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An Economic Analysis of Alternative Cropping Decisions Under Uncertainty

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ABSTRACT

This project has examined after tax gross margin net present values accruing to Alberta wheat farmers under three fertilizer and crop rotation systems; a fixed rotation traditional fertilizer system, a static economic fertilizer decision system within a fixed rotation, and a static economic fertilizer decision system within a dynamic flex-cropping framework. Decision rules appropriate to each system were developed for case farms in three Alberta agro-climatic regions; Medicine Hat, Lethbridge and Olds.

The flex-cropping issue is expressed in a dynamic programming framework and incorporates elements not fully explored in previous studies; income taxation, variable input level decisions and stochastically determined moisture conditions and crop prices. Decisions are compared by simulating net present values of after tax gross margins for each system. The traditional system generated the lowest net present value, approximately 5 to 17 per cent below the static economic system. Greater improvements, on the order of 14 to 31 per cent above the static economic system, were observed by following dynamic flex-cropping decision rules. Not only did the dynamic flex-cropping decision rules generate superior decision rules regarding mean net present values, the rules were also risk efficient. The probability of low gross margins was minimized in all cases by following the dynamic flex-cropping decision rules.

The results of this and related studies indicate that dynamic flex-cropping models are viable for solving crop scheduling problems. The prescriptive power of the model is limited by available data, limitations which reside primarily in the agronomic components. The relationship between spring soil moisture, soil nutrients, and yield must be more clearly defined. This may be accomplished through extensive and long term field trials or through use of emerging biophysical models. Standardization of soil moisture classifications, including method of sampling and depth of measurement, would make field data more adaptable for making fertilizer and recropping decisions. The production functions defining the relationship between spring soil moisture levels and yields are particularly important. These require continued empirical attention.

The model developed lends itself readily to extensions such as additional crops, fertilizer inputs, erosion costs and soil degradation issues, financial structure of the farm, and evaluating the influence of government programs. Modern computers with large computational and storage capabilities make the implementation of stochastic dynamic programming methodology a viable farm management tool.

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1 INTRODUCTION

Summer fallowing is practiced in the arid regions of the prairies to accumulate a store of soil moisture and to increase soil nitrogen levels through the process of mineralization thereby reducing the probability of crop failure and lowering the cost of inputs. This long standing cultural practice is being challenged due to the growing concerns about soil degradation which occur from the associated processes of soil erosion and salinization (Rennie, 1986).

In arid regions periodic fallowing provides improved weed control, reduced fertilizer requirements, and reduced variability of returns (Young and van Kooten, 1989; Burt and Stauber, 1989). Traditionally, farmers in different parts of the prairies have followed rigid rotations of crop-fallow. While the exact proportion of fallow to crop varies from area to area the rotation is generally the same from year to year within a given region.

Considerable research has been done into the economics of flex-cropping, a system which allows periodic fallowing without imposing a rigid rotation (Brown et al, 1981). In flex-cropping the decision of whether or not to crop is based on some criterion such as soil moisture at seeding time (Taylor and Novak; Brown et al, 1981; Burt and Allison, 1963) in addition to previous year's crop.

Studies to date (Burt and Allison, 1963; Burt and Johnson, 1967; Burt, 1981; Burt and Stauber, 1989; Weisensel, van Kooten, and Schoney, 1991, Young and van Kooten, 1988; Young and van Kooten, 1989; Taylor and Novak) have suggested that guiding decisions with dynamic flex-cropping models will increase the present value of net returns over the planning horizon although the variability of returns is generally higher than with other decision criteria. The studies reviewed have been limited in their scope and have thus not been able to model actual farm situations completely. All but one of the studies have developed field level models that may not adapt well to farm level planning. Except in one of the studies, income tax and crop storage have not been dealt with. None of the studies cited has incorporated variable inputs such as fertilizer. Testing of decision rules through stochastic simulation to compare wealth accumulation over the planning horizon has received only limited attention.

Although work to date has shortcomings, dynamic flex-cropping models show promise in solving crop scheduling problems. This study attempts to address these issues in the Alberta agricultural setting.

The objective of this research is to address these deficiencies by comparing three alternative decision systems in terms of differences in net present values. The three decision systems are:

1. the traditional system in which the farmer follows a rigid crop-fallow rotation and uses a fixed amount of fertilizer each year without regard to either moisture or economic conditions.
2. the static economic system in which the farmer follows a rigid crop-fallow rotation but adjusts fertilizer use to spring soil moisture conditions and crop and fertilizer prices.
3. the dynamic flex-cropping system in which the farmer adjusts both fertilizer use and the proportion of cropped land to fallow in response to spring soil moisture, available stubble acres, and crop and fertilizer prices.

Three farm businesses in each of three agro-climatic zones of Alberta will be defined, the specific decision rules will be elaborated and resulting net present values compared through stochastic simulation.

2 DESCRIPTION OF DECISION SYSTEMS

Three distinct cropping decision practices characterized as traditional, static economic, and dynamic flex-cropping are considered in this project.

2.1 The traditional decision system

The traditional system assumes a fixed rotation through time. In the Medicine Hat and Lethbridge regions the rotation is crop-fallow. In any given year one half of the farm is in crop and the other in fallow. In the Olds region the entire acreage is planted each year.

The system assumes a constant amount of available nitrogen (initial soil nitrogen plus the amount applied) each year. In the Medicine Hat region this is 75 lbs per acre of total nitrogen, in Lethbridge 85 lbs per acre and in Olds 115 lbs per acre. The initial soil nitrogen at planting time is assumed to be 50 lbs per acre on fallow and 10 lbs per acre on stubble at each of the three locations. Fertilizer costs $0.20 per lbs.

2.2 The static economic decision system

The crop rotation under the static economic decision system is identical to that followed in the traditional system. A crop-fallow system is followed for the Medicine Hat and Lethbridge regions and a continuous crop rotation for the Olds region.

Crop yields on fallow and on stubble, in this system, depend upon the amount of spring soil moisture and on the level of applied nitrogen. Consequently fertilizer decisions respond to economic and soil moisture conditions.

$$Y_{f,t} = \vartheta(M_{f,t}, N_{f,t})$$

$$Y_{s,t} = \vartheta(M_{s,t}, N_{s,t})$$

Y is the expected yield in the tth year, M is soil moisture, and N the amount of nitrogen fertilizer applied. The subscripts f and s respectively refer to fallow and stubble. Profit functions for crop on fallow and on stubble are obtained by including prices and costs.

$$\pi_{f,t} = p_t Y_{f,t} - r_t N_{f,t}$$

$$\pi_{s,t} = p_t Y_{s,t} - r_t N_{s,t}$$

π represents expected profit, p_t the expected price of wheat in the current period, and r_t the unit cost of fertilizer.

The fertilizer level is decided each year by measuring the spring soil moisture M and equating the expected value of the marginal product of fertilizer, conditional on spring soil moisture, to the marginal factor cost of fertilizer. The appropriate level of nitrogen fertilizer N is determined by solving the first order partial derivative.

$$p_t\left[\frac{\partial Y_{f,t} \mid M_t}{\partial N_{f,t}}\right] = r_t$$

$$p_t\left[\frac{\partial Y_{s,t} \mid M_t}{\partial N_{s,t}}\right] = r_t$$

Fertilizer is the only variable cost item of interest. All other costs, such as seed, weed control, tillage and harvest operations, and capital costs are assumed unaffected by the fertilizer decision.

Because of the nature of technical production and economic relationships one would expect nitrogen fertilizer level to be increased in years when expected prices and/or spring soil moisture are high. In years when soil moisture and/or expected prices are low the level of nitrogen fertilizer would be decreased.

2.3 The dynamic flex-cropping system

Under the dynamic flex-cropping system fertilizer decisions are made in the manner outlined for the static economic decision system but the proportions of crop to fallow is allowed to vary in response to economic and spring soil moisture conditions. It is expected that in years when wheat price and/or spring soil moisture is high, the proportion of cropped land to fallowed land is increased. In years when soil moisture and/or the price are low, the proportion of cropped to fallowed land is expected to decrease and stored soil moisture allowed to accumulate.

The flex-cropping problem is formulated as a present value stochastic dynamic programming model with the objective to maximize after tax net present value of gross margins on the farm. The dynamic flex-cropping decision model is composed of a recursive objective function, stages, stage return functions, state variables, decision variables, and state transition functions.

2.3.1 Stages

A stage, in the formulation of this problem, is a single production period one year in length allowing for a complete cycle of the farming operation to occur. There is one year between plantings and one year between harvests. There are a total of T stages corresponding a planning horizon of sufficient length for the system to achieve a steady state.

2.3.2 State Variables

State variables, which describe the condition of the system at any stage include include the expected price of wheat p_t, spring soil moisture level on fallow and stubble $M_{f,t}$ and $M_{s,t}$ respectively, and the acres of stubble carried over from the previous year X_{t-1}. The price of wheat and spring soil moisture levels are stochastic variables while the acreage of stubble carried over from one period to the next is deterministic. There is no fertilizer carry over from year to year, and so the amount applied does not affect the state of the system in the next period.

2.3.3 Decisions

A set of choice or decision variables are associated with each stage. A decision, in this case X_t the number of acres seeded to crop in this stage, transforms the state associated with the current stage into a state associated with the succeeding stage. In this problem the decision variable is. Nitrogen fertilizer level is determined by the same optimization method used for the static economic decision framework and is not treated as a dynamic decision variable.

2.3.4 State transition relationships

State transition relationships describe the movement from a state associated with the current stage to the state associated with the succeeding one. The number of acres seeded in the current year X_t and the number of acres of stubble in the succeeding X_{t-1} year form a serially dependent transition relationship. Wheat price, on the other hand, is a time dependant stochastic transition relationship and does not change as a result of decisions made in the model. It is assumed that all of the grain produced is sold at the current price p_t in the current year.

Even though wheat price is not affected by decisions made in the model, the best predictor of the current wheat price is the price in the previous stages. Annual prices for wheat were obtained from the Cansim data base. A second order autoregressive model was estimated resulting in the price transition equation.

$$p_t = .093641 + .63953 D_{73} + .50498 p_{t-1} + .42406 p_{t-2}$$

$$\sigma_\epsilon = .16392$$

The current price, p_t, is estimated from p_{t-1} and p_{t-2} the one and two year price lags respectively. The dummy variable, D_{73}, is included to offset the price distortion caused by the 1973 Soviet grain deal, and σ_ϵ the standard error of the estimate.

Since the size of dynamic programming models increase exponentially with the number of state variables the method of Burt and Taylor was used to produce a first order autoregressive price transition equation.

$$p_t = .16259 + 1.1104 D_{73} + .87679 p_{t-1}$$

$$\sigma_\epsilon = .181$$

Price transition probabilities were derived from the first order transition equation using a hyperbolic tangent method (Taylor 1984).

Spring soil moisture levels for each representative farm were generated using the Versatile Soil Moisture Budget (Sly, 1982) outlined by De Jong and Bootsma (1988) for the years 1925 to 1984. The Versatile Soil Moisture Budget generates available spring soil moisture data for uniformly textured soils with given available water capacities based upon such meteorological factors as ambient air and soil temperature, daily precipitation, evapotranspiration. Soils moisture conditions were divided into three classes depending upon stored soil moisture in the top 90 cm of soil depth; dry (0 mm to 50 mm), medium (50 mm to 100 mm), and wet (over 100 mm). The soil moisture state is determined from the historic distribution.

$$(M_{f,t}, M_{s,t}) = \rho(M_{f,hist}, M_{s,hist})$$

$M_{f,hist}, M_{s,hist}$ represent the historic distributions of fallow and stubble spring soil moisture and ρ the probability function.

2.3.5 Stage Return Functions

A return function, depending on the current states and decisions, exists for each stage.

$$R_t(S_t, X_t)$$

R_t is the return function, S_t the current state of the system and X_t the decision at the tth stage.

The return function is defined by the soil moisture state variables which determine the relevant production function, the state variable for the price of wheat and the decision variable for acres of crop planted. The fertilizer application is made in each period according to the static optimization rule. The returns function is adjusted to an after 1990 income tax position with appropriate credits for the farm operator, spouse and two dependant children (Canadian Income Tax Schedule for Farmers and Fishermen, 1990).

$$H(R(\cdot))$$

The progressiveness of the tax function helps smooth out revenue flows from one year to the next. Extremely high revenues in any one year would place the operator in a higher marginal tax bracket and may make it optimal to leave some land fallow so that revenue is spread over two years. This helps avoid the problem of the farm being entirely in crop in one year and the completely fallowed in the next (Burt and Johnson, 1967; Burt, 1981; Taylor and Novak).

Combining the tax adjusted return function with the state transition relationships specifies the recursive system.

$$V_t(X_{t-1}, M_{s,t}, M_{f,t}) = \underset{X_t, N_{s,t}, N_{f,t}}{\text{MAX}} E\{H(R(X_{t-1}, p_{t-1}, M_{s,t}, M_{f,t},$$

$$N_{f,t}, N_{s,t}, X_t) + \beta V_{t+1}(X_t, p_t, M_{s,t+1}, M_{f,t+1})\}$$

$V_t(\cdot)$ is the maximum expected present value of after tax gross margin from the present year t to the terminal year T, $H\{R(\cdot)\}$ is the after tax gross margin function, $R(\cdot)$ is the before tax gross margin return function, X_t is the cropped acreage in the present year t, p_t is the price of crop in dollars per bushel, $M_{s,t}$ is the spring moisture level of stubble which may be cropped this year, $M_{f,t}$ is the spring soil moisture level of land fallowed in the previous year, $N_{f,t}$ is the amount of nitrogen applied to land fallowed in the previous year, $N_{s,t}$ is the amount of nitrogen applied to land being re-cropped, E is the expectations operator, and β the discount factor.

The system is solved through backwards recursion (Hillier and Lieberman, 1974) by summing current expected gross margins and the present value of expected gross margins, specified in the value function, for all remaining periods. The subscript $t+1$ denotes elements of the value function occuring in the future.

3 DESCRIPTION OF CASE FARMS

Three representative case farms, located in three agro-climatic regions, were developed for the project. The sites selected were in the Medicine Hat, Lethbridge, and Olds regions. Each farm was 1500 acres in size, divided into fifteen fields of 100 acres each. This provided a farm level model in which crop area could be adjusted by discrete 100 acre increments.

A uniformly textured soil with an available water holding capacity of 150 mm in a profile depth of one metre was assumed for each farm. Standardization of the available water capacity allows different combinations of organic matter content and soil textures to be considered (De Jong and Bootsma, 1988).

Nitrogen is the nutrient required in greatest abundance for the production of cereal crops and makes up a large portion of annual costs. Soils mineralize nitrogen during the fallowing period, reducing the need for supplemental application. Soil nitrogen was assumed totally depleted at the time of crop maturity with only a small amount of mineralization occurring between harvest and May 1. Soil nitrogen levels in spring were thus 50 lbs per acre on fallow and 10 lbs per acre on stubble.

The production functions for wheat on fallow and on stubble were modified from Alberta Agriculture Soil Test Recommendations (1988). Information from the CERES wheat production model indicated yield differentials between dry and wet soil conditions were understated by the Alberta Agriculture production functions. Furthermore the Alberta Agriculture functions considered soil moisture only to the 30 cm level whereas data to the 90 cm level were available. Since the 90 cm depth more fairly represents the soil profile from which wheat plants are able to extract moisture production functions were adjusted accordingly. Under the suggested method[1] the production function for a medium-fine textured soil with medium spring soil moisture was used as the base from which other production functions were determined. Wet spring moisture soils were adjusted to produce 125 per cent of the base and dry spring moisture soils 60 per cent of the base. Because of greater weed pressure on re-cropped land, wheat yields on stubble were adjusted to 80 per cent of their fallow counterparts.

3.1 The Medicine Hat Case Farm

Medicine Hat is located in the brown soil zone. Brown soils have a shallow surface horizon averaging 12.5 cm in depth with an organic matter content of approximately 2 percent in the top 30 cm (Campbell et al, 1990). The Medicine Hat area is characterized by low rainfall and high temperatures. Precipitation during the growing season from May 1 to August 31 averages 180.4 cm and is accompanied by a mean temperature of 16.8 C (Alberta Agriculture, 1991). The area receives an average of 1600 effective degree days of energy per year (Alberta Agriculture, 1987). This area is subject to high average daily winds and soils are subject to risk of wind erosion. The region is rated as agro-climatic class 3A indicating a moderate moisture limitation but no limitation due to heat. Soil moisture transition probabilities are presented in Table 3.1.

Production functions for three moisture levels on fallow and on stubble in the Medicine Hat area appear in Figure 3.1.

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1 Personal consultation with Dr. Robert Grant, Department of Soil Science, University of Alberta.

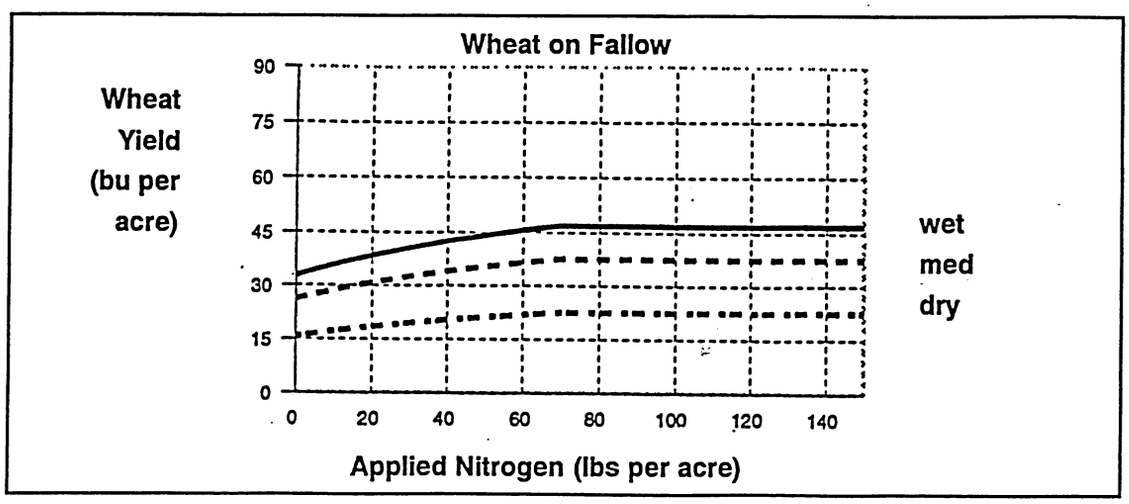
Table 3.1
Soil Moisture Transition Probabilities
Medicine Hat Region

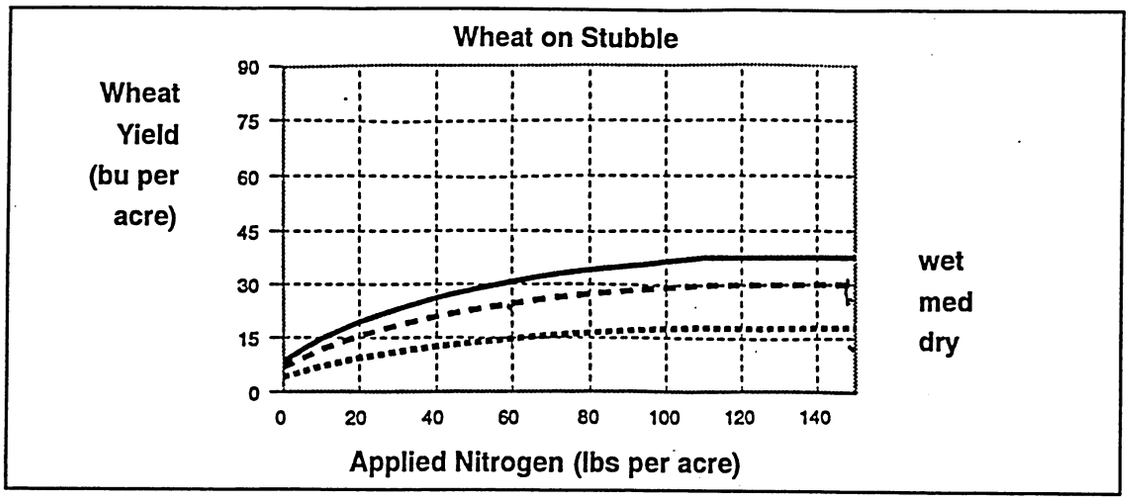
	Stubble		
Fallow	Dry	Medium	Wet
Dry	0.4000	0.0167	0.0000
Medium	0.2000	0.2500	0.0000
Wet	0.0000	0.1000	0.0330

Note: The possibility that a medium level of spring soil moisture on stubble would occur simultaneously with dry fallow seems counter intuitive. Consequently, the probability level 0.0167 for such an occurance was treated as an aberation in the data and not given further consideration.

Variable costs, other than for nitrogen fertilizer, are assumed to be $10.50 per acre on fallow and $40.00 per acre on stubble. The higher costs on stubble reflect additional tillage operations, herbicide costs, and non-nitrogen fertilizer costs.

Figure 3.1
Fertilizer Response
Medicine Hat Region





3.2 The Lethbridge Case Farm

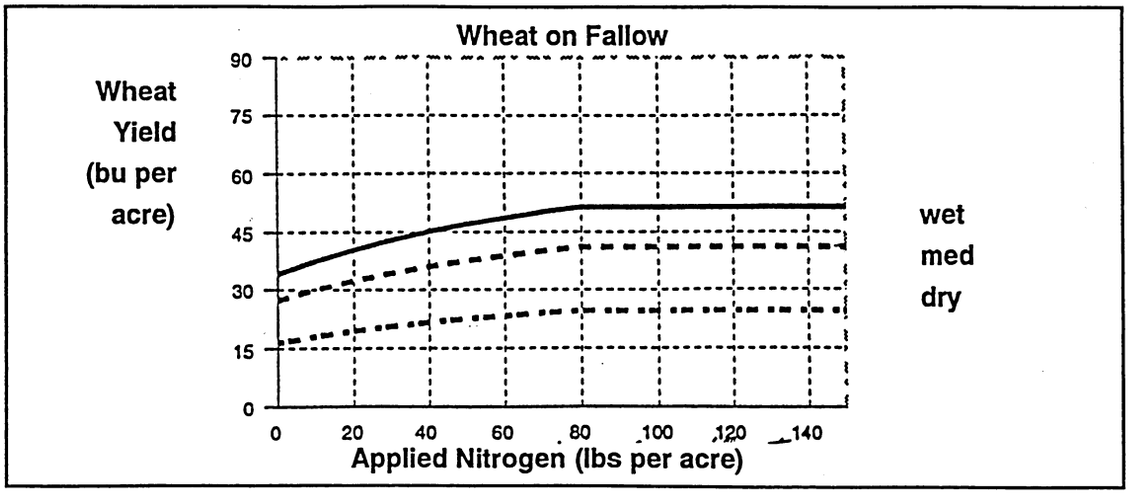
Soils in the Lethbridge area are classified as dark brown with a surface horizon of about 17.5 cm and an organic matter content of 4 per cent in the first 30 cm of soil depth (Campbell et al, 1990). The average growing season precipitation is 219.6 mm and the long term average temperature in the May to August period is 15.6 C (Alberta Agriculture, 1990). The Lethbridge area receives approximately 1400 Effective Degree Days of energy per year and is rated as having a slight moisture limitation for crop growth but no heat limitation (Alberta Agriculture, 1987). High daily wind speed is a factor contributing to evapotranspiration and the probability of soil erosion. Soil moisture probabilities are presented in Table 3.2.

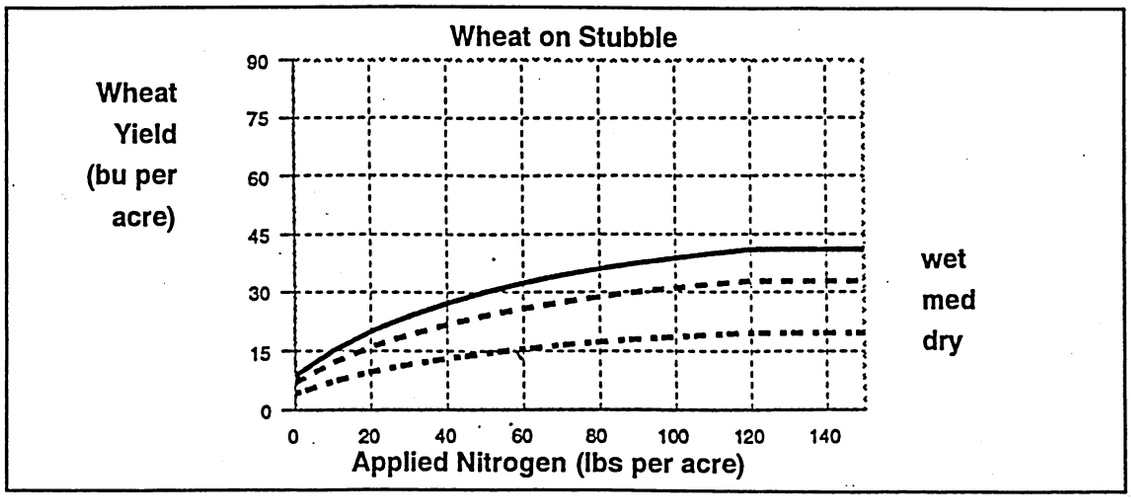
The production functions used for the Lethbridge case are shown in Figure 3.2.

Table 3.2
Soil Moisture Transition Probabilities
Lethbridge Region

	Stubble		
Fallow	Dry	Medium	Wet
Dry	0.2000	0.0000	0.0000
Medium	0.2500	0.1500	0.0000
Wet	0.0000	0.1667	0.2333

Figure 3.2
Fertilizer Response
Lethbridge Region





Variable costs are higher at Lethbridge than at Medicine Hat reflecting additional tillage operations necessary to break down crop residues. Costs at Lethbridge are assumed to be $14.00 per acre on fallow and $49.00 per acre on stubble. The difference is attributed to the additional herbicide, tillage, and non-nitrogen fertilizer costs incurred in cropping stubble.

3.3 The Olds Case Farm

Located in central Alberta, Olds is in the black soil zone. Black soils are characterized by a deep surface horizon of 20 cm to 25 cm with a relatively high organic matter content of about 7 percent in the first 30 cm (Campbell et al, 1990). Olds receives an average growing season precipitation of 293.5 mm with an average daily temperature during the growing season of 13.2 C. Olds receives approximately 1100 effective degree days of energy and is rated as agro-climatic class 3H which has a moderate heat limited for crop growth but no moisture limitation (Alberta Agriculture, 1987). Wind is not as important a factor in this region as in Medicine Hat or Lethbridge, although wind erosion can occur. Continuous cropping is the typical practice followed in this area.

Spring soil moisture probabilities are presented in Table 3.3.

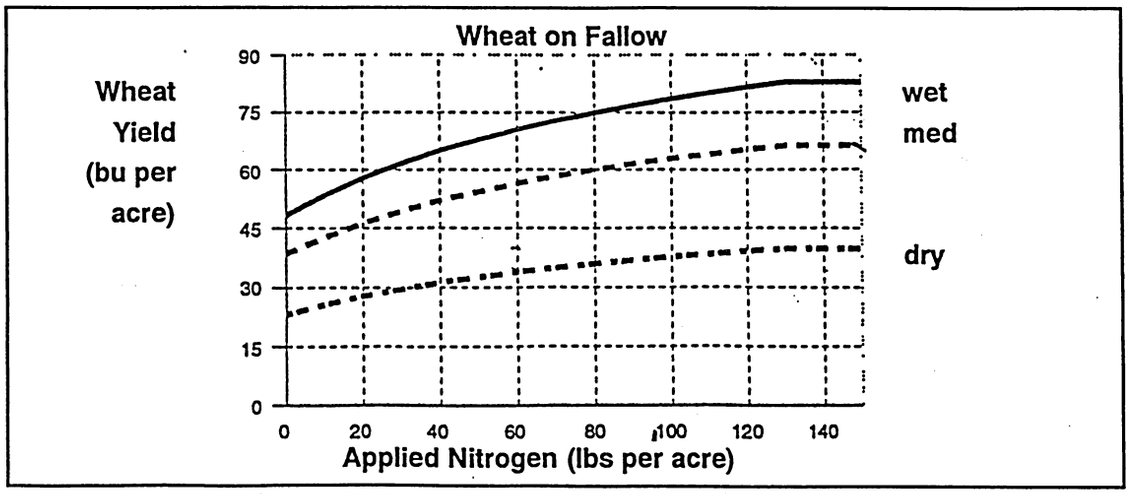
Potential yields in the Olds area are higher than at Medicine Hat or Lethbridge due to the greater growing season precipitation. Production functions for Olds are presented in Figure 3.3.

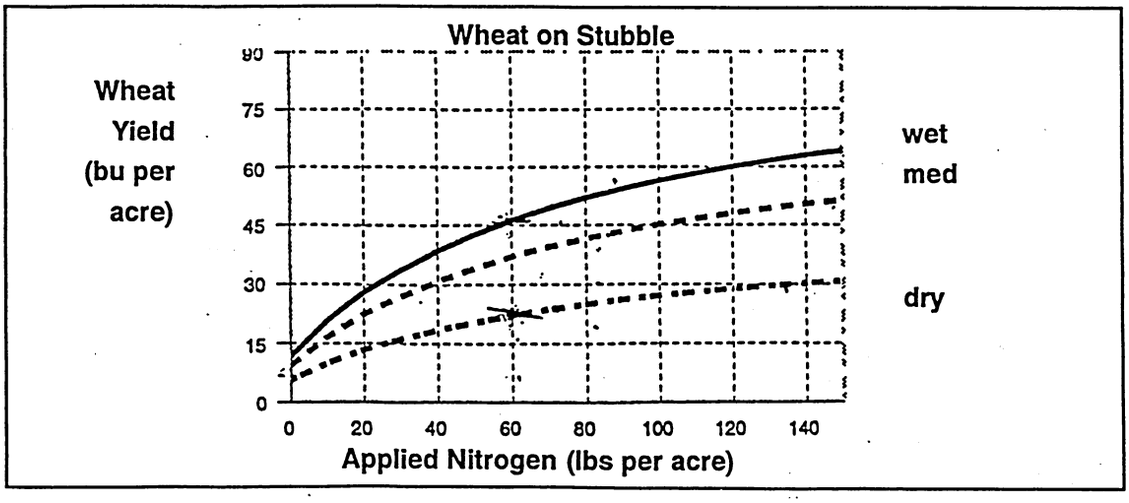
Variable costs are considerably higher than at Medicine Hat or Lethbridge reflecting the additional costs associated with higher yields. The operating cost for fallow land is assumed to be $21.00 per acre and $57.00 per acre for stubble. Cost differences are attributed to additional tillage operations, non nitrogen fertilizer costs and herbicide costs for stubble cropping.

Table 3.3
Soil Moisture Transition Probabilities
Olds Region

	Stubble		
Fallow	Dry	Medium	Wet
Dry	0.0667	0.0000	0.0000
Medium	0.2000	0.1000	0.0000
Wet	0.0500	0.3167	0.2667

Figure 3.3
Fertilizer Response
Olds Region





4 OPTIMUM DECISION RULES

Decision rules were developed for the three systems; traditional decision rules, static economic decision rules, and dynamic flex-cropping decision rules.

4.1 Traditional Decision Rules

The traditional framework results in the simplest decision rules where the same amount of fertilizer and the same amount of crop is planted each year. The rule varies from location to location as to follow decisions in each region as closely as possible. Table 4.1 outlines the rule for each of the regions.

Table 4.1
Traditional Decision Rules

	Location		
	Medicine Hat	**Lethbridge**	**Olds**
Crop Rotation	50-50 Crop-Fallow	50-50 Crop-Fallow	Continuous Wheat
Spring Soil Nitrogen	50 lbs per acre	50 lbs per acre	10 lbs per acre
Applied Nitrogen	25 lbs per acre	35 lbs per acre	115 lbs per acre
Total Nitrogen	75 lbs per acre	85 lbs per acre	125 lbs per acre

Since the traditional decision rule does not involve re-cropping land at Medicine Hat or Lethbridge the spring soil nitrogen is the amount mineralized through the summer fallowing process. The rotation in the Olds region is continuous crop therefore spring soil nitrogen is 10 lbs per acre, the amount mineralized on stubble since last harvest.

4.2 Static Economic Decision Rules

The static economic decision framework is more complex than the traditional approach. Although the fixed rotation is used, both soil moisture and expected price of wheat determine fertilizer application rates.

To generate the fertilizer application the spring soil moisture state is selected according to the historic probability of a particular soil moisture state occurring. The production function that coincides with the soil moisture state is then selected. Wheat price is then determined from the wheat price transition equation.

The value of the marginal product of fertilizer is then equated with the marginal factor cost of fertilizer to determine the optimal level of nitrogen. Optimal fertilizer decision rules for the Medicine Hat, Lethbridge and Olds case farms appear in Table 4.2, Table 4.3 and Table 4.4 respectively.

Table 4.2
Static Economic Decision Rules
Lbs Nitrogen Applied to Wheat on Fallow
Medicine Hat Region

Wheat Price	Dry Soil	Medium Soil	Wet Soil
1.00	0	30	40
1.20	10	40	60
1.40	20	50	70
1.60	20	60	70
1.80	30	60	70
2.00	30	70	70
2.20	40	70	70
2.40	50	70	70
2.60	50	70	70
2.80	60	70	70
3.00	60	70	70
3.20	60	70	70
3.40	70	70	70

Table 4.3
Static Economic Decision Rules
Lbs Nitrogen Applied to Wheat on Fallow
Lethbridge Region

Wheat Price	Dry Soil	Medium Soil	Wet Soil
1.00	10	40	50
1.20	10	50	70
1.40	20	60	80
1.60	30	70	80
1.80	40	70	80
2.00	40	80	80
2.20	50	80	80
2.40	60	80	80
2.60	60	80	80
2.80	70	80	80
3.00	70	80	80
3.20	70	80	80
3.40	80	80	80

The tables provide optimum fertilizer application levels for the particular spring soil moisture conditions and expected prices. Since, under the static economic decision system only fallow is seeded on the Medicine Hat and Lethbridge case farms, rates on stubble are irrelevant. Similarly, only rates on stubble are provided for Olds because of the underlying assumption of a continuous cropping system.

In the static economic optimization process, the value of the marginal product of fertilizer is equated with its marginal factor cost. As wheat price increases so does the value of the marginal product and consequently a higher amount of fertilizer is recommended than with lower prices. In the case of wet soil moisture conditions, expected yields are higher and greater amounts of fertilizer are applied at any given grain price. Due to the functional form of the response curves selected, yield increases quickly as fertilizer levels are increased, then levels off and remains flat as further amounts are applied.

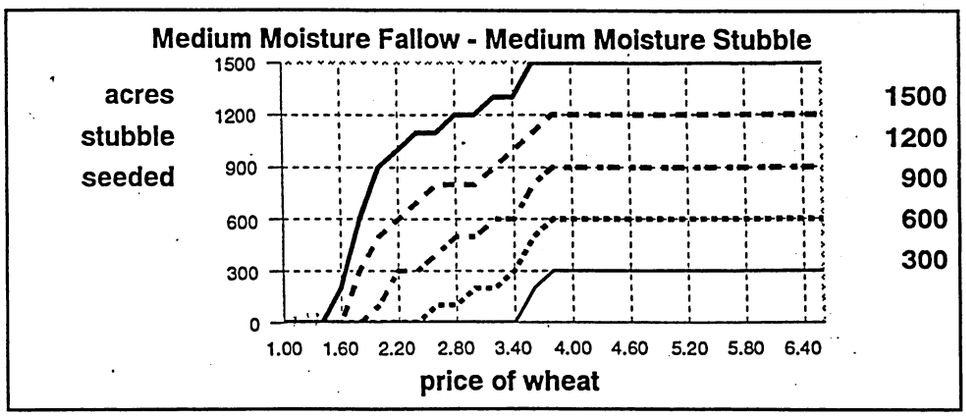
Table 4.4
Static Economic Decision Rules
Lbs Nitrogen Applied to Wheat on Stubble
Olds Region

Wheat Price	Dry Soil	Medium Soil	Wet Soil
1.00	60	0	120
1.20	70	110	130
1.40	80	120	140
1.60	80	140	150
1.80	100	140	150
2.00	110	150	150
2.20	120	150	150
2.40	120	150	150
2.60	120	150	150
2.80	130	150	150
3.00	140	150	150
3.20	140	150	150
3.40	150	150	150

4.3 Dynamic Flex-Cropping Decision Rules

The most complex set of decision rules are those associated with the dynamic flex-cropping system. Spring soil moisture and wheat price are determinants of both fertilizer level and acreage planted. The decision rule derived for medium spring soil moisture on both fallow and stubble in the Medicine Hat region, found in Figure 4.1, will be used to explain the process.

Figure 4.1
Dynamic Flex-Cropping Decision Rules
As an Illustrative Example (Medicine Hat)



The dynamic flex-cropping decision rule described in Figure 4.1 recommends an allocation of stubble and fallow acres so as to maximize the after tax net present value of the gross margin for the current states of spring moisture level, the price of wheat, and available stubble acreage. The graph shows the recommended cropping decision for the situation where both fallow and stubble have a medium level of soil moisture. Wheat price is read from the horizontal axis and the current available stubble is identified by the numbers on the right. The vertical axis represents the stubble acreage to be seeded. All acres in fallow will be seeded within the range of prices, and therefore, the total acres seeded will be the sum of fallow acres and the number of stubble acres re-cropped.

Consider first the situation where there is a carry-over of 900 acres of stubble and 600 acres of fallow. The number of acres for the current period will then consist of the 600 fallow acres plus a portion of the available stubble acres. If the price of wheat is $1.80 or less the decision will be to fallow the entire stubble carry-over. As the price increases some of the stubble land will be re-cropped and some fallowed. For example, at a price of $2.20, 300 acres of stubble will be re-cropped and 600 acres fallowed. If price rises to $2.80, re-cropping will be increased to 500 acres with the remaining 400 acres left for fallow. At $3.80 the entire 900 acres of stubble will be planted.

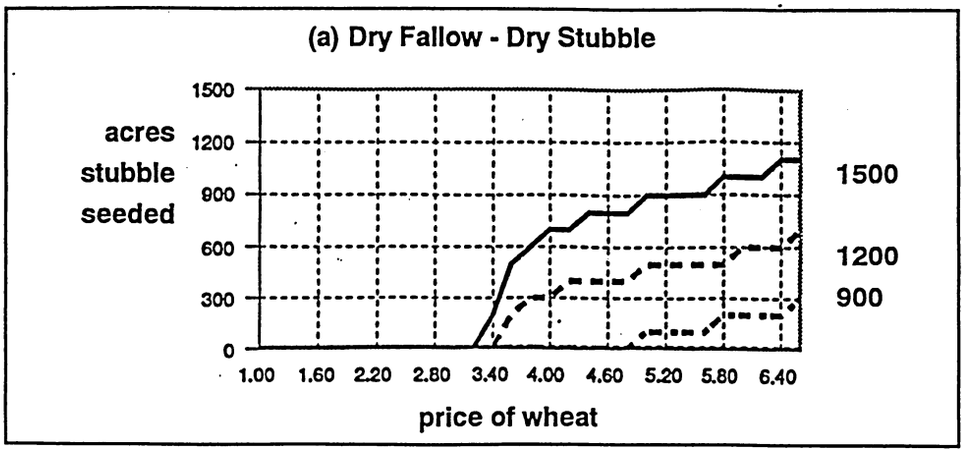
In the situation where there are 300 acres of stubble carried over, there would be no re-cropping unless the price for wheat exceeded $3.40. For example, at a price of $3.60, 200 acres of stubble would be planted and the remaining 100 acres fallowed. At $3.80 the total 300 acres of stubble would be re-cropped. Of course, the 1200 acres of fallow would be seeded at the range of prices indicated.

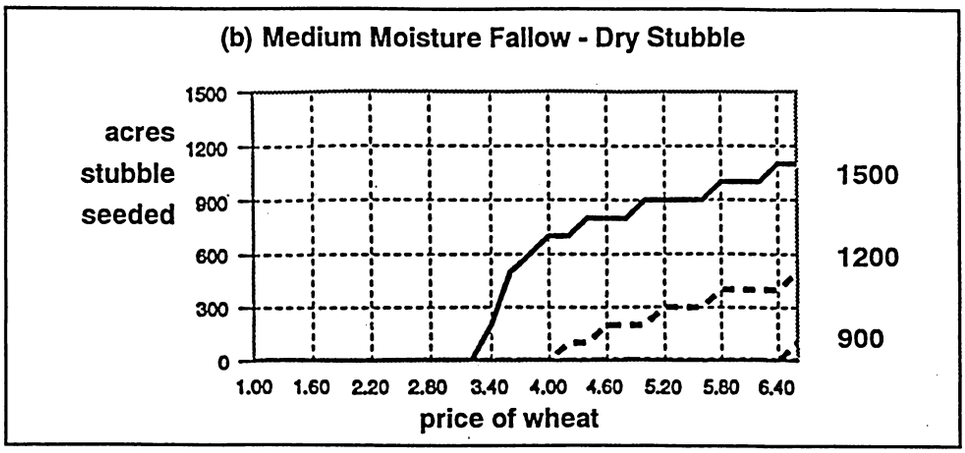
The complete set of decision rules for all locations and soil moisture states follow in Figure 4.2, Figure 4.3, and Figure 4.4. The decision rules are interpreted in the same way as for the medium moisture fallow - medium moisture stubble state in the Medicine Hat region. While there nine possible fallow and stubble soil moisture combinations, only five have non zero probabilities of occurring. There is no probability of stubble having a higher moisture than fallow and the combination wet fallow - dry stubble did not occur in Medicine Hat or Lethbridge.

Comparing situations within a region raises some interesting economic issues. For a given moisture state the number of acres seeded increases as the price of wheat goes up. Intuition leads to this conclusion since, with higher prices and no change in costs, wheat farming will be more profitable. This illustrates the point that as the price of wheat increases the immediate profit anticipated from planting outweighs the opportunity lost by having less fallow acres available for the following year.

Figure 4.2

Dynamic Flex-Cropping Decision Rules (Medicine Hat)





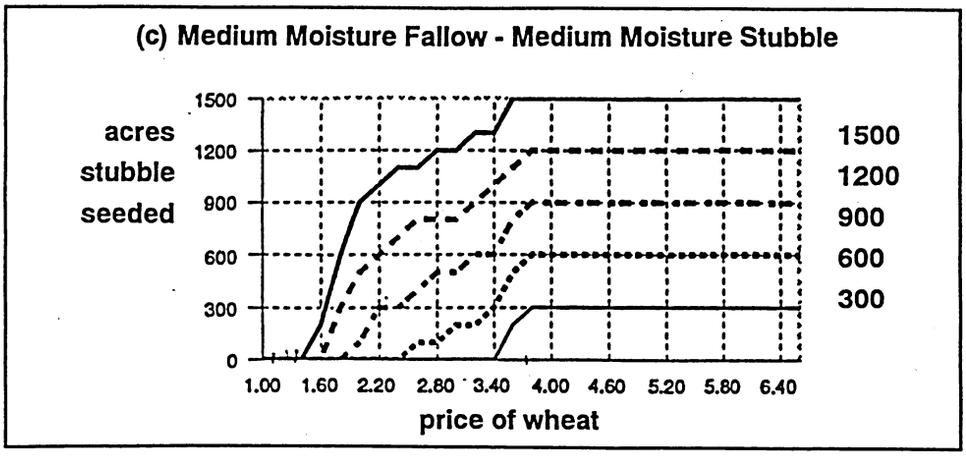
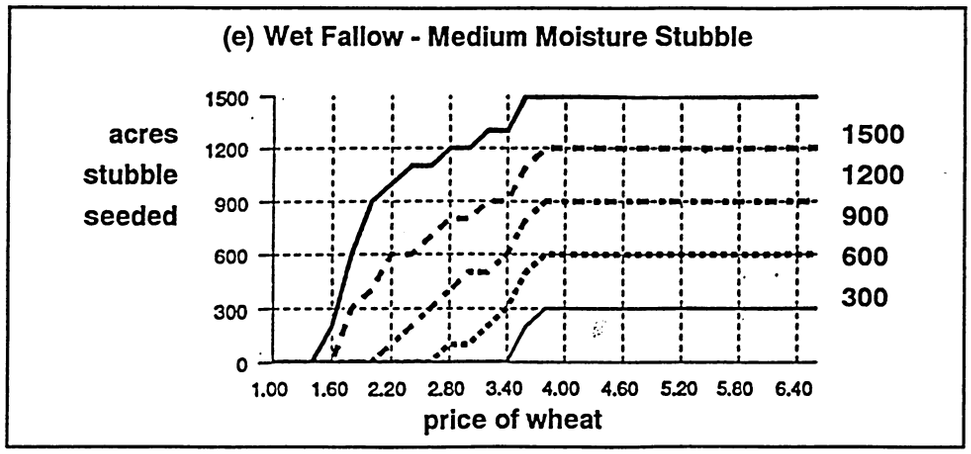
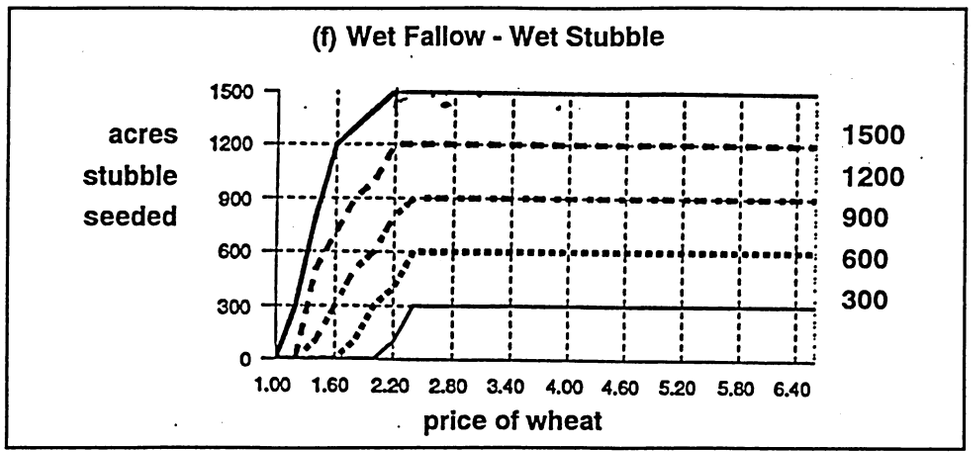


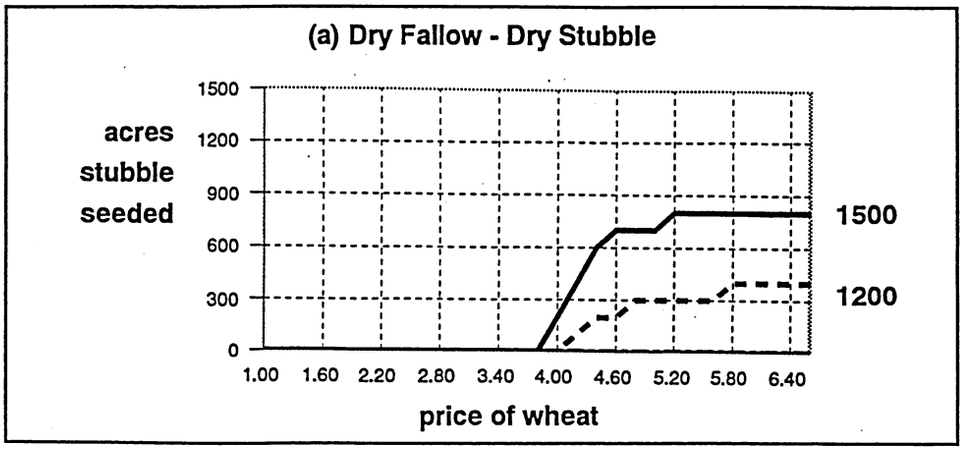
Figure 4.2 (continued)
Dynamic Flex-Cropping Decision Rules (Medicine Hat)

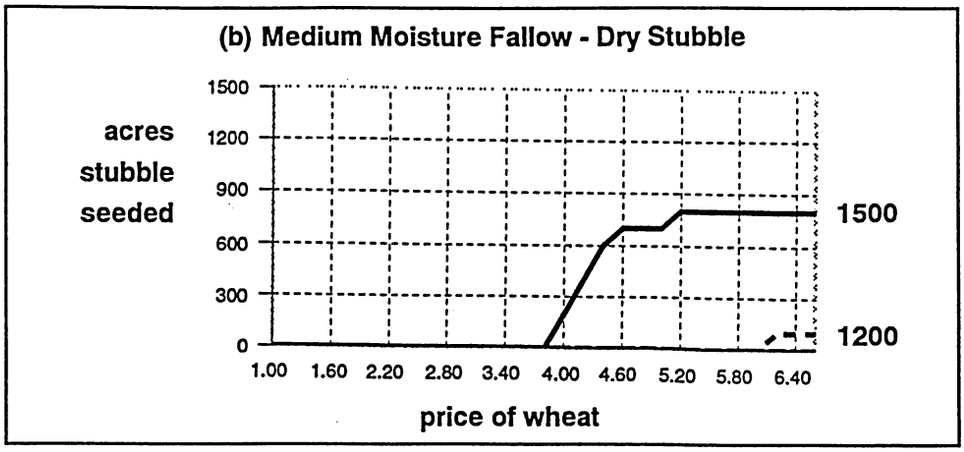




Note: Panel d is not included because the combination, wet fallow - dry stubble, has a zero probability of occurrence and does therefore not appear as a valid state.

Figure 4.3
Dynamic Flex-Cropping Decision Rules (Lethbridge)





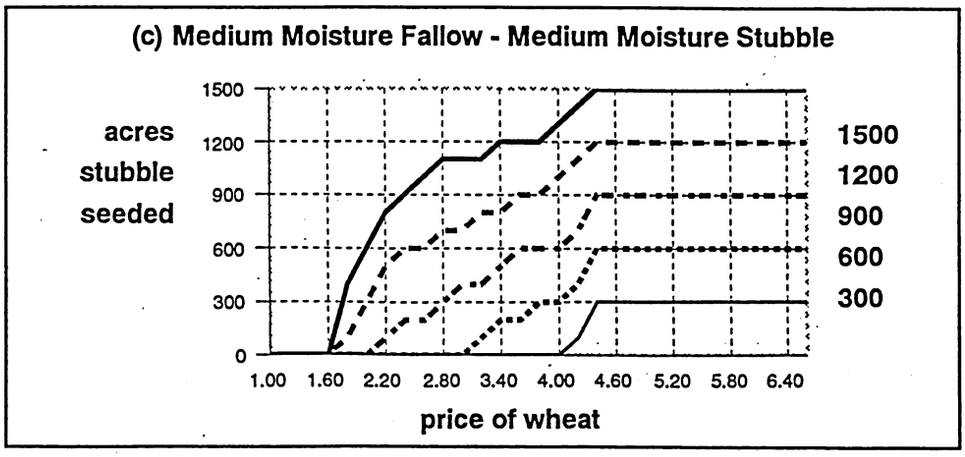
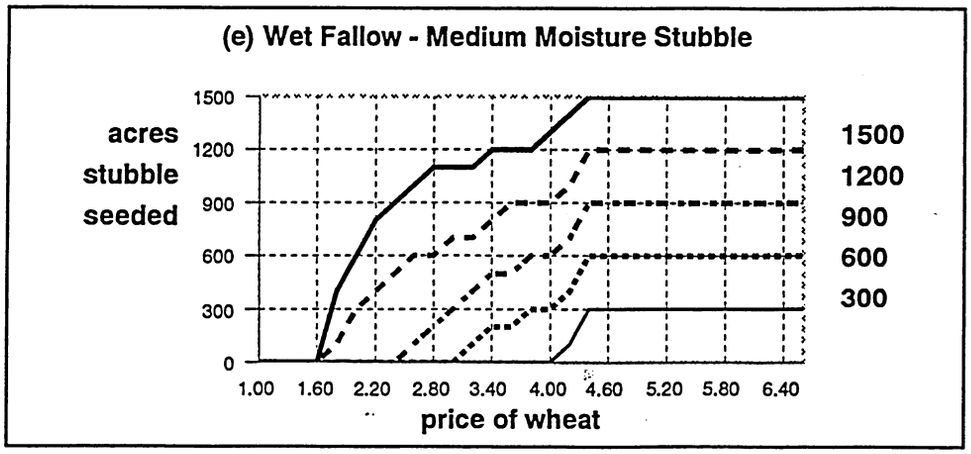
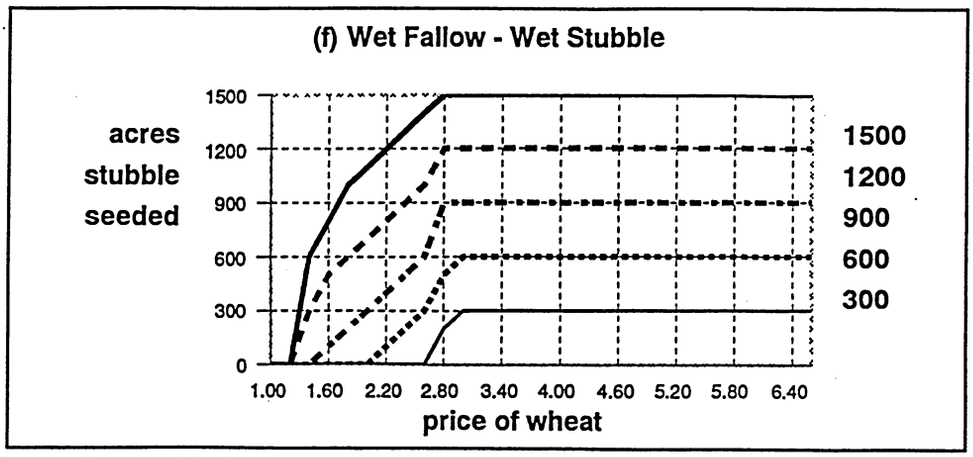


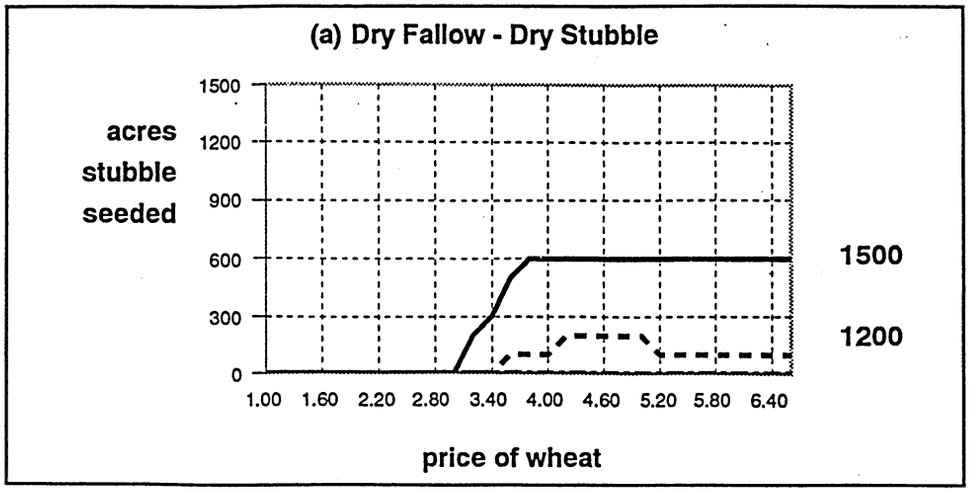
Figure 4.3 (continued)
Dynamic Flex-Cropping Decision Rules (Lethbridge)

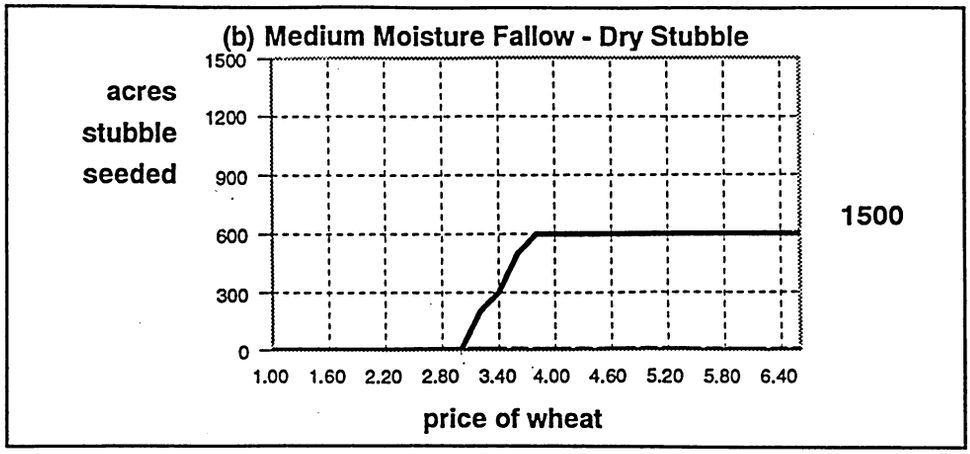




Note: Panel d is not included because the combination, wet fallow - dry stubble, has a zero probability of occurrence and does therefore not appear as a valid state.

Figure 4.4
Dynamic Flex-Cropping Decision Rules (Olds)





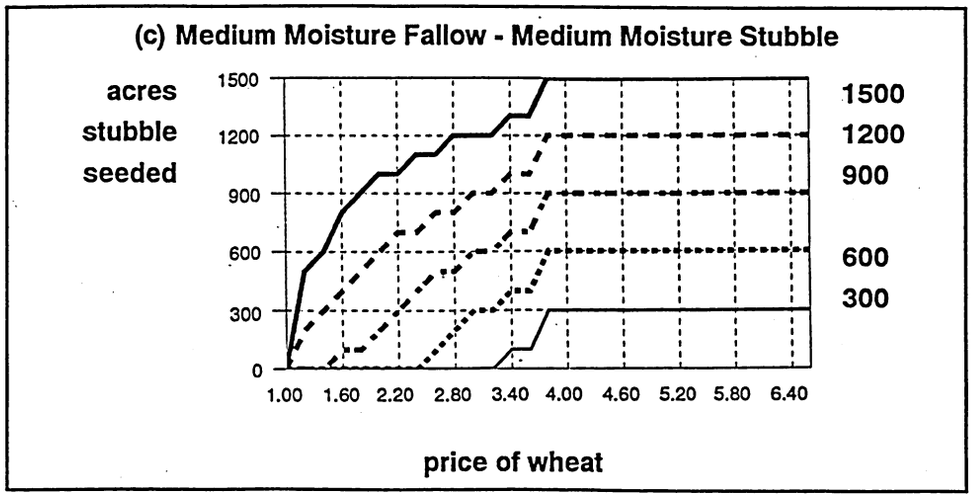
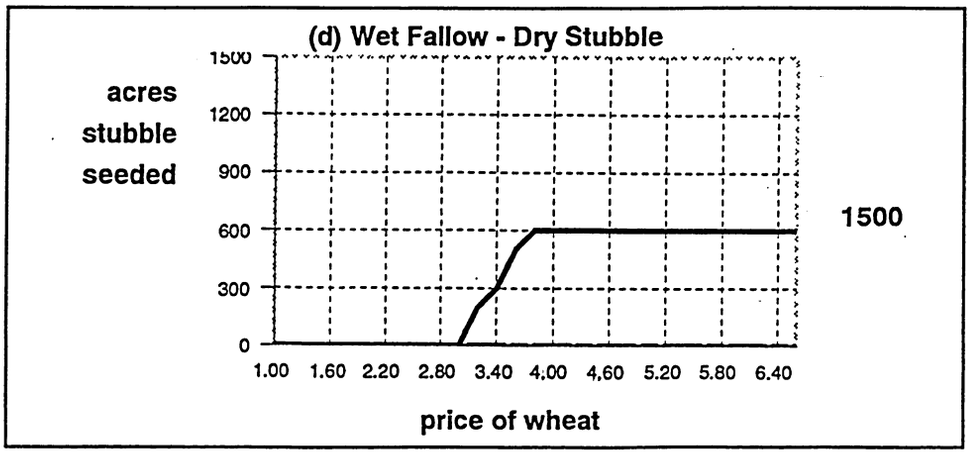
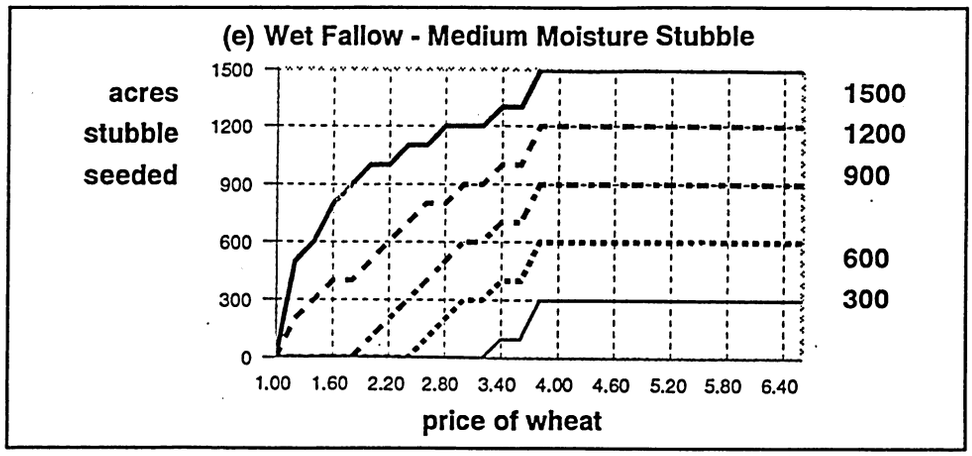
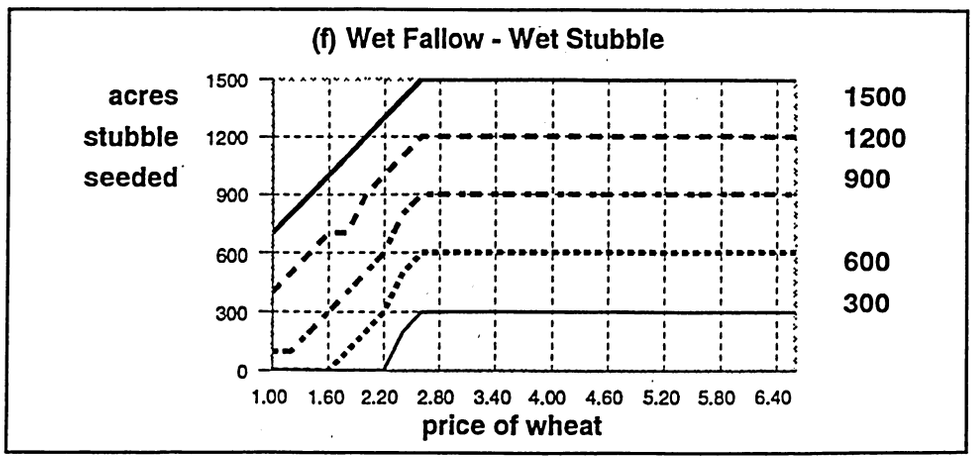


Figure 4.4 (continued)
Dynamic Flex-Cropping Decision Rules (Olds)







Re-cropping will occur at a lower price in years of large stubble carry over than in years when there is less carry over. For example, re-cropping in the case of 900 available stubble acres, with medium moisture conditions on both fallow and stubble at Medicine Hat, begins at a price of $1.80 while in the 300 acre case an price of $3.40 is required. Because of progressive income taxation, re-cropped acreage is increased to the point where diminishing after tax marginal returns and the expected increases in future returns balance each other. The progressiveness of the tax function helps smooth out revenue flows from one year to the next. Extremely high revenues in any one year would place the operator in a higher marginal tax bracket and may make it optimal to leave some land fallow so that revenue is spread over two years. Furthermore, this helps avoid the problem of the farm being entirely in crop in one year and the completely fallowed in the next (Burt and Johnson, 1967; Burt, 1981; Taylor and Novak).

Another interesting observation concerns differences in spring soil moisture states. When the difference in soil moisture states is larger, for example wet fallow and medium moist stubble as opposed to wet fallow and wet stubble re-cropping occurs at relatively higher wheat prices. Reference to the Medicine Hat case for medium moisture fallow and dry stubble shown in Figure 4.2, shows that re-cropping is deferred to a higher price than in the case of dry fallow and dry stubble. In the wet fallow and wet stubble situation the entire farm is seeded for all states of stubble carry-over when a price of $2.40 per bushel is reached. When the soil moisture state is wet fallow and medium moist stubble the entire farm is not placed in crop for all carry-over states unless a price of at least $3.80 per bushel is achieved. This shows that when the stubble soil moisture state is wet it is more profitable to seed stubble since expected yields are higher and re-cropping becomes profitable at lower prices. If stubble moisture reserves are low or medium expected yield is not as high and re-cropping becomes profitable only at higher prices.[2]

The optimal dynamic programming decision rule recommends a course of action from any possible set of states for the system. Any combination of fallow and stubble acreages, soil moisture levels, and wheat prices are possible contenders as the current state at the start of any stage. No matter what the state of the system an optimal decision will exist for the remaining stages.

The decision rule is stable and remains optimal no matter what stage the system is in. The planning horizon was chosen to be of sufficient length for the present value of gross margins to be maximized, that is for the system to converge. Near the end of the planning horizon the optimal decision may change. For example, in the last year of the operation when the farmer retires and the farm is to be sold, the optimal decision may be to crop the entire farm. However, under the assumption of efficient land markets, it is not unreasonable to assume that the purchaser of the farm will offer a premium for available fallow land or demand a discount if there is only stubble. If the difference in land price accurately reflects the present value of fallowed land, and there are no economies through technical improvements, the decision rule will remain constant indefinitely.

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2 Because of differences in yield functions and rotations used for each case farm caution must be advised in making inter-regional comparisons. An apparent anomaly occurs in comparing decision rules for Medicine Hat and Lethbridge. The assumed crop rotation is the same but the production functions are not. The Lethbridge decision rules recommend re-cropping at a higher price for all moisture states than for Medicine Hat. This is contrary to what would be expected. Lethbridge has a lower evapotranspiration rate and receives more annual precipitation than does Medicine Hat and it should be possible to grow crop more efficiently, at a lower cost, in the Lethbridge region. The apparent anomaly may be due to the fact that for large problems with many states small differences in data or in validation can produce unexpected results, particularly at model extrema.

5 STOCHASTIC SIMULATION

A Monte Carlo simulation was used to compare differences between the three decision rules. Cumulative probability distributions of present values of the after tax gross margins are generated over a 50 period planning of 50 cropping periods with 1000 replications.

The method involved calculating the price of wheat according to the price transition equation, and selecting a soil moisture state according to the soil moisture transition probabilities. Fertilizer application rates were chosen according to the decision rule, and yield levels generated from applicable production functions. Variable costs were subtracted from the resulting gross income to determine gross margin. Gross margins per acre were then multiplied by the acres planted, as specified by the decision rule. Finally, total gross margin was adjusted to an after tax basis. The net present value of the after tax gross margins generated for each year of the 50 year planning horizon were then computed at a discount rate of 5 per cent per annum. The procedure was repeated 1000 times and the results expressed as a cumulative probability distribution.

The Olds case farm was revised for purposes of simulation. The Olds Original case used yield functions where wet soil moisture yields were assumed to be 125 per cent of the medium yields and the dry yields as 60 per cent.[3] The revised model, referred to as the Olds New case, used a more stable yield function where wet soil moisture yields that were 105 per cent the medium moisture soil and dry soil moisture were assumed to yield 95 per cent.

Average net present values for each case farm location and decision rules are presented in Table 5.1. The annuity equivalents are in Table 5.2.

Table 5.1
Simulated Net Present Values
After Tax Gross Margins

Decision System	Medicine Hat	Leth-bridge	Olds Original	Olds New
Traditional	200,000	300,000	875,000	1,070,000
Static Economic	210,000	350,000	975,000	1,100,000
Dynamic Flex-crop	275,000	400,000	1,250,000	1,140,000

The dynamic flex-cropping decision rule provided the highest net present value of gross margin in all cases while the traditional decision rule provided the lowest net present value of gross margin. Modest gains can be made from optimizing fertilizer application, but considerably larger gains are possible by optimizing both fertilizer levels and acreage planted. The mean net present value for the traditional decision rule at Medicine Hat was $200,000 followed by $210,000 for the static economic decision rule and $275,000 for the dynamic flex-cropping decision rule. In Lethbridge the traditional decision rule providing a mean of about $300,000, the static economic decision rule $350,000 and the dynamic flex-cropping decision rule

3 The yield functions were for a medium fine textured soil, taken from the 1988 Soil Test Recommendations for Alberta.

Table 5.2
Simulated Annuity Equivalents of Net Present Values
After Tax Gross Margins

Decision System	Medicine Hat	Leth-bridge	Olds Original	Olds New
Traditional	10,956	16,434	47,932	58,615
Static Economic	11,504	19,173	53,410	61,070
Dynamic Flex-crop	15,064	21,912	68,475	62,449

Note: For ease in interpretation the net present values have been transformed into their annuity equivalents by a factor of 0.05478 the present value factor for a uniform series at 5 per cent per annum over 50 years.

just over $400,000. These results seem reasonable because Lethbridge receives more precipitation than Medicine Hat, a lower evapotranspiration rate and consequently in greater yields profits. Results for Olds, with less moisture limitations, are consistent with these observations.

The cumulative distribution functions generated are shown in Figure 5.1, Figure 5.2, Figure 5.3 and Figure 5.4.

Figure 5.1
Cumulative Probability Distributions
Medicine Hat Region

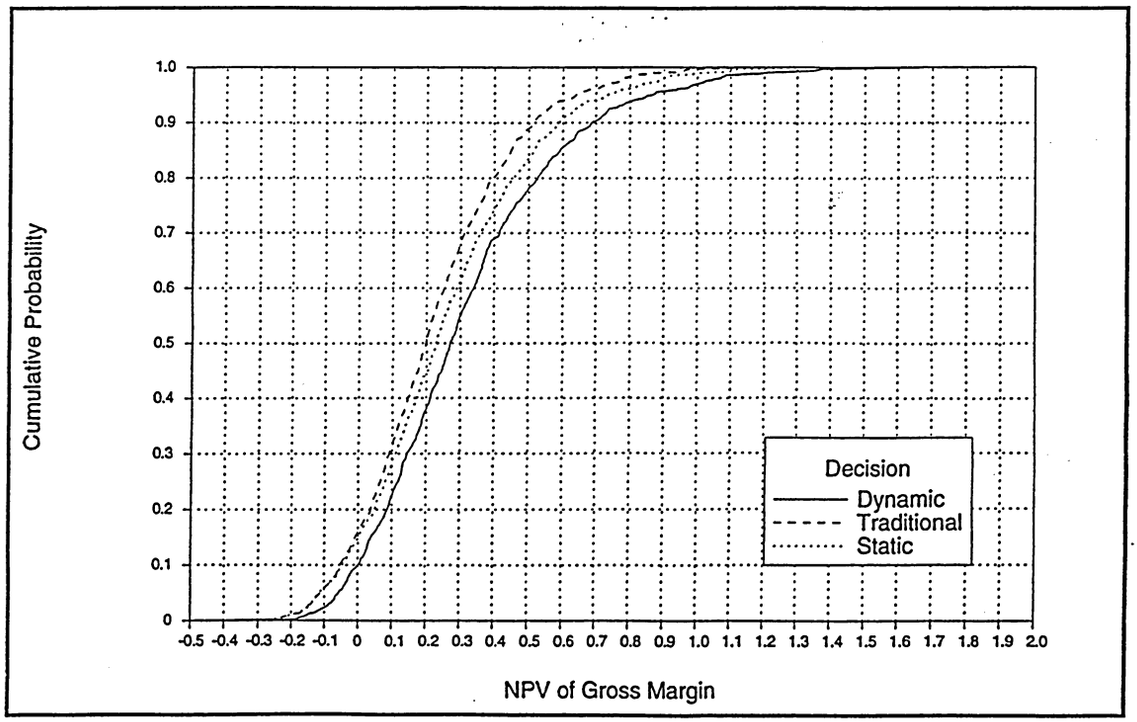


Figure 5.2
Cumulative Probability Distributions
Lethbridge Region

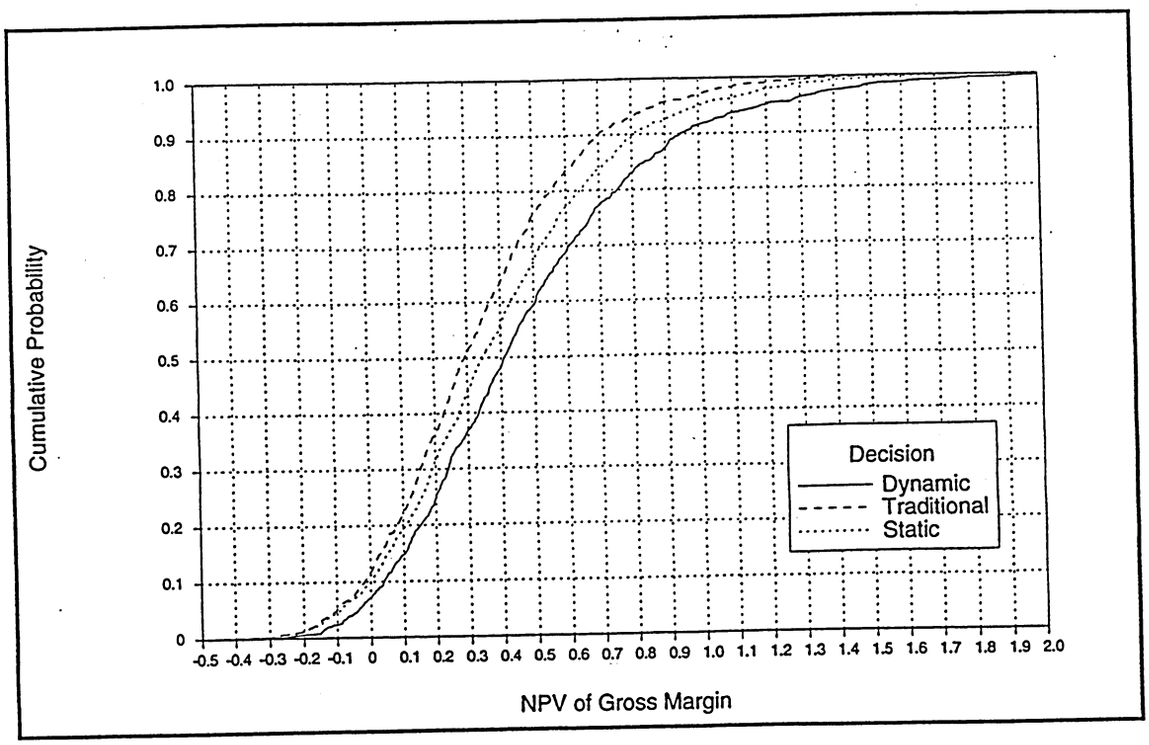


Figure 5.3
Cumulative Probability Distributions
Olds Region (Original)

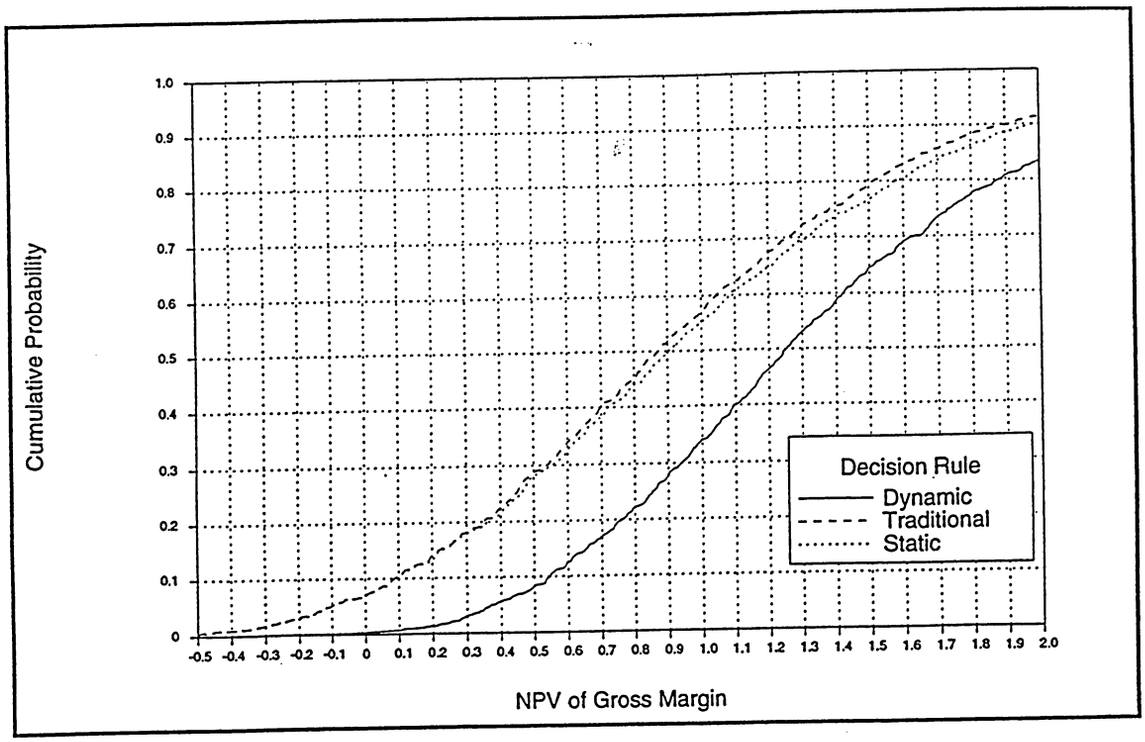
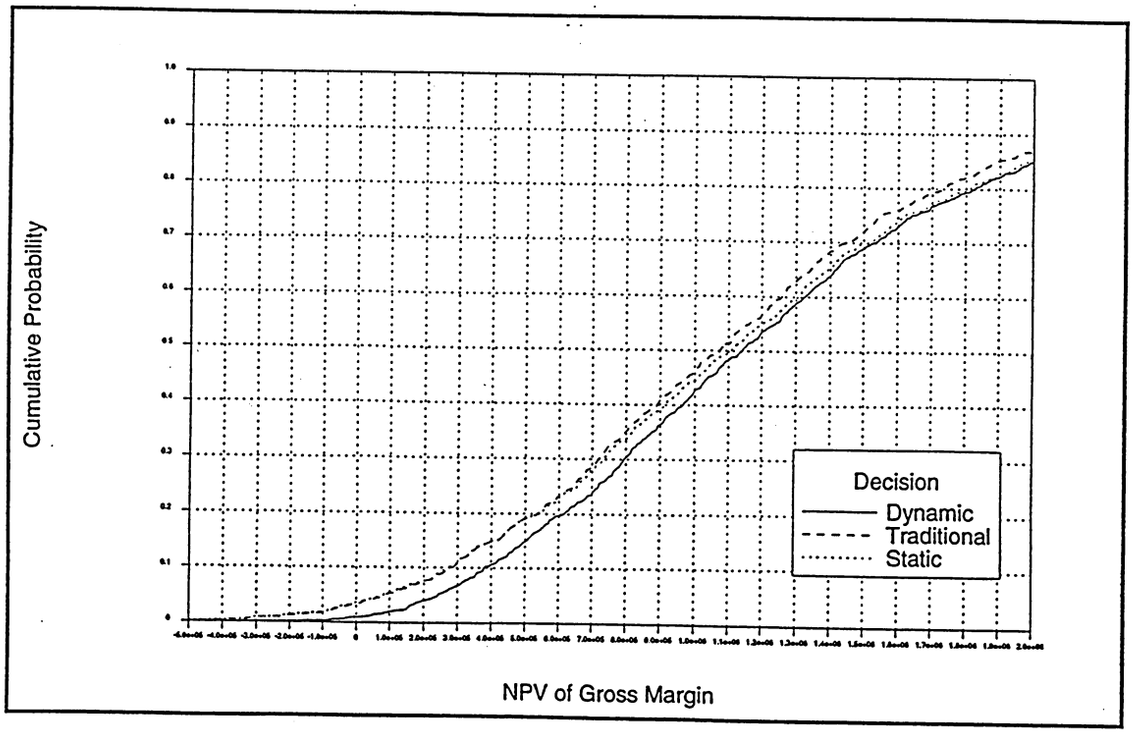


Figure 5.4
Cumulative Probability Distributions
Olds Region (New)



The after tax net present value of gross margin for the 50 year planning horizon is read from the horizontal axis and the cumulative probability level from the vertical axis. The cumulative probability distribution for the original Olds case shows that in following the dynamic flex-cropping decision rule the farmer has a 50 per cent probability of making $1,250,000 or less as net present value of after tax gross margin $1,250,000. Alternatively there is a 50 per cent probability of making more than this amount. This farmer would have an 80 per cent chance of making $1,900,000 or less and a 20 per cent chance of making more.

Simulations carried out for the Olds Original and Olds New provide illustrate model responsiveness to variability in base data. In the Olds Original case, the traditional decision rule, shown in Figure 5.3, generated a net present value of $875,000, the static economic decision rule $975,000, and the dynamic flex-cropping rule $1,250,000. In the Olds New case of Figure 5.4, the traditional decision rule generated $1,070,000, considerably more than for its Olds Original counterpart. The static economic decision rule produced just over $1,100,000, also significantly more. The dynamic flex-cropping decision rule for Olds New provided a net present value of only $1,140,000 a reduction of $110,000 from the Olds Original.

The difference between the static and dynamic decision rules for the Olds Original model is $375,000 while the same difference for the Olds New decision rule is just $70,000. This difference in net present value of after tax gross margin is highly dependant on the influence of spring soil moisture in the fertilizer response functions, namely in the yield variation expected from dry to wet spring soil moisture conditions. If spring soil moisture has no major influence on crop yield, as in the Olds New case, dynamic flex-cropping decision rules provide only minor improvement over the static economic rule. The large gains available from re-cropping stubble land in high soil moisture years do not exist in this situation.

The traditional decision rule provides different results because fertilizer levels are not optimized. Since spring soil moisture is an important variable for predicting wheat yields, the dynamic decision rule will provide a higher net present value than the fixed rotation static decision rule. Because a dry spring soil moisture state results in a low yield and wet spring soil moisture state contributes very large yields a continuous crop decision to be suboptimal because in dry years crop is still seeded. Expenses are paid out and losses incurred. The dynamic decision rule allows re-cropped acres to vary, and in case of a dry spring, stubble land will be fallowed instead of seeded. The gross margin would be greater for the flex-cropping system in this case.

If the static rotation is near the optimum for the climatic region, and soil moisture states are reasonably constant through time, there will be less advantage to adopting a flex-cropping system. In situations where rainfall is limiting to crop growth and stored soil moisture is important to the success of the crop, production functions will exhibit greater variability in the yields associated with different spring soil moisture states. The cumulative probability function of the dynamic system lies completely to the right of the other systems.[4] The flex-cropping system not only generates higher net present values than the other systems, it also does so at a lower level of risk.

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4 Technically it exhibits first degree stochastic dominance.

6 SUMMARY AND CONCLUSIONS

This project has examined after tax gross margin net present values accruing to Alberta wheat farmers under three fertilizer and crop rotation systems; a fixed rotation traditional fertilizer system, a static economic fertilizer decision system within a fixed rotation, and a static economic fertilizer decision system within a dynamic flex-cropping framework. Decision rules appropriate to each system were developed for case farms in three Alberta agro-climatic regions; Medicine Hat, Lethbridge and Olds.

The flex-cropping issue is expressed in a dynamic programming framework and incorporates elements not fully explored in previous studies; income taxation, variable input level decisions and stochastically determined moisture conditions and crop prices. Decisions are compared by simulating net present values of after tax gross margins for each system. The traditional system generated the lowest net present value, approximately 5 to 17 per cent below the static economic system. Greater improvements, on the order of 14 to 31 per cent above the static economic system, were observed by following dynamic flex-cropping decision rules. Not only did the dynamic flex-cropping decision rules generate superior decision rules regarding mean net present values, the rules were also risk efficient. The probability of low gross margins was minimized in all cases by following the dynamic flex-cropping decision rules.

The results of this and related studies indicate that dynamic flex-cropping models are viable for solving crop scheduling problems. The prescriptive power of the model is limited by available data, limitations which reside primarily in the agronomic components. The relationship between spring soil moisture, soil nutrients, and yield must be more clearly defined. This may be accomplished through extensive and long term field trials or through use of emerging biophysical models. Standardization of soil moisture classifications, including method of sampling and depth of measurement, would make field data more adaptable for making fertilizer and recropping decisions. The production functions defining the relationship between spring soil moisture levels and yields are particularly important. These require continued empirical attention.

The model developed lends itself readily to extensions such as additional crops, fertilizer inputs, erosion costs and soil degradation issues, financial structure of the farm, and evaluating the influence of government programs. Modern computers with large computational and storage capabilities make the implementation of stochastic dynamic programming methodology a viable farm management tool.

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