generated Means, Standard Deviations (S.D.) and Coefficients of Variation (C.V.) of Ending Equity Values (Medium Debt and High Debt Situations)

	MEDIUM DEBT			HIGH DEBT		
STRAT	MEAN	S. D.	C.V.	MEAN	S.D.	C.V.
S_0	767127	224723	.29	108495	168238	1.55
S_1	752408	239905	.32	116611	179000	1.54
S_2	741723	248564	.34	118081	181003	1.53
S_3	458780	316303	.69	7495	12246	1.63
S_4	360158	282343	.78	0	0	-
S_5	793022	167450	.21	92909	145705	1.57
S_6	798056	153509	.19	84563	133702	1.58
S_7	725442	177683	.24	118037	181828	1.54
S_8	778394	179226	.23	99911	154296	1.54
S_9	782259	165363	.21	91216	141354	1.55
S_{10}	767495	186026	.24	101149	155567	1.54
S_{11}	770418	172396	.22	92067	141879	1.54
S_{12}	456078	290883	.64	0	0	-
S_{13}	450226	283559	.63	0	0	-
S_{14}	758354	113580	.15	99595	154875	1.56

FIGURE 14

Plot of Adjustment Strategies (the Debt-Free Situation)

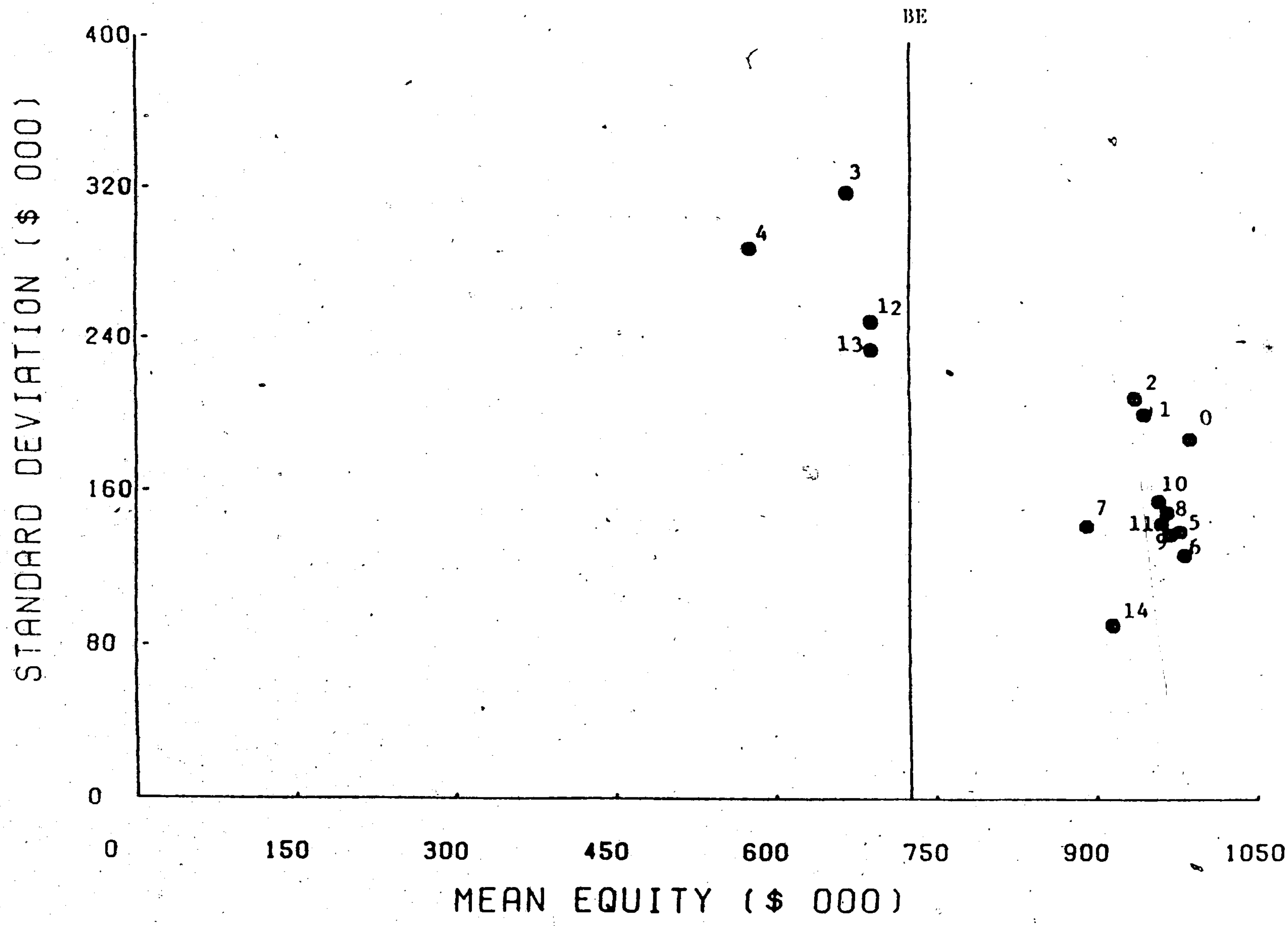


FIGURE 15

Plot of Adjustment Strategies (the Low Debt Situation)

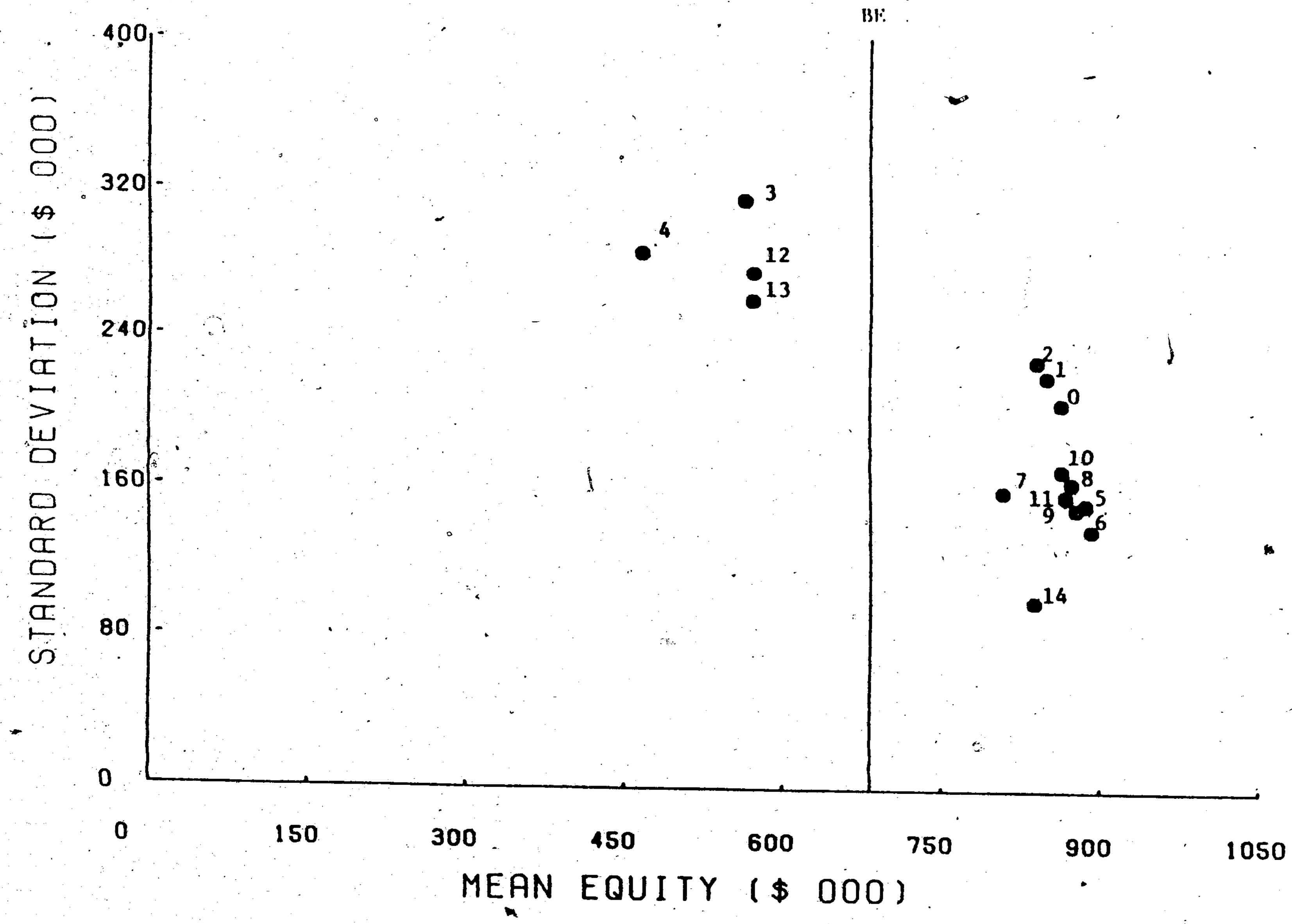
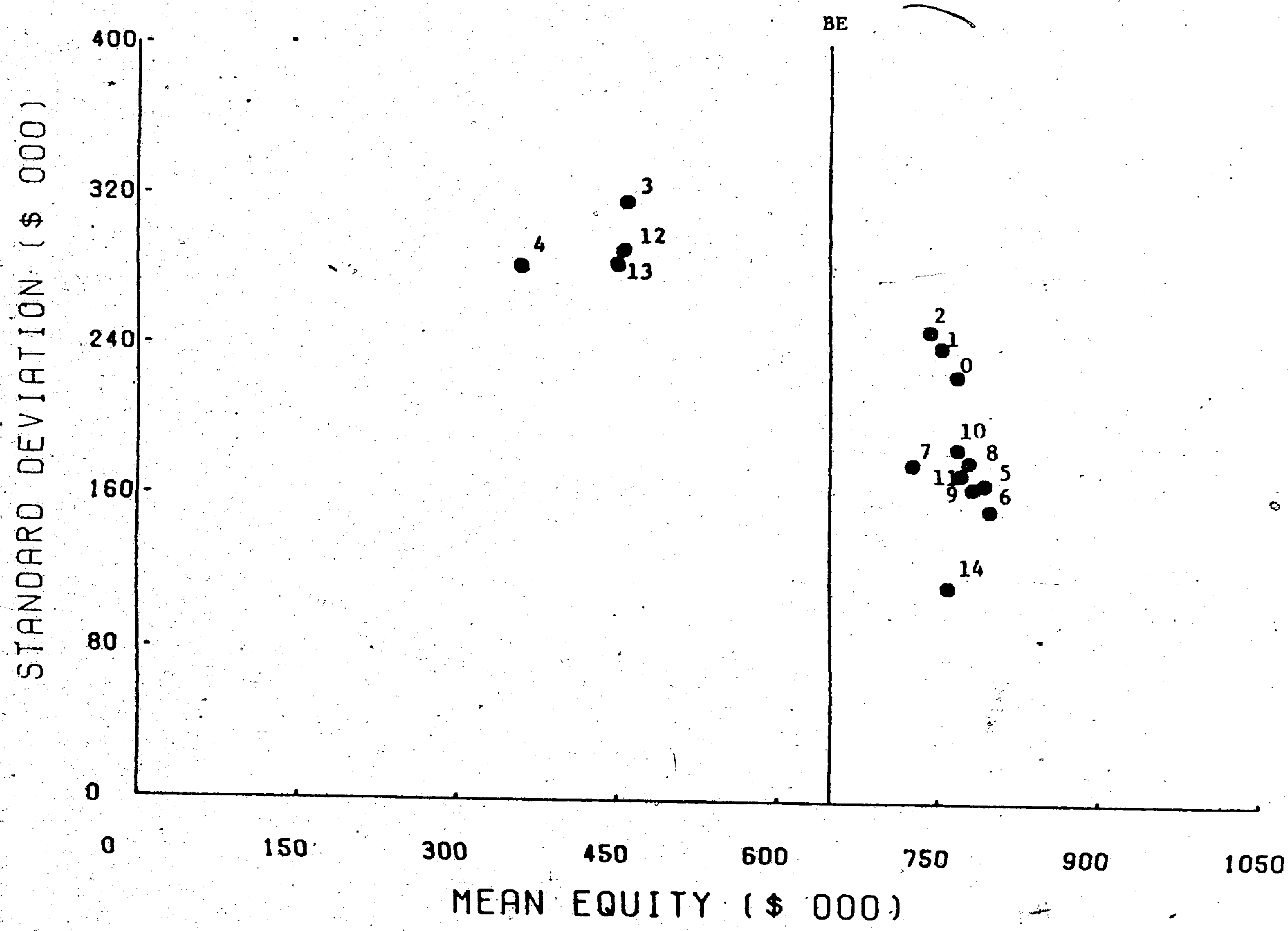


FIGURE 16

Plot of Adjustment Strategies (the Medium Debt Situation)



equity decreases and causes the points to move leftwards. Based on stochastic dominance criteria discussed in Chapter 3, the following general observations can be made for Figures 14 to 16:

1. That the 1/2 summerfallow - 1/2 crop rotation dominates all other crop rotations tested.
2. That the high machinery replacement practice appears to be inferior and is accentuated in periods of drought. Hence purchase of machinery during drought will in general produce an inferior strategy (S_4), such that S_0 dominates S_4.
3. That crop insurance purchase increases ending equity position and reduces risk so that the 70% coverage is dominating,
4. That the two levels of consumption belonged to the same efficient set - i.e. S_6 does not dominate S_{14} (and *vice versa*), and S_0 does not dominate S_7 (and *vice versa*).

The vertical line (BE) marks the position of the beginning equity. Strategies to the right of this line would result in the growth of the farm business and therefore put the farmer in a more favourable position after ten years of operation than he started with. On the basis of this, strategies S_3, S_4, S_{12}, and S_{13} would result in poor performance of the farm business. The beginning equity values for the four debt situations are shown in Table 4.

The high debt situation resulted in several cases of bankruptcy, as was observed earlier and evidenced by Figure

17 and Tables 8 and 10. Table 10 reveals that the strategies in general produced fairly constant coefficients of variation of a value greater than unity. Since the coefficient of variation also measures the slope of a line through the origin and the coordinates of each strategy, constant values of the coefficient of variation indicate that the strategies are arranged on a line passing through the origin (Figure 17).[1] No strategy dominates the other and, as a result, all the strategies belong to the same efficient set.

The high debt situation represent the expected performance of a farmer who starts his operation with heavy reliance on debt financing. The results indicate that under such condition the possibility of business failure is great. Since all 15 strategies are positioned far to the left of the beginning equity position, as shown in Figure 16, ending equity positions are much lower than beginning equity, and growth in farm equity is greatly depressed, hence the high rates of bankruptcy. Table 11 presents values of mean growth in equity over the simulated ten year production period for all strategies and all debt situations. The growth rate values (in absolute terms) are directly related to the horizontal distance of each strategy from the beginning equity positions shown in Figures 14 to 17, and inversely related to the level of farm indebtedness as may be observed

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[1] It is worth noting that this arrangement of the strategies was the result of the constraint imposed on the equity values.

FIGURE 17

Plot of Adjustment Strategies (the High Debt Situation)

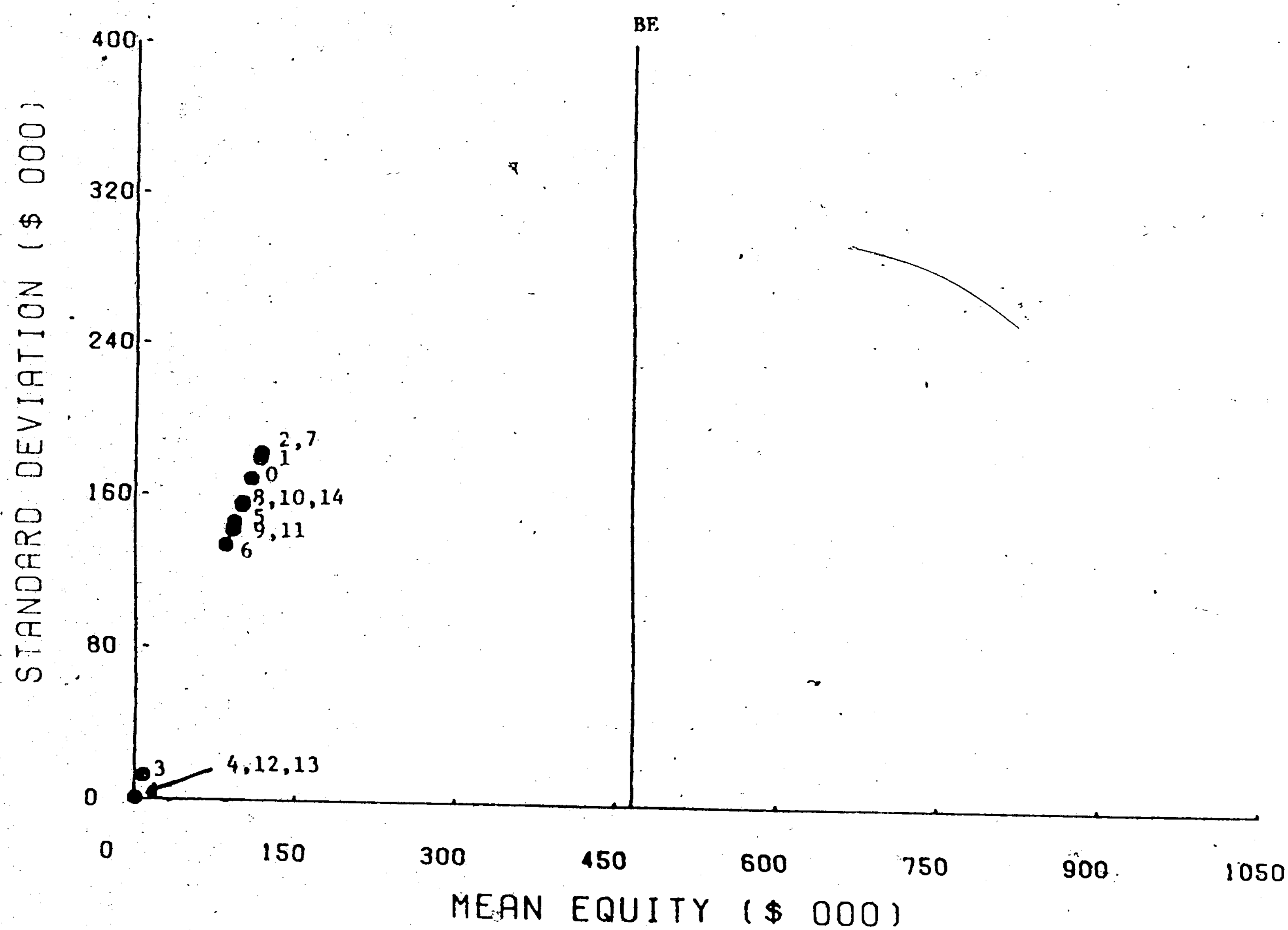


TABLE 11

Expected Growth Rates (% p.a.) of the Case Farm Business After Ten Years of Operation (All Strategies and Debt Situations)

Strat[1]	DEBT FREE	LOW DEBT	MED. DEBT	HIGH DEBT
S_0	2.81	2.38	1.70	-13.55
S_1	2.67	2.21	1.50	-12.93
S_2	2.58	2.10	1.36	-12.81
S_3	-0.85	-1.89	-3.40	-33.82
S_4	-2.29	-3.73	-5.71	-
S_5	3.03	2.64	2.04	-14.88
S_6	3.08	2.70	2.10	-15.68
S_7	2.07	1.70	1.13	-12.82
S_8	2.91	2.49	1.85	-14.26
S_9	2.94	2.54	1.90	-15.03
S_{10}	2.82	2.38	1.70	-14.15
S_{11}	2.84	2.42	1.74	-14.96
S_{12}	-0.51	-1.76	-3.46	-
S_{13}	-0.50	-1.77	-3.58	-
S_{14}	2.35	2.06	1.58	-14.28

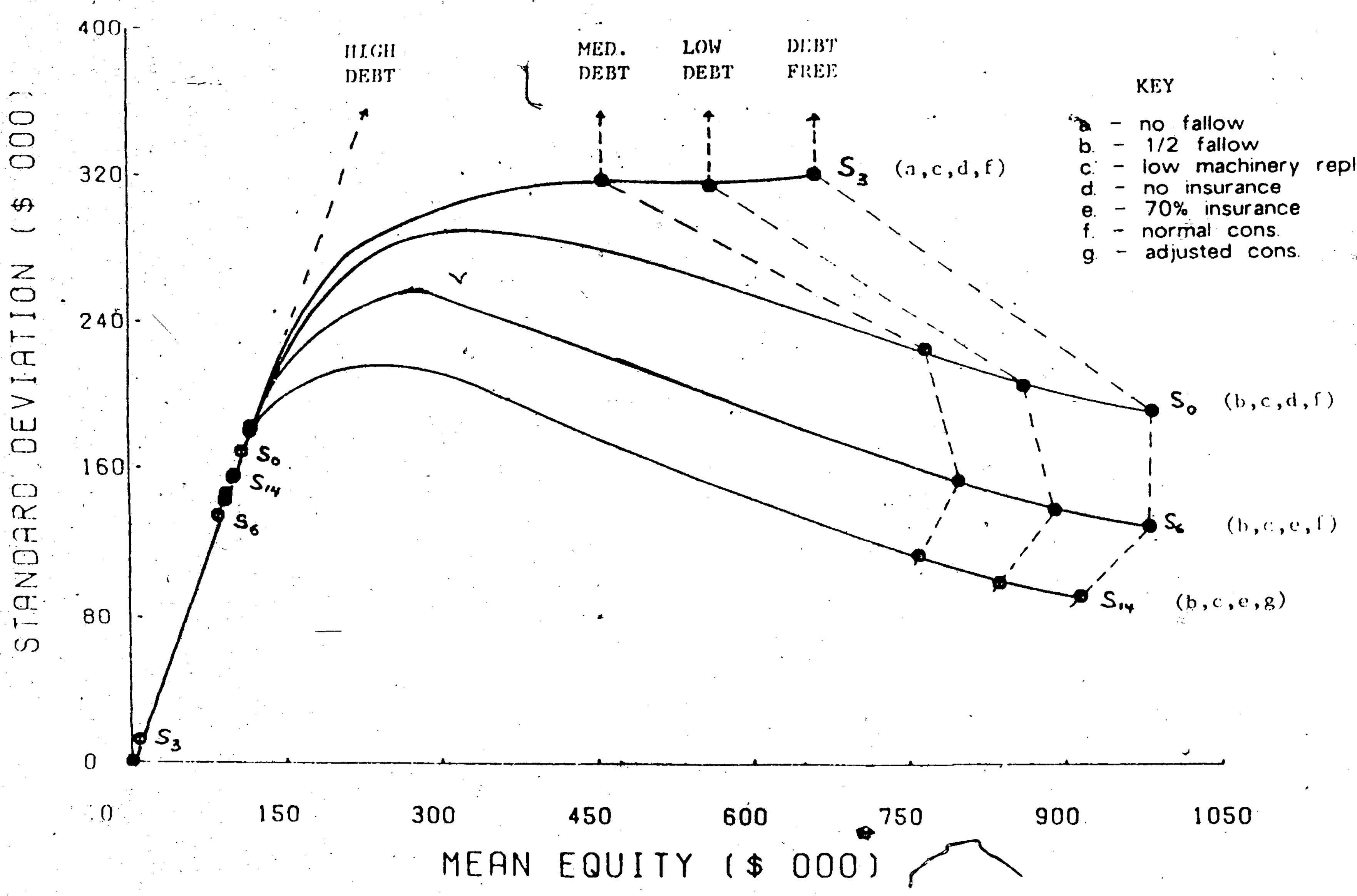
[1] Strategies have been described in Table 7

in Table 11. Business growth may never be achieved if farm indebtedness is high enough, and this situation must be avoided as much as possible. Similarly, the poor results produced by strategies 3, 4, 12 and 13 eliminate them from any consideration.

The paths of the strategies from the debt-free situation to the high debt situation may be traced for strategies S_0, S_3, S_6 and S_1[illegible] as shown in Figure 18. The broken lines join points with the same debt load. For clarity, only four strategies were selected for analysis, and similar paths could be traced for the other strategies. Figure 18 confirms previous observation that attempts at business growth through excessive use of debt financing increases exposure to risk. As the debt load increases, the coeffic[illegible]riation of each strategy also increases. Therefo[illegible]ncreases, which makes the farmer more vulnerab[illegible]e effects of drought. Figure 18 also reveals that any [illegible]e aimed at helping the farmer improve on his equity pos[illegible]on may first result in increasing risk at a faster rat[illegible]and as equity is increased sufficiently, risk levels off[illegible] decreases. Figure 18 is important since it represents four farms of similar size but differing in their level of d[illegible]t obligations. Alternatively, the figure may be used to represent the performance of a farm, with fixed management practice, from its inception, when debts were very high, to the point where the business is fully established and carries no debt load or the point of

FIGURE 18

Paths of Selected Strategies from Debt-Free Situation to High Debt Situation



transfer.

6.3 Concluding Remarks

The objectives of the study, as stated in Chapter 1, are to develop methodology for determining the impact of drought on farm business and to evaluate farm management strategies in terms of farm growth and risk. The results presented in this chapter indicate that both objectives have been realized, especially since growth patterns of the case farm operation under drought conditions have been traced in a simulated way. Furthermore, the study was able to achieve results using actual yield data recorded on the case farm. Such data present a better reflection of drought impacts at the farm level than regional (average) data, since the farm data show greater variability.

7. SUMMARY, CONCLUSIONS AND RECOMMENDATIONS

The study is addressed to the problem associated with the occurrences of drought on the Canadian prairies. Emphasis is placed on the determination of drought impacts at the farm level, and involves tracing the potential growth patterns of grain farms using simulation methodology. The study also focuses on the evaluation of drought management strategies, developed by prairie farmers over the years, with respect to the criteria of business growth and survival. This chapter presents summary and conclusion of the study and discusses possible ways of improving on the farmers' capacity to cope with drought. The chapter also discusses ways of improving on the methodology used in the study.

7.1 Summary and Conclusion

The objectives of the study are to develop methodology for evaluating the impact of prairie droughts on the business, and to identify and evaluate alternate management strategies that farmers might follow in order to minimize the impact of drought and ensure the long-run survival of the farm business. The objectives and hypotheses are outlined in Chapter 1, together with a discussion of the problem and its analysis. A review of the history of prairie droughts and previous efforts toward the development of drought mitigation techniques is presented in Chapter 2.

The first objective, to develop methodology for evaluating drought impacts, is accomplished with the aid of the dryland crop simulation model, which was developed by Agriculture Canada, Lethbridge, Alberta. The model served as the basis from which a model, capable of handling a wider range of crop yields obtained outside the model, was developed. The processes involved in the development of the methodology and a discussion of the major steps followed in this study are presented in Chapter 4. The procedure followed involves the selection of a typical dryland grain farm as the case farm and an interview with the case farmer to determine the specifics of his operation and to identify the basic strategy followed and other drought management strategies available to him. The basic management practices of prairie farmers, in general, have drought adjustment strategies built into them, and the study is concerned with evaluating the strategies in terms of two management goals of business growth and survival. The case farm operation and the identified strategies are described in Chapter 5.

The strategies are evaluated in terms of their means and standard deviations, using the *E-V* analysis discussed in Chapter 3. The modified simulation model is employed for analysing the identified strategies. Four series of simulations are conducted, each representing a different level of debt load, namely, debt-free, low debt, medium debt and high debt situations. A detailed account of the evaluation process and the results of the analysis are presented in Chapter 6.

From the results of the analysis it is clear that unfavourable climatic conditions (such as drought) resulting in lower crop yields affect the net farm income adversely, thereby reducing the farmer's capacity to re-invest in the farm operation. The study identifies three essential components of farm management strategy under drought conditions, namely

1. the inclusion of fallow in the crop rotation programme (particularly the 1/2 crop - 1/2 fallow rotation),
2. the purchase of crop insurance coverage, and
3. the postponement of certain cost related activities such as machinery purchase or building repairs.

A fourth item, consumption variation, could not be included because the results obtained for the case farm were inconclusive, as explained below. If a farmer's consumption withdrawals are sufficiently reduced during drought periods, then it is possible to consider reduced consumption withdrawals as part of the adjustment strategy. Specifically, the following conclusions may be drawn:

1. Drought can be considered normal and adjustments are part of the basic strategy.
2. Some improvements to the basic strategy appear possible by carrying crop insurance.
3. The annual adjustments made are mainly to postpone machinery replacement decisions and reducing level of consumption during times of drought.
4. The combined effects of high indebtedness and high rates

of interest preclude real business growth and, in the event of severe drought, ensure business failure or bankruptcy.

7.2 Recommendations of the Study

The recommendations of the study concern the farmer and the model used for evaluating the strategies. In the case of the latter, the recommendations mainly focus on ways of handling the adjustment strategies more efficiently.

7.2.1 Suggestions for Improving on Farm Business Performance under Drought Conditions

The results of the study identify two important areas where government intervention may be beneficial to prairie grain farmers. The first stresses the need for provincial extension services to place greater emphasis on training farmers in the general principles of farm management, particularly farm financial management. Improved knowledge of farm financial management principles is essential since farmers would be better able to manage their loan requirements and regulate their cash flows so that adequate cash reserves are maintained to protect the farm against the adverse effects of drought. For example, improved financial management techniques will put the farmer in a better position to handle decisions regarding machinery replacement and consumption withdrawals, which form part of drought adjustment strategies. With adequate cash reserves, a farm business may be able to survive without the need to carry any crop insurance.

The second point relates to the crop insurance programme, which the case farmer considers inadequate. The study reveals the importance of crop insurance, in drought management strategies, in cases where cash reserves are generally low and recommends the need to conduct research into the adequacy of an all-risk crop insurance programme for prairie farmers.

7.2.2 Suggestions for Further Development of the Model

The study has a number of shortcomings which mainly arise from the fact that the basic simulation model used was not developed specifically for a study such as this. Time constraints prevented the development of a model that adequately incorporates drought mitigation strategies.

The drawbacks of the grain model as far as this study is concerned relate to the presence of rigidities in the dynamic nature of the model which do not permit the timing of the adjustment strategies to coincide with the actual drought years. For instance, such activities as consumption withdrawals, machinery replacement, changes in crop inventories, and the number of summerfallow operations are determined by the model user at the beginning of the simulation run or by the model during the run, and cannot be changed once the simulation has begun. Future drought studies may rectify this problem so that changes or adjustments to drought may be made during the course of the run, and to coincide with the corresponding drought years. Particular attention may be given to the how consumption behaviour and machinery decisions may be handled, since they are important components of adjustment strategy. This study used other approaches to overcome this problem, as explained below.

The nature of the consumption behaviour as built into the simulation model is of the Keynesian form and permits high consumption withdrawals in high income years and lower withdrawals in poor years. The two consumption options evaluated withdraw the same amount ($13,000) for consumption at a net income of $10,000. Consumption withdrawals appear to be greater in strategies S_7 and S_{14} than in strategies S_0 and S_4 respectively, hence lower equity values for S_7 and S_{14}. These results were obtained because of the form of the adjusted consumption function obtained from the farmer. It is possible that with suitable slope for the function, consumption withdrawals may be sufficiently reduced during the poor years to cause the mean equity values for S_7 and S_{14} to be respectively greater than those of S_0 and S_4, and for the former strategies to dominate the corresponding strategies in the latter pair.[1]

The crop model allows the farmer to indicate the level at which he would normally sell or replace his machinery. In

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[1] This is true because consumption behaviour varies among individuals and is influenced, *inter alia*, by the individual time preference.

this case, the farmer noted that he would replace his machinery at 87% of maximum useful life. With the machinery available on the case farm, there was no need for machinery replacement within the ten year period for which the basic simulation run was made. To evaluate the impact of machinery purchase on the ending equity positions, the farmer's machine replacement policy was changed and, with the help of the case farmer, an alternate policy which permitted machinery replacement at 50% of maximum useful life was used. As a result, it was made possible for machinery to take place during the 10 year run. Undoubtedly, this approach of handling machinery replacement decisions during drought periods may be improved as suggested above.

Finally, subsequent studies may also consider the use of the model to track the potential merits of practices, such as the use of snow management techniques on stubble land, and the use of windbreaks and shelterbelts to prevent soil moisture loss and soil erosion.

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APPENDIX I:QUESTIONNAIRE

Think of drought as inadequate levels of moisture at the critical time in crop and livestock production resulting in output levels below normal.

1. Do you agree with the following statements ? "It is possible for me to predict the occurrence of a drought, based upon conditions in the

	disagree				agree
"a) previous autumn	1	2	3	4	5
"b) previous winter	1	2	3	4	5
"c) early spring(prior to seeding)	1	2	3	4	5
"d) late spring(after seeding)	1	2	3	4	5
"e) summer"	1	2	3	4	5

2. If you agree, or agree in part (a score of 3 or better), with the statements above what indicators of drought do you use in the

a) previous autumn ? ________________________________

____

____

b) previous winter ? ________________________________

____

____

c) early spring (prior to seeding) ? ______________________

____

____

d) late spring (after seeding) ? ______________________

____

____

e) summer ? ______________________________________

____

____

3. What adjustments do you make to your production management practices if you have predicted a drought in the

a) previous autumn ? ______________________________

____

____

b) previous winter ? ______________________________

____

____

c) early spring (prior to seeding) ? ______________________

____

____

d) late spring (after seeding) ? ______________________

____

____

e) summer ? ______________________________________

____

____

4. What adjustments do you make to your marketing management

practices if you have predicted a drought in the

a) previous autumn ? ______________________________

____

____

b) previous winter ? ______________________________

____

____

c) early spring (prior to seeding) ? ________________

____

____

d) late spring (after seeding) ? ___________________

____

____

e) summer ? ____________________________________

____

____

5. What adjustments do you make to your financial management practices if you have predicted a drought in the

a) previous autumn ? ______________________________

____

____

b) previous winter ? ______________________________

____

____

c) early spring (prior to seeding) ? ________________

____

____

d) late spring (after seeding) ? ______________________________

____

____

e) summer ? ____

____

____

APPENDIX II: WHEAT YIELDS ON FALLOW AND STUBBLE IN BU/AC

YEAR	FALLOW[1]	STUBBLE[2]
1947	4.0	*1.5
1948	3.0	*1.0
1949	4.0	*1.5
1950	*12.3	*6.1
1951	*15.4	*7.7
1952	*20.0	*10.2
1953	30.0	*15.7
1954	*7.6	*3.5
1955	28.0	*14.6
1956	*18.0	*9.1
1957	18.6	*9.5
1958	19.5	6.0
1959	23.0	9.3
1960	11.3	6.9
1961	4.9	2.6
1962	14.5	6.8
1963	23.0	12.0
1964	17.5	6.9
1965	22.0	17.2
1966	30.0	19.5
1967	18.0	10.4
1968	27.5	8.2
1969	22.5	11.7
1970	29.0	15.0
1971	23.0	11.5
1972	22.5	12.1
1973	27.0	11.5
1974	27.0	18.1
1975	27.0	12.5
1976	15.0	8.6
1977	20.4	8.7
1978	30.0	16.5
1979	30.3	17.2
1980	20.0	10.3
1981	21.7	*11.1

[1] Source: Farmer's own records.

[2] Source: Statistics Canada - Wheat yields on stubble for Crop District 4B, Saskatchewan.

* Data were not available for these years. Figures represent estimates from regression analysis.

APPENDIX III: COMPUTER PROGRAMMES FOR SELECTING YIELD SERIES AND FOR CALCULATING MEANS AND STANDARD DEVIATIONS

```
C     THIS PROGRAM SELECTS A SERIES OF CROP YIELDS
      DIMENSION YIELD(50,12),XYIELD(10,12),IYEAR(10)
      WRITE(9,9990)
 9990 FORMAT(' INPUT RANDOM SEED ')
      READ(4,1001) K
      DO 100 I=1,35
      READ(5,1000) (YIELD(I,J),J=1,12)
  100 CONTINUE
      DO 500 II=1,10
      X=URAND(K)
      WRITE(9,9999) II,K,X
 9999 FORMAT(I8,I15,F12.6)
      L=25*X
      WRITE(9,9999) L
      DO 200 M=1,10
      DO 200 J=1,12
      I=M+L
      IYEAR(M)=I+46
      XYIELD(M,J)=YIELD(I,J)
  200 CONTINUE
      WRITE(9,1002) (IYEAR(M),M=1,10)
      WRITE(6,1002) (IYEAR(M),M=1,10)
      DO 300 J=1,12
      N=43+J
      WRITE(6,1005) N,(XYIELD(M,J),M=1,10)
  300 CONTINUE
  500 CONTINUE
 1000 FORMAT(12F10.1)
 1001 FORMAT(I5)
 1002 FORMAT(' ',10I7)
 1005 FORMAT(I2,10F7.1)
 1010 FORMAT(F15.5,I15)
      STOP
      END
```

```
C     THIS PROGRAM COMPUTES MEANS AND STANDARD DEVIATIONS OF EQUITY
      DIMENSION EQUITY(12,3),K(12)
 9998 FORMAT(I10,2F10.0,F10.2)
      DO 50 I=1,12
      K(I)=0
      DO 50 J=1,3
      EQUITY(I,J)=0.0
   50 CONTINUE
      DO 100 I=1,10
      READ(7,9998)K(I),(EQUITY(I,J),J=1,2)
  100 CONTINUE
      DO 110 I=1,10
      EQUITY(11,2)=EQUITY(11,2)+EQUITY(I,2)
      EQUITY(12,2)=EQUITY(12,2)+EQUITY(I,2)**2
      IF (EQUITY(I,2).GT.0.0) GO TO 105
      EQUITY(I,3)=0.0
      GO TO 110
  105 EQUITY(I,3)=(((EQUITY(I,2)/EQUITY(I,1))**0.1)-1.0)*100.0
  110 CONTINUE
      EQUITY(11,2)=EQUITY(11,2)/10.0
      EQUITY(12,2)=SQRT((EQUITY(12,2)-10.0*EQUITY(11,2)**2)/10.0)
      EQUITY(11,1)=EQUITY(1,1)
      IF(EQUITY(11,2).GT.0.0) GO TO 120
      EQUITY(11,3)=0.0
      GO TO 125
  120 EQUITY(11,3)=(((EQUITY(11,2)/EQUITY(11,1))**0.1)-1.0)*100.0
  125 DO 130 I=1,12
      WRITE(6,9998) K(I),(EQUITY(I,J),J=1,3)
  130 CONTINUE
      STOP
      END
```

APPENDIX IV: NET FARM INCOMES ($) FOR SELECTED STRATEGIES AND YIELD SERIES (BU/AC)

	S_0		S_5		S_6		YIELD	
SERIES	48	71	48	71	48	71	48	71
1982	-19310	54460	6028	52568	11428	51635	3.0	23.0
1983	-20639	48860	3741	46968	9142	46036	4.0	22.5
1984	-23481	61434	-15323	59542	-14459	58609	12.3	27.0
1985	-19127	60829	-7828	58937	-6045	58004	15.4	27.0
1986	1260	65266	15033	63374	17292	62441	20.0	27.0
1987	40070	20645	56777	18753	59277	17820	30.0	15.0
1988	-35790	41363	-6812	39471	139	38538	7.6	20.4
1989	48803	64645	70934	62753	70001	61821	28.0	30.0
1990	-13576	70644	10164	68752	9581	67819	18.0	30.3
1991	9902	41711	33308	39819	32375	38886	18.6	20.0