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An Economic Evaluation of Tillage Systems
on
Dark Brown Soils in Alberta

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ABSTRACT

Field trials, under commercial farm conditions were conducted on 14 farms, located on dark brown soils in Alberta, during the three year period 1985 through 1987. Because of farm to farm variability in tillage methods used, and because of the wide geographic dispersion of participating farm operations, general statistical inferences about agronomic matters are not warranted. In some cases the reduced tillage practice resulted in higher yields, while in other cases reduced tillage resulted in yield reductions. The results presented, although of limited scope and generality, are not dissimilar to previous research. Some researchers have reported a yield disadvantage for conservation tillage practices; other researchers have suggested the opposite may be true. The lack of statistical significance in yield differences in this study, and the inconclusiveness in other research suggests that differences between tillage methods may be economic rather than agronomic.

Because agronomic results about the relative merits of tillage methods evaluated in field trials, in this study and elsewhere were inconclusive, further and more long term experimentation to establish yield differences for alternative tillage systems is important.

Considerable effort in this study was directed toward refinement of analytical techniques for economic comparison of the alternatives available. Asset costing and replacement theory was applied to farm machinery compliments used in three tillage systems - conventional, reduced and minimum tillage - under two cropping systems - continuous cropping and a crop fallow program. Comparisons were made across three farm sizes - 960 acres, 1280 acres and 1600 acres.

Under continuous cropping, costs for the conventional and the minimum tillage systems were virtually identical. Both were lower than the reduced tillage system. This suggests that there are no economic cost penalties for adopting minimum tillage in preference to the conventional system. Under the crop fallow program, however, conventional tillage had a distinct cost advantage over reduced tillage, and even more pronounced over minimum tillage. A word of caution must be given. This study was confined, due to data limitations, to expected values and does not investigate stability of income issues for the various options evaluated. If there are sizeable differences between the variability of yields under minimum and conventional tillage, preferences would go towards the more stable system.

Additional studies of an empirical nature are warranted with regard to the relative risks involved. In the first place, the empirical question about the relative variability of crop yields under alternative tillage and cropping systems needs to be answered. This answer must be obtained, at least in part, from long term field experimentation. Secondly, sound data about forecasting errors in machinery repair rates, in downtimes and in salvage values are currently not available. For this reason the present study relied on an arbitrary discount rate, rather than one incorporating a market determined risk premium, for evaluating the costs of machinery complements.

It is crucial that these empirical questions of crop yield variability under alternative tillage and cropping programs be addressed. It is equally important that research be carried on to provide a better understanding of machinery asset management.

Finally, the economic analysis was conducted in a static framework. Useful additional information, of a dynamic nature, would investigate relative cost advantages under a flexible cropping system in which the cropping program responds to economic and technical variables from year to year. Data requirements for dynamic economic analysis include inter-relationships among agronomic variables such as crop yields, soil moisture, growing season precipitation, nutrient carryover, and weed and pest problems. Further research to accumulate data in these areas should be encouraged.

1 INTRODUCTION

Tillage management and cropping intensity is an important agricultural issue directly related to soil conservation. The reported disadvantages of summer fallow, combined with the high cost of land, have resulted in a higher level of cropping intensity. The degree to which summer fallowing is practiced varies with soil type and zone. In the brown soils summer fallowing is generally accepted as necessary. The black soils, on the other hand, need not be summer fallowed on a regular basis. Agronomic evidence suggests that a reduction in the level of summer fallow may be feasible within the dark brown soil zone.

Available soil moisture, when stubble cropping on dark brown soils, has been demonstrated as a limiting factor on yields (Govindasamy, 1983). The level of stored soil moisture is strongly influenced by the method of tillage and the number of tillage operations. Timing of tillage operations in the spring and fall is also thought to be a related factor.

No clear evidence exists about the impact of reduced tillage on the profitability of crop production on dark brown soils. Accordingly, the main objectives of this research was to evaluate alternative tillage methods from an agronomic perspective, and to assess the relative importance of tillage methods on the profitability of commercial farms.

2 FIELD EXPERIMENTS

The field experimentation was conducted, on a field scale, to determine spring wheat yield differences among selected tillage practices over a three year period, 1985 through 1987.

2.1 Methodology

Cooperating farm operators were located in the Three Hills - Drumheller - Standard area of the dark brown soil zone. The farms were selected on the basis of their current complement of tillage equipment and the tillage practices being followed, and as such, represent a wide range of commercially used tillage practices. The participating farms were, for the most part, earlier participants in the Farm Management Field Laboratory (Bauer et al.) and thus their willingness and ability to cooperate was a major factor in selection. No attempt was made to select farms randomly from within the sample frame.

Two main treatments were used in the study. The first treatment, which can be considered the control, consisted of conventional tillage methods. The second treatment consisted of a reduced tillage method. Plots were selected by each of the farmers involved in consultation with the project fieldman and divided into two strips, one for each of the treatments. The strips were tested for fertility and fertilized accordingly. The fertilizer program, and the proximity of the strips to one another, allowed variables such as soil fertility, tilth, soil type, precipitation, and topography to be considered as constants, or controlled variables within a treatment site. As a result, yield variability, due to the influence of common variables is minimized and the only major difference between the test strips is the tillage treatment.

The conventional tillage method, or the control, required the test strip to be cultivated once in the fall, followed by several cultivations in the spring. The reduced tillage method required that there be no fall tillage and one less tillage operation, than under the conventional method, in the spring. Since the farmers own commercial scale cultivation equipment was used, specific tillage practices varied from farm to farm, reflecting specific equipment available.

Due to the late start-up of the project in the fall of 1984, the fall tillage operation for the control strip was not possible. In partial compensation an extra tillage operation was done in the spring of 1985. In subsequent years the study methodology was followed as closely as possible subject to weather conditions in the fall of the year.

Crops were harvested using field scale commercial harvesting equipment available on the subject farms. Initially, yield measurements were to have been determined by weighing the harvest at the local elevator. Difficult harvesting conditions, due to frequent rains and a wet fall, imposed severe time constraints and proved this plan to be impractical. Furthermore, a single measurement from the entire test strip does not reflect variability of crop yields that may exist within the treatment.

To resolve these shortcomings, an alternate harvesting procedure was adopted. Harvest sites were selected randomly within the test strip, and then the volume of yield was measured at each site. Five randomly selected 300 foot lengths of swath were marked in each test strip. The grain harvested from the length of swath was collected from the combine into a heavy paper cylinder on the grain truck. The cylinders, commonly used as concrete forms, measured 48 inches in height and 36 inches in diameter. The cylinders were easily filled, measured, and emptied without a significant cost in time and convenience. The volume measurement was converted to weight, after correcting for moisture content, and reported in bushels per acre using standard bushel weights.

The use of field scale machinery did not pose major difficulty with respect to tillage or seeding operations. Obtaining consistent yield data using commercial harvesting equipment and methods, on the other hand, did present some difficulties. Replication to remove the effect of topographical and other field variations at a particular experimental site is essential if inferences are to be drawn. Although measures were taken to minimize disruption, the measurement procedure, nevertheless, presented a significant inconvenience to participating farm operators during the rather hectic harvest season. An ideal situation would include supervision of yield measurements, and a local project technician within easy access of the participating farmers. Unfortunately the fieldman was headquartered some 300 kilometres distant from the experiment location, and this required considerable, ineffective and frequent, because of unpredicted unsuitable harvest weather, travel expenses. These logistical problems could be overcome with the presence of local supervision.

2.2 Growing Conditions

The weather conditions during the study period cannot be described as typical. Table 2.2-1 shows the average rainfall received during the growing season on the subject farms in comparison to the mean long-term average precipitation recorded at nearby locations.

Total rainfall received during the 1985 growing season was 67% of normal. The distribution of rainfall caused some stress to the growing crop as average rainfall in May, June, and July was only about 45% of the thirty year average. In addition much of the total rain received fell after the harvest had started. Rainfall in August was 127% of the long-term average and may have resulted in further losses in yield due to poor harvesting conditions.

Conditions during the 1986 growing season were also atypical. Precipitation during May was reported as 28% above average. Only 63% of normal rainfall was received in June but July was wet. August was drier than normal receiving only half of the normally expected rain. Total growing season precipitation received was only 44% of the long-term average for the area.

In 1987 total precipitation during the growing season was 93% of the long-term average. May and June however were extremely dry. Only 28% of the normally expected rainfall fell in May. June was only slightly better with 34% of the thirty year mean precipitation received. July received normal amounts of rainfall and August precipitation was 82% of the long-term average.

Table 2.2-1 Study Area Precipitation Data

	May	June	July	August
Growing Season Precipitation:				
1985	20.3 mm	31.9 mm	21.4 mm	64.3 mm
1986	41.6 mm	41.9 mm	76.2 mm	25.4 mm
1987	12.3 mm	22.9 mm	49.7 mm	41.2 mm
Long-term average	42.6 mm	67.3 mm	49.7 mm	50.4 mm
Percent of Long-Term Average:				
1985	47.7 %	47.4 %	43.1 %	127.4 %
1986	128.1 %	63.3 %	153.2 %	50.4 %
1987	28.8 %	34.0 %	100.0 %	81.7 %
Long-Term Average Precipitation:				
Strathmore	50.6 mm	81.7 mm	48.6 mm	49.2 mm
Three Hills	43.0 mm	70.7 mm	54.4 mm	56.9 mm
Drumheller-Andrew	41.7 mm	62.4 mm	51.2 mm	52.0 mm
Drumheller	35.2 mm	54.3 mm	44.7 mm	43.6 mm
Long-term average	42.6 mm	67.3 mm	49.7 mm	50.4 mm

2.3 Results

Results for the three years are summarized in Table 2.3-1. In 1985, the first year of operation, yields were determined on a total plot basis without regard to random sampling of test plots. In 1986 and 1987, due in large measure to disruptive harvest weather, not all test locations yield measurements were done on a replicated basis. Furthermore, not all farmers were able to participate for the full three years of the study. Nevertheless, some general observations are possible.

Table 2.3-1 Comparative Crop Yields in Bushels per Acre

Farm	Year	Conventional Tillage	Reduced Tillage	Increase due to treatment	Probability Level[a]
1	1985	29.3	24.4	-4.9	n/a
	1987	27.2	25.0	-2.1	.4902
2	1986	38.0	32.0	-6.0	n/a
3	1985	20.0	16.9	-3.1	n/a
	1986	58.6	50.2	-8.4	n/a
	1987	18.9	18.9	0.0	n/a
4	1985	19.3	27.4	8.1	n/a
	1986	31.2	45.9	14.7	n/a
	1987	31.5	37.0	5.5	.0365
5	1985	16.5	19.3	2.8	n/a
	1986	26.5	29.1	2.6	.2302
6	1985	38.2	32.1	-6.2	n/a
	1986	46.7	44.1	-2.6	.1551
	1987	47.1	46.1	-1.0	.2791
7	1985	37.3	35.3	-2.0	n/a
	1986	33.2	38.5	5.3	.0376
8	1986	31.7	34.3	2.6	n/a
9	1985	27.2	25.6	-2.1	n/a
	1986	26.6	33.1	6.5	n/a
10	1986	32.2	38.2	6.0	.0075
11	1986	65.3	52.8	-12.5	n/a
12	1985	32.0	29.0	-3.0	n/a
	1986	44.2	43.3	-0.9	.6223
13	1986	54.4	52.8	-1.6	.8521
14	1986	63.8	69.8	6.0	.2327
	1987	62.0	62.5	0.5	.0965

(a) Note: levels indicate the probability of the reported difference arising because of chance rather than a difference between conventional and reduced tillage.

Eight farms provided useable data in 1985, the initial year of the study. During 1986 thirteen farms completed the project satisfactorily and in 1987 data were supplied by five farms. Three farms participated in all three years of the study.

Six of the eight of the farms participating in 1985 reported higher yields on the conventional tilled plots as compared to reduced tillage. In 1986 seven of the thirteen farms reported higher yields for the reduced tillage treatment. Four of the five farms reported higher yields in 1987 under reduced tillage. Generally however, the yield differences between the two treatments cannot be shown to be statistically significant. This is due to the limited number of replications and the resulting lack of degrees of freedom.

Despite the failure to show statistical significance some of the yield differences are noteworthy. As an example, farm number 4 reported higher yields on the reduced tillage in all three years of the study. The difference ranged from a low of 5.5 bushels per acre in 1987 to a high of 14.7 bushels per acre in 1986. On average the reduced tillage treatment yielded 9.4 bushels per acre more than the conventional tillage practices. Similarly, farm numbers 5, 8, 10 and 14 also reported better yields on the reduced tillage plots in the years in which they participated. These differences may have been due to conservation of soil moisture under the reduced tillage regimes.

Previous studies have reported similar results. Lindwall and Anderson (1981) obtained higher yields under a zero-tillage system for spring wheat in southern Alberta. The higher yields were attributed to conservation of soil moisture from the practice of chemical fallow. Mahli et al. (1988) reported a higher number of tillers on zero-tillage plots in all but one location, yet a lower yield for all plots using zero-till. Other researchers (Harder, 1979; Koehler et al. 1983; Rasmussen et al. 1983) reported a yield reduction under zero-tillage in comparison to conventional tillage.

2.4 Agronomic Conclusions

Because of farm to farm variability in tillage methods used, and because of the wide geographic dispersion of participating farm operations, general statistical inferences about agronomic matters are not warranted. In some cases the reduced tillage practice resulted in higher yields, while in other cases reduced tillage resulted in yield reductions. The lack of statistical significance in the yields suggests that differences between tillage methods will be economic rather than agronomic. The results presented here, although of limited scope and generality, are not dissimilar to previous research. Some researchers have reported a yield disadvantage for conservation tillage practices; other researchers have suggested the opposite may be true. The question is therefore one of the degree of sensitivity to cost differences between tillage systems.

3 ECONOMIC ANALYSIS

The agronomic results reported in this research indicate that there were no statistically significant yield differences between the two treatments tested. From an economic point of view this means that the gross revenues associated with reduced and conventional tillage regimes can be taken as equal. Differences in the profitability of the two methods will depend primarily upon differences in costs. The costs will depend upon the tillage method used and the particular cropping program followed. Costs will also be influenced by farm size.

To derive cost structures for various tillage systems, eighteen simulated farm businesses representing three tillage systems, two cropping systems and three farm sizes were created. The three tillage systems were conventional tillage, reduced tillage and minimum tillage systems. The two cropping systems chosen were continuous cropping and a crop fallow program. To analyze the effect of size a 960 acre farm, a 1280 acre farm and a 1600 acre farm were included.

The definition of tillage practices varies widely and for the purposes of this study the definitions of Jensen and Timmermans (1987) were adopted and refined by Hazelwood[2]. A brief definition for each tillage system appears below.

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2 Personal communication with J. Hazelwood, Conservation and Development Branch, Alberta Agriculture, Edmonton and formerly District Agriculturist, Alberta Agriculture, Three Hills.

Conventional Tillage (CT): Conventional tillage involves the use of tillage operations to control weeds and prepare the seedbed. Both pre-emergent, soil incorporated herbicides and in-crop post-emergent herbicides are used. Specifically, for purposes of this research, conventional tillage is described as a program involving a fall cultivation combined with the application of fertilizer and wild oat control chemicals and two pre-seeding cultivations in the spring. Summer fallow operations are performed by cultivation.

Reduced Tillage (RT): Reduced tillage involves the reduction of tillage operations to decrease erosion, maintain soil moisture, or to save time and fuel by combining operations. Specifically, for purposes of this research, reduced tillage is described as a program involving a fall cultivation combined with the application of fertilizer and wild oat control chemicals and one pre-seeding cultivation in the spring. Summer fallow operations are performed partially by cultivation and partially by chemical means.

Minimum Tillage (MT): Minimum tillage involves the reduction of tillage to a minimum and the use of herbicides to delay or reduce the amount of tillage required. Minimum tillage can occur within a summer fallow system by using chemicals to delay tillage. In a continuous cropping system, glyphosate can be used to control weeds. Specifically, for purposes of this research, minimum tillage is described as a program involving a fall cultivation combined with the application of fertilizer and wild oat control chemicals and no pre-seeding cultivations in the spring. Summer fallow operations are performed mainly by chemical means.

For purposes of this research, the cropping systems are as described below.

Continuous Cropping System (CWW): The continuous cropping system is a program with one crop of canola followed by two crops of wheat.

Crop Fallow System (CWF): The crop fallow system is a program with a crop of canola followed by a crop of wheat followed by fallow.

3.1 The Economic Model

The major cost components of tillage operations are those associated with the machinery and equipment required and with the chemical weed control measures and levels of fertilization.

Machinery costs can be separated into two components, namely the costs associated with the capital invested in the machinery and the costs of maintenance, repair, fuel and labour. To obtain a valid comparison between the two cropping systems, harvesting costs are included in the analysis. Machinery costs vary with the length of time specific machines are kept in operation. To resolve this issue, optimum replacement times were determined following methodology developed by Woloshyn (1990).

Cost of materials consist of fertilizer and herbicides. Herbicide use varies directly with tillage operations on the crop fallow system. Fertilizer use, while not directly related to tillage system, varies with the cropping program and is, therefore, included to facilitate comparison.

3.1.1 Capital Costs

The net present value of capital invested into a machine lasting for a specific number of years can be expressed by the equation:

$$K = C - \frac{SV_n}{(1+r)^n}$$

where "K" represents the net present value of capital invested in the machine, "C" the original outlay of capital, "SV_n" the salvage value of the machine at the end of the "n" years and "r" the discount rate reflecting the opportunity cost of capital.

In the case of an on going farming operation, machinery is purchased, used for a period of time and then replaced. Suppose, for simplicity, that the situation developed above is for the first machine in a series of identical machines. Assume that the first machine is replaced after "n" years with a second identical one. More specifically this might be expressed as:

$$K_{1,n} = C - \frac{SV_n}{(1+r)^n}$$

where "K_1" now represents the net present value of capital invested in the first machine.

The second machine in the series of machines, also assumed to be used for "n" years, has exactly the same net present value at the start of its life as did the first. It must be discounted by "n" years if it is to represent the present value at the date of the decision. The net present value of the second machine can be expressed as:

$$K_{2,n} = \frac{1}{(1+r)^n}\left[C - \frac{SV_n}{(1+r)^n}\right]$$

The present value, today, of the capital invested in the k^{th} machine would be:

$$K_{k,n} = \frac{1}{(1+r)^{(k-1)n}}\left[C - \frac{SV_n}{(1+r)^n}\right]$$

Since each of the machines in the sequence have identical net capital outlays, the net present value of all capital invested in the machines from the first through to and including the "k^{th}", each replaced after "n" years would be:

$$K_n = \left[C - \frac{SV_n}{(1+r)^n}\right]\left[1 + \frac{1}{(1+r)^n} + \ldots + \frac{1}{(1+r)^{(k-1)n}}\right]$$

If the replacement process is continued indefinitely (i.e. as "k" approaches infinity) the above equation can be reduced to:

$$K_n = \left[C - \frac{SV_n}{(1+r)^n}\right]\left[\frac{(1+r)^n}{(1+r)^n - 1}\right]$$

The value "K_n" represents the net present value of all funds invested into the particular machine. Multiplication of this total amount by the discount rate results in the annual cost of capital invested in the machine:

$$AK_n = \left[C - \frac{SV_n}{(1+r)^n}\right]\left[\frac{(1+r)^n}{(1+r)^n - 1}\right]r$$

The quantity "AK_n" represents the annual annuity equivalent of the net present value.

The outlay of capital for the purchase of the machine, "C", and the recovery of its salvage value at the end of its life, "SV" should be expressed in real (i.e. inflation removed) terms. This requires, also, that the discount rate, "r", be expressed in real terms. Furthermore, the discount rate should reflect the degree of risk involved in holding the machinery asset, particularly in estimating the salvage value. Data series on salvage values for farm machinery are not well developed. The American Society of Agricultural Engineers (ASAE) data reflect only the age of the machine in years. Its age in hours of use or its condition are not reflected in the salvage value. Other available methods (Peacock and Baker, 1970; McNeill, 1979) do not appear to be superior. For purposes of this study salvage values were determined from ASAE data, but adjusted for annual use.

3.1.2 Machinery Repair and Maintenance Costs

Annual repair and maintenance costs were determined from ASAE methodology and data. Although widely used these data are not without problems. Bradford and Reid (1982) discuss some of the weaknesses and the resulting implications. They suggest that "the crux of the problem is a lack of data on [repairs and maintenance] for farm tractors and other major farm machines for specific situations over an extended number of years". Nevertheless, no superior alternative methods are available.

According to ASAE methodology, repair costs are related to the original cost of the machine and the age of the machine in hours in addition to specific characteristics of the particular category of machine. The annual cost is expressed in the equation:

$$R_t = Ca_1\left[\left[\frac{H_t}{1000}\right]^{a_2} - \left[\frac{H_{t-1}}{1000}\right]^{a_2}\right]$$

In the above formulation the quantity "R_t" represents the repair and maintenance cost in year "t", "C" the original cost of the machine, "H_t" the accumulated hours of use of the machine to the end of year "t" and "H_{t-1}" the accumulated hours of use to the end of the previous year, namely "$t-1$". The coefficients, "a_1" and "a_2" represent the particular category of machine.

The present value of repair and maintenance costs for a single machine kept to the end of "n" years is obtained from the equation:

$$O_{1,n} = \frac{R_1}{(1+r)} + \frac{R_2}{(1+r)^2} + \ldots + \frac{R_n}{(1+r)^n} = \sum_{(i=1)}^{n} \frac{R_t}{(1+i)^t}$$

The quantity "$O_{1,n}$" represents the present value of repair and maintenance costs of the first machine kept for each of "n" years in the repeating cycle. A series of "k" machines each kept for "n" years has a total present repair and maintenance cost of:

$$O_n = \sum_{i=1}^{n} \frac{R_t}{(1+r)^t} + \frac{1}{(1+r)^n}\left[\sum_{i=1}^{n} \frac{R_t}{(1+r)^t}\right] + \ldots + \frac{1}{(1+r)^{(k-1)n}}\left[\sum_{i=1}^{n} \frac{R_t}{(1+r)^t}\right]$$

If the process is repeated indefinitely i.e. as "k" approaches infinity, the above equation can be reduced to:

$$O_n = \left[\sum_{i=1}^{n} \frac{R_t}{(1+r)^t}\right]\left[\frac{(1+r)^n}{(1+r)^n - 1}\right]$$

The repair costs occurring over the infinite series of replacement cycles were reduced to an annual annuity equivalent:

$$AO_n = \left[\sum_{i=1}^{n} \frac{R_t}{(1+r)^t}\right]\left[\frac{(1+r)^n}{(1+r)^n - 1}\right]r$$

In this formulation, "AO_n", is the average annual cost of repair.

Downtime, specifically the loss of time due to breakdown and repair during critical operations, is an important component of operating cost. Central to this issue is the expected amount of downtime, especially as the machine ages. ASAE provides methodology and data on this issue, but as in the case of salvage values and repairs, this is not well documented. A recent study estimated the hours of annual downtime from data collected over the period 1971 to 1982 (Hardesty and Carmen, 1988).[3] For purposes of this study, the Hardesty, Carmen data were used to establish expected downtimes for the primary tractor, to which custom charges during downtime were applied. The net present value of the downtime costs are incorporated into annual repair costs, "AO_n".

The annual repair costs, "R_t", and the downtime costs, must of course, be expressed in real (i.e. inflation removed) terms.

3.1.3 Optimal Machinery Replacement Cycle

Machinery costs of capital and operations vary with age of machine. As a machine ages, the capital costs are spread out over more years, and become less on a per year basis. Operating costs, particularly repair and downtime costs, increase with machine age. The optimal replacement age occurs where the average net present value, or the annual equivalent, is at a minimum. The replacement age is determined through the following algorithm.

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3 An alternate method would be to calculate downtime costs directly as the reduced revenue resulting from crop yield and quality losses attributable to machine breakdown. While having an intuitive appeal, particularly in the case of harvest equipment breakdown, the losses resulting from delays suffered at seeding or during spraying are less obvious. A loss in timeliness at these stages in crop production may have a serious impact on both yield and grade but the cost is more difficult to measure.

$$AC_{n^*} = \underset{n=1}{\overset{N}{\text{MIN}}} [AK_n + AO_n]$$

In this formulation AC_{n^*} represents the minimum annual cost of capital and operation for a machine in a cycle requiring replacement at the end of n^* years.

3.1.4 Other Variable Costs

Other variable costs include, in addition to the repair costs already determined as part of machinery operating costs, fuel and lubrication expenses, labour costs, fertilizer, and weed control chemicals. These costs vary in proportion to the number of hours required to perform tillage and harvesting operations, and to the particular cropping program being followed.

3.2 Simulated Production Costs For Selected Cropping and Tillage Systems

Eighteen simulated situations - three tillage systems, two cropping systems and three farm sizes - were developed to study the behavior of production cost structures. Detailed specifications were given for each situation in terms of the machinery operations and the fertilizer and herbicide materials required. The specific machines used and the number of operations on each crop are outlined for each tillage and cropping option.

Harvesting operations, as represented by swathing and combining activities, although not directly a part of the tillage system were, nevertheless included in the analysis to allow a better comparison between continuous cropping and crop fallow programs.

Each of the systems were specified with as much technical detail with as much detail so that the results can be reproduced as economic conditions, in particular input prices, change. Hours of operation for each machine and activity were determined from ASAE data. Hours of operation were then used to obtain hours of labour and fuel consumption for each operation. The unit costs of materials and services used in the analysis are contained in Table 3.2-1.

Detailed and summarized costs for machinery services, fertilizer, and herbicides are provided for each tillage system and cropping program in the appendix.

Table 3.2-1 Per Unit Input Costs

Item of Cost	Cost per unit
Labour	$7.00 per hour
Diesel Fuel	$1.00 per gal
Discount rate	10 % per annum
Fertilizer:	
Nitrogen	$0.25 per lb
Phosphorus	$0.28 per lb
Herbicides:	
Wild Oat Control	$12.00 per acre
Broadleaf Control	$6.00 per acre
March Fallow Control	$1.50 per acre
August Fallow Control	$14.00 per acre

3.3 Production Cost Comparisons Among Selected Cropping and Tillage Systems and Farm Size

Comparison of costs between the three tillage systems across the two cropping system and the three farm sizes reveals a number of interesting points.

Comparing the conventional tillage system and the minimum tillage systems, under the continuous cropping system, reveals that the total cost of operation, including both machinery and materials, are essentially the same, (see Table 3.3-1). Examination of Table 3.3-2 shows that the minimum tillage system costs for the small farm of 960 acres were 0.33% higher than for the conventional system but were lower for both the medium sized farm of 1,280 acres and the large farm of 1,600 acres by 0.51% and 1.51% respectively.

Reduced tillage was the highest cost system, ranging from 3% to almost 6% higher than the conventional system. The higher cost, under the reduced tillage system, is due mainly to the duplication resulting from retaining a field cultivator in the machinery complement in addition to the air seeder. This duplication adds approximately $4,700 for the small farm and almost $4,000 for the large farm.

Under the crop fallow system the conventional tillage system was the lowest cost system. The reduced tillage system was considerably higher for each of the farm sizes, ranging from about 3% to 6% higher. The minimum tillage system, under the crop fallow system, was the most costly at from 7% to 9% higher (see Table 3.3-1 and Table 3.3-2). The machinery duplication serves to explain most of the higher cost of the reduced tillage system relative to the conventional approach. On the 1,600 acre farm for example, the $2,800 higher cost was due to $2,000 as a machinery cost difference with the remaining $800 due to material costs. The higher cost of the minimum tillage system under a crop fallow system was due to the higher cost of materials, notably weed control chemicals in the fallowing operation. On the 1,600 acre farm, machinery costs were $1,548 lower than the conventional tillage system, but the material costs were $8,267 higher, for a net cost disadvantage of $6,719.

Table 3.3-1 Total Costs on a Total Farm Basis

Tillage System	Continuous Crop System			Crop Fallow System		
	960 acres	1280 acres	1600 acres	960 acres	1280 acres	1600 acres
Machine Cost						
CT	46162	52405	63749	42849	47422	57266
RT	50879	56896	67664	46366	50747	59264
MT	46439	51880	61823	43885	47823	55718
Material Cost						
CT	37824	50432	63040	22176	29568	36960
RT	37824	50432	63040	22656	30202	37752
MT	37824	50432	63040	27136	36181	45227
Total Cost						
CT	83986	102837	126789	65025	76990	94226
RT	88703	107328	130704	69022	80949	97016
MT	84263	102312	124863	71021	84005	100945

Table 3.3-2 Percentage Change of Selected Tillage System Costs from Conventional Tillage

	Continuous Crop System			Crop Fallow System		
Tillage System	960 acres	1280 acres	1600 acres	960 acres	1280 acres	1600 acres
CT	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%
RT	5.62%	4.37%	3.09%	6.15%	5.14%	2.96%
MT	0.33%	-0.51%	-1.52%	9.22%	9.11%	7.13%

Costs associated with machinery operation account for a major portion of total costs. Table 3.3-3 shows the percentage of total costs represented by machinery costs. Under the continuous cropping system, machinery costs as a percentage of total costs range from a low of 49.51% on the 1,600 acre farm under minimum tillage to a high of 57.36% for the 960 acre farm under reduced tillage. Under the crop fallow system the percentages range from a low of 55.20% for the large 1600 acre farm under minimum tillage to a high of 67.18% for the small 960 acre farm under reduced tillage. The high percentage under reduced tillage results from the machinery duplication. The relatively lower percentage under the minimum tillage, specifically in the crop fallow system, is due to the higher cost of weed control chemicals.

Table 3.3-3 Machinery Cost as Per Cent of Total Cost

	Continuous Crop System			Crop Fallow System		
Tillage System	960 acres	1280 acres	1600 acres	960 acres	1280 acres	1600 acres
CT	54.96%	50.96%	50.28%	65.90%	61.60%	60.78%
RT	57.36%	53.01%	51.77%	67.18%	62.69%	61.09%
MT	55.11%	50.71%	49.51%	61.79%	56.93%	55.20%

Comparison of costs on a per acre basis reveal the existence of size economies for each of the three tillage systems (see Table 3.3-4). Costs of material do not change with changes in farm size. Costs associated with machinery do, however, decline as farm size increases. Even though the complement of machinery was matched to farm size, lumpiness in available machinery sizes, nevertheless imposes a higher capital cost on the smaller farm. The per acre cost of machinery drops by approximately $10.00 per acre for the three tillage systems, and for the two cropping systems. Table 3.3-4 displays, in its last block, total cost per acre including a charge for cash rent. Since this is a fixed amount of $25.00 per acre, the differences between systems and size are not altered.

A more detailed examination of machinery size economies is facilitated by separating capital costs from the operating costs of repairs, fuel and labour (see Table 3.3-5). Machinery operating costs are, as expected, fairly stable across farm size. There is a minor reduction in operating costs of about $1.00 per acre in the minimum tillage system as compared to the conventional system under the continuous cropping system. There was virtually no difference between the conventional and reduced tillage systems. Reductions for operating costs were greater in comparing the conventional and minimum till under the crop fallow system, on the order of $1.50. Reduced till was approximately $0.50 less than conventional till.

Table 3.3-4 Total Costs on a Per Acre Basis

Tillage System	Continuous Crop System 960 acres	1280 acres	1600 acres	Crop Fallow System 960 acres	1280 acres	1600 acres
Machinery Cost						
CT	48.09	40.94	39.84	44.63	37.05	35.79
RT	53.00	44.45	42.29	48.30	39.65	37.04
MT	48.37	40.53	38.64	45.71	37.36	34.82
Material Cost						
CT	39.40	39.40	39.40	23.10	23.10	23.10
RT	39.40	39.40	39.40	23.60	23.60	23.60
MT	39.40	39.40	39.40	28.27	28.27	28.27
Total Cost (excluding land rental)						
CT	87.49	80.34	79.24	67.73	60.15	58.89
RT	92.40	83.85	81.69	71.90	63.24	60.64
MT	87.77	79.93	78.04	73.98	65.63	63.09
Total Cost (including land rental)						
CT	112.49	105.34	104.24	92.73	85.15	83.89
RT	117.40	108.85	106.69	96.90	88.24	85.64
MT	112.77	104.93	103.04	98.98	90.63	88.09

Capital costs on the other hand, are considerably reduced, by approximately $8.00 as farm size is increased from 960 acres to 1,280 acres and an additional $2.00 as farm size is expanded further to 1,600 acres under the continuous cropping system. Capital cost differences between cropping programs, for the various tillage systems, are minor. These differences are in the range of $1.00 with capital costs per acre being higher under a crop fallow system in the cases of conventional and reduced tillage. The reverse is true in the case of minimum tillage where continuous cropping has a higher capital cost per acre than the crop fallow system, except on the 1,600 acre farm.

The proportion of total machinery costs represented by capital costs ranges from a low of 73.56% for conventional tillage on continuous crop to a high of 87.95% for minimum tillage on a crop fallow system (see Table 3.3-6 for details). As farm size increases the proportion of total machinery costs represented by capital decreases. This is because the level of operating costs remain constant across size while cost economies occur with respect to capital. Since machinery operating costs per acre are lower for the crop fallow program than for continuous cropping but capital cost differences are minor, it follows that the proportion of capital costs is higher for the canola, wheat, wheat system than for the canola, wheat, fallow system.

Table 3.3-5 Machinery Costs on a Per Acre Basis

Tillage System	Continuous Crop System 960 acres	1280 acres	1600 acres	Crop Fallow System 960 acres	1280 acres	1600 acres
Machine Operating Costs						
CT	9.58	9.93	10.53	6.92	6.98	7.47
RT	9.79	9.93	10.59	6.45	6.38	6.91
MT	8.61	8.73	9.30	5.51	5.45	5.90
Machine Capital Costs						
CT	38.51	31.02	29.31	37.72	30.07	28.32
RT	43.21	34.52	31.70	41.85	33.27	30.14
MT	39.77	31.80	29.34	40.21	31.91	28.92
Total Machinery Cost						
CT	48.09	40.94	39.84	44.63	37.05	35.79
RT	53.00	44.45	42.29	48.30	39.65	37.04
MT	48.37	40.53	38.64	45.71	37.36	34.82

Table 3.3-6 Machinery Capital Costs as a Per Cent of Total Machinery Costs

Tillage System	Continuous Crop System 960 acres	1280 acres	1600 acres	Crop Fallow System 960 acres	1280 acres	1600 acres
CT	80.09%	75.75%	73.56%	84.50%	81.16%	79.12%
RT	81.53%	77.67%	74.95%	86.65%	83.91%	81.36%
MT	82.21%	78.45%	75.93%	87.95%	85.40%	83.06%

Cost differences between the continuous cropping system and the crop fallow system are sizeable. Reference to Table 3.3-7 reveals that these differences range from $13.79 to $21.05. Cost reductions in moving from continuous cropping to crop fallow are greatest under conventional tillage, and least under the minimum tillage case. The cost reductions increase across farm size for a given tillage system, but are minimal.

Crop fallow costs as a percent of continuous crop costs range from a high of 84.29% on small farm under minimum tillage to a low of 74.23% in the case of reduced tillage on the large farm (see Table 3.3-8). The costs associated with the crop fallow system relative to the continuous cropping system decline with increases in farm size. The addition of the cash rental charge increases the proportion of the crop fallow system costs to those incurred under the continuous cropping system by 4 to 5 percentage points and more accurately reflect the situation.

Table 3.3-7 Per Acre Cost Reductions of the Crop Fallow System over Continuous Cropping System

Tillage System	960 acres	1280 acres	1600 acres
CT	19.76	20.19	20.35
RT	20.50	20.19	21.05
MT	13.79	14.30	14.95

Table 3.3-8 Crop Fallow System Costs as per cent of Continuous Cropping System

Tillage System	960 acres	1280 acres	1600 acres
Excluding land rental			
CT	77.42%	74.87%	74.32%
RT	77.81%	75.42%	74.23%
MT	84.29%	82.11%	80.84%
Including land rental			
CT	82.44%	80.83%	80.48%
RT	82.54%	81.07%	80.27%
MT	87.77%	86.37%	85.49%

As costs decline in moving from a continuous cropping system to the crop fallow system, so does the proportion of land available for generating revenue. Consequently, the revenue per cropped acre must rise to hold net revenue constant.

For example, suppose that costs per cultivated acre under a two thirds crop - one third fallow program on a 960 acre farm were $77.42 and $100.00 under a continuous cropping program. Suppose also, that the variability of revenue under the two cropping programs was identical. It stands to reason that revenue per cropped acre in the crop fallow program must be $38.71, or 50%, higher than under the continuous cropping program for an equal, or break-even, level of income. The revenue per cropped acre would need to be $116.13, and with 640 acres in crop would amount to $74,323.20. The costs of $77.42 per cultivated acre over the entire farm of 960 acres would amount to $74,323.40, yielding a break-even situation. Hence the revenue per cropped acre, under the crop fallow system needs to be 16.13% greater than the revenue per cropped acre under the continuous cropping system.

The desirability of holding net revenue constant in the analysis proceeds under the assumption of equal variability in revenue generated by the two cropping systems. If the variability in returns from the continuous system is higher than for a crop fallow program the continuous cropping system would need to pay a premium, or alternatively, the crop fallow system would require a smaller percentage increase for its justification.

If, for example, the variability under the crop fallow program was lower than for continuous cropping, the required revenue level would be less than $116.13. If the crop fallow program was more risky the required added revenue would rise accordingly. The degree of variability is an empirical question not addressed in this study.

Table 3.3-9 shows the increased revenue per cropped acre, under the crop fallow system, needed to justify the crop fallow system over the continuous cropping system. The calculations are derived directly from the cost proportions of Table 3.3-8. The extra revenue needed is greatest in the minimum tillage case. There appears to be little difference between the conventional and reduced tillage systems. The extra revenue required for equality of income declines as farm size increases.

Inclusion of a charge for cash rent does not change the relative positions of tillage systems. It does however increase the extra income per cropped acre required to justify the crop fallow program by from 5 to 10 percentage points.

Table 3.3-9 Per Cent Increase in Revenue Per Cropped Acre Required on a Crop Fallow System over the Continuous Cropping System for Equality of Cropping Systems

Tillage System	960 acres	1280 acres	1600 acres
Excluding land rental			
CT	16.13%	12.31%	11.48%
RT	16.72%	13.13%	11.35%
MT	26.44%	23.17%	21.26%
Including land rental			
CT	23.66%	21.25%	20.71%
RT	23.81%	21.60%	20.40%
MT	31.65%	29.55%	28.24%

3.4 Economic Conclusions

The cost differences between the conventional and minimum tillage systems under a continuous cropping program are minor. The reduced tillage system has a distinct cost disadvantage by comparison. On the other hand, the conventional tillage system has a marked advantage over both the reduced and minimum tillage systems under the crop fallow program. The higher costs of chemical fallow under this cropping option place the minimum tillage system in last position.

For continuous cropping, the conventional tillage system and the minimum tillage system are virtually identical from a cost stand point, and dominate the reduced tillage system. The conventional tillage system dominates the tillage choices evaluated under the crop fallow program.

The economically most desirable choices, based upon costs alone under the assumption of no difference in yield level or variability, would be either the conventional or the minimum tillage system for the continuous cropping program and the conventional tillage system for the crop fallow program.

In the absence of information about crop yield variability under the continuous cropping system and the crop fallow system, choice is restricted to the conventional tillage system and depends upon the extra revenue generated because of the fallow operations. If the fallow operation increases crop yields by at least 20% - and more on smaller scale operations, it is justified.

4 GENERAL CONCLUSIONS AND RECOMMENDATIONS

Field trials, under commercial farm conditions were conducted on 14 farms, located on dark brown soils in Alberta, during the three year period 1985 through 1987. Because of farm to farm variability in tillage methods used, and because of the wide geographic dispersion of participating farm operations, general statistical inferences about agronomic matters are not warranted. In some cases the reduced tillage practice resulted in higher yields, while in other cases reduced tillage resulted in yield reductions. The results presented, although of limited scope and generality, are not dissimilar to previous research. Some researchers have reported a yield disadvantage for conservation tillage practices; other researchers have suggested the opposite may be true. The lack of statistical significance in yield differences in this study, and the inconclusiveness in other research suggests that differences between tillage methods may be economic rather than agronomic.

Because agronomic results about the relative merits of tillage methods evaluated in field trials, in this study and elsewhere were inconclusive, further and more long term experimentation to establish yield differences for alternative tillage systems is important.

Considerable effort in this study was directed toward refinement of analytical techniques for economic comparison of the alternatives available. Asset costing and replacement theory was applied to farm machinery compliments used in three tillage systems - conventional, reduced and minimum tillage - under two cropping systems - continuous cropping and a crop fallow program. Comparisons were made across three farm sizes - 960 acres, 1280 acres and 1600 acres.

Under continuous cropping, costs for the conventional and the minimum tillage systems were virtually identical. Both were lower than the reduced tillage system. This suggests that there are no economic cost penalties for adopting minimum tillage in preference to the conventional system. Under the crop fallow program, however, conventional tillage had a distinct cost advantage over reduced tillage, and even more pronounced over minimum tillage. A word of caution must be given. This study was confined, due to data limitations, to expected values and does not investigate stability of income issues for the various options evaluated. If there are sizeable differences between the variability of yields under minimum and conventional tillage, preference would go towards the more stable system.

Additional studies of an empirical nature are warranted with regard to the relative risks involved. In the first place, the empirical question about the relative variability of crop yields under alternative tillage and cropping systems needs to be answered. This answer must be obtained, at least in part, from long term field experimentation. Secondly, sound data about forecasting errors in machinery repair rates, in downtimes and in salvage values are currently not available. For this reason the present study relied on an arbitrary discount rate, rather than one incorporating a market determined risk premium, for evaluating the costs of machinery complements.

It is crucial that these empirical questions of crop yield variability under alternative tillage and cropping programs be addressed. It is equally important that research be carried on to provide a better understanding of machinery asset management.

Finally, the economic analysis was conducted in a static framework. Useful additional information, of a dynamic nature, would investigate relative cost advantages under a flexible cropping system in which the cropping program responds to economic and technical variables from year to year. Data requirements for dynamic economic analysis include inter-relationships among agronomic variables such as crop yields, soil moisture, growing season precipitation, nutrient carryover, and weed and pest problems. Further research to accumulate data in these areas should be encouraged.

5 REFERENCES

American Society of Agricultural Engineers. 1988. *ASAE Standards.* St. Joseph, MI. American Society of Agricultural Engineers.

Bauer, L., T.A. Petersen and T.J. Lougheed. 1980. The Farm Management Field Laboratory - Its Concept and Objective and The 1980 Business Summary. Edmonton: University of Alberta, Department of Rural Economy, November.

Bauer, L., T.A. Petersen and T.J. Lougheed. 1985. An Analysis of the Capital Structure and Earning Performance of 16 Alberta Case Farms - 1980 to 1984. Edmonton: University of Alberta, Department of Rural Economy.

Bradford, G. and D. Reid. 1982. Theoretical and Empirical Problems in Modeling Optimal Replacement of Farm Machines. *Southern Journal of Agricultural Economics* 14(July):109-116.

Govindisamy, N. 1983. An Economic Analysis of Continuous Cropping in the Dark Brown Soil Zone of Alberta. MSc thesis, Department of Rural Economy, University of Alberta.

Harder, R.W. 1979. The Relationship of Three Tillage Systems to Soil Nitrate and Phosphate and Yield Responses of Winter Wheat. Proceedings of the 30th Annual Northwest Fertilizer Conference, Spokane, Washington, p63-71.

Hardesty, Sermin D. and Hoy F. Carman. 1988. A Case Study of California Farm Machinery: Repair and Downtime. Giannini Information Series No. 88-2. University of California, Berkeley: Giannini Foundation.

Jensen, Tom and John Timmermans. 1987. Conservation Tillage. Agdex 516-3. Alberta Agriculture. Edmonton.

Koehler, F.E., G.M. Hyde and J. Hammel. 1983. Optimum Methods of Fertilizer Application for Minimum Till and No-Till in Eastern Washington and Northern Idaho. Proceedings of the 34th Annual Northwest Fertilizer Conference, Portland, Oregon, p43-48.

Lindwall, C.W. and D.T. Anderson. 1981. Agronomic Evaluation of Minimum Tillage Systems for Summer Fallow in Southern Alberta. *Canadian Journal of Plant Science* 61: 247-253.

Mahli, S.S., G. Mumey, P.A. O'Sullivan and K.N. Harker. 1988. An Economic Comparison of Barley Production Under Zero and Conventional Tillage. *Soil Tillage Research* 11: 159-166.

McNeill, R.C. 1979. Depreciation of Farm Tractors in British Columbia. Canadian Journal of Agricultural Economics 27(1):53-58.

Owen, Lorne and R.P. Zentner. 1988. Economic Challenges to the Adoption of Soil Conservation Practices in the Brown and Dark Brown Soil Zone. In *Land Degradation and Conservation Tillage*. Proceedings of the Canadian Society of Soil Science 34th Annual Meeting, Calgary.

Peacock, David L. and John R. Brake. 1970. What is Farm Machinery Worth? Michigan State University, Agricultural Experiment Station. Report 109.

Rasmussen, P.E., R.E. Ramig and D.E. Wilkins. 1983. Wheat and Fertilizer Response in Conservation Tillage Systems. Proceedings of the 34th Annual Northwest Fertilizer Conference, Portland, Oregon, p49-56.

Woloshyn, P. 1990. Fixed Cost Compensation for Farm Land Expropriation. MSc thesis, Department of Rural Economy, University of Alberta (forthcoming).

Zentner, R.P. and C.W. Lindwall. 1978. An Economic Assessment of Zero Tillage in Wheat-Fallow Rotations in Southern Alberta. *Canadian Farm Economics* 13(6): 1-6.

APPENDIX 1

Conventional Tillage under a Continuous Cropping System (CT-CWW)

This appendix section provides detail about the conventional tillage system under continuous cropping. A precise description of the option is given in Figure A.1-1. The specific machines used and the number of operations on each crop are outlined in Table A.1-1. Details of machinery cost components, including purchase price, replacement age, annual use as well as capital, repair and fuel costs are found in Table A.1-2. Costs of fertilizer and herbicide materials are detailed in Table A.1-3. Finally, Table A.1-4 provides a summary of the costs associated with the conventional tillage system under continuous cropping.

Figure A.1-1 Detailed Description of Conventional Tillage under a Continuous Cropping System (CT-CWW)

Fall cultivation: Fall cultivation with a heavy duty field cultivator includes application of soil incorporated wild oat weed control chemical ($12.00 per acre) and fertilizer (nitrogen at 60 lbs per acre and phosphorus at 30 lbs per acre).

Spring cultivation: Two spring cultivations by heavy duty field cultivator followed by harrows.

Seeding: Seeding with double disk press drill during the period April 27 through May 31.

Weed spraying: Weed spraying of the wheat crop only, in June, for the control of broad leaf weeds ($6.00 per acre).

Table A.1-1 Machine Operations for Conventional Tillage under a Continuous Cropping System (CT-CWW)

	Operations per acre		
Machine	**Canola**	**Wheat**	**Total**
Combine	1(0)[a]	1(0)	1.00(0.00)
Cultivator	3(2)	3(2)	3.00(2.00)
Harrows	2(2)	2(2)	2.00(2.00)
Press Drill	1(1)	1(1)	1.00(1.00)
Sprayer	0(0)	1(0)	0.67(0.00)
Swather	1(0)	1(0)	1.00(0.00)

(a) Note: brackets denote the number of operations during seeding.

Table A.1-2 Machine Sizes, Replacement Cycles, and Costs for Conventional Tillage under a Continuous Cropping System (CT-CWW)

Machine	size	purch price	repl age	annual use[a]	capital cost	repair cost	fuel cost
960 acre base:							
Combine (SP)[b]	16ft	86288	9yr	134hr	13648	1457	1203
Cultivator	28ft	16905	9yr	132hr	2681	665	1053
Harrows	55ft	5590	11yr	45hr	813	30	129
Press Drill	20ft	21216	9yr	66hr	3301	359	474
Sprayer	60ft	7301	11yr	11hr	1058	16	32
Swather (PTO)	16ft	5600	10yr	69hr	845	57	198
First Tractor	161hp	67895	10yr	197hr	9926	269	
Second Tractor	80hp	32567	10yr	124hr	4697	51	
Total		243362		457hr	36970	2904	3089
1280 acre base:							
Combine (SP)[b]	16ft	86288	9yr	179hr	14093	2666	1604
Cultivator	30ft	17998	9yr	164hr	2918	962	1391
Harrows	55ft	5590	11yr	60hr	813	44	129
Press Drill	26ft	27175	9yr	67hr	4229	485	516
Sprayer	60ft	7301	11yr	15hr	1058	24	43
Swather (PTO)	16ft	5600	9yr	92hr	885	89	264
First Tractor	171hp	72257	9yr	231hr	11008	360	
Second Tractor	80hp	32567	10yr	166hr	4697	91	
Total		254776		577hr	39700	4720	3947
1600 acre base:							
Combine (SP)[b]	16ft	86288	8yr	224hr	15247	3815	2005
Cultivator	32ft	19091	8yr	193hr	3340	1226	2155
Harrows	55ft	5590	11yr	75hr	813	59	216
Press Drill	32ft	33134	9yr	68hr	5156	611	693
Sprayer	60ft	7301	11yr	18hr	1058	32	53
Swather (PTO)	16ft	5600	9yr	114hr	885	133	331
First Tractor	226hp	102945	9yr	261hr	15699	542	
Second Tractor	80hp	32567	10yr	207hr	4697	142	
Total		292516		692hr	46894	6558	5453

(a) Note: total hours of use do not include hours of tractor operation.

(b) Note: combines have a capacity or "effective width" compatible with the swather.

Table A.1-3 Total Farm Fertilizer and Weed Control Chemical Costs for Conventional Tillage under a Continuous Cropping System (CT-CWW)

Item	Costs per acre		
	Canola	Wheat	Total
Wild Oat	12.00	12.00	
Broadleaf	n/a	6.00	
Herbicide Cost	12.00	18.00	16.00
Nitrogen	15.00	15.00	
Phosphorus	8.40	8.40	
Fertilizer Cost	23.40	23.40	23.40
Material Cost			39.40

Table A.1-4 Summary of Costs for Conventional Tillage under a Continuous Cropping System (CT-CWW)

Item	Total farm basis			Per acre basis		
	960 acres	1280 acres	1600 acres	960 acres	1280 acres	1600 acres
Capital	36970	39700	46894	38.51	31.02	29.31
Repair	2904	4720	6558	3.03	3.69	4.10
Fuel	3089	3947	5453	3.22	3.08	3.41
Labour[a]	3199	4039	4844	3.33	3.16	3.03
Machinery Cost	46162	52405	63749	48.09	40.94	39.84
Herbicide	15360	20480	25600	16.00	16.00	16.00
Fertilizer	22464	29952	37440	23.40	23.40	23.40
Material Cost	37824	50432	63040	39.40	39.40	39.40
Total Cost	83986	102837	126789	87.49	80.34	79.24

(a) Note: labour costs are determined by multiplication of total machine hours by a labour rate of $7.00 per hour.

APPENDIX 2

Conventional Tillage under a Crop Fallow System (CT-CWF)

This appendix section provides detail about the conventional tillage system under a crop fallow program. A precise description of the option is given in Figure A.2-1. The specific machines used and the number of operations on each crop are outlined in Table A.2-1. Details of machinery cost components, including purchase price, replacement age, annual use as well as capital, repair and fuel costs are found in Table A.2-2. Costs of fertilizer and herbicide materials are detailed in Table A.2-3. Finally, Table A.2-4 provides a summary of the costs associated with the conventional tillage system under a crop fallow program.

Figure A.2-1 Detailed Description of Conventional Tillage under a Crop Fallow System (CT-CWF)

Fall cultivation: Fall cultivation with a heavy duty field cultivator on canola stubble to be seeded to wheat in spring includes application of soil incorporated wild oat weed control chemical ($12.00 per acre) and fertilizer (nitrogen at 60 lbs per acre and phosphorus at 30 lbs per acre). Fall cultivation with a heavy duty field cultivator on fallow land to be seeded to canola in spring includes application of soil incorporated wild oat weed control chemical ($12.00 per acre) and fertilizer (nitrogen at 30 lbs per acre and phosphorus at 30 lbs per acre).

Spring cultivation: Two spring cultivations by heavy duty field cultivator followed by harrows.

Seeding: Seeding with double disk press drill during the period April 27 through May 31.

Weed spraying: Weed spraying of the wheat crop only, in June, for the control of broad leaf weeds ($6.00 per acre).

Fallow operations: Four fallow operations with a heavy duty field cultivator during May, July, August and October. The October fallow operation includes application of soil incorporated wild oat weed control chemicals and fertilizer as outlined above.

Table A.2-1 Machine Operations for Conventional Tillage under a Crop fallow Cropping System (CT-CWF)

	Operations per acre			
Machine	**Canola**	**Wheat**	**Fallow**	**Total**
Combine	1(0)[a]	1(0)	0(0)	0.67(0.00)
Cultivator	3(2)	2(2)	4(0)	3.00(1.33)
Harrows	2(2)	2(2)	0(0)	1.33(1.33)
Press Drill	1(1)	1(1)	0(0)	0.67(0.67)
Sprayer	1(0)	1(0)	0(0)	0.67(0.00)
Swather	1(0)	1(0)	0(0)	0.67(0.00)

(a) Note: brackets denote the number of operations during seeding.

Table A.2-2 Machine Sizes, Replacement Cycles, and Costs of Operation for Conventional Tillage under a Crop fallow Cropping System (CT-CWF)

Machine		size	purch price	repl age	annual use[a]	capital cost	repair cost	fuel cost
960 acre base:								
Combine (SP)[b]		16ft	86288	10yr	89hr	13022	685	802
Cultivator		28ft	16905	9yr	132hr	2681	665	1053
Harrows		55ft	5590	11yr	30hr	813	18	86
Press Drill		20ft	21216	10yr	44hr	3217	169	316
Sprayer		60ft	7301	11yr	6hr	1058	7	16
Swather (PTO)		16ft	5600	11yr	46hr	812	29	132
First Tractor		161hp	67895	10yr	176hr	9909	212	
Second Tractor		80hp	32567	10yr	81hr	4697	22	
	Total		243362		347hr	36209	1806	2405
1280 acre base:								
Combine (SP)[b]		16ft	86288	9yr	119hr	13461	1138	1069
Cultivator		30ft	17998	9yr	164hr	2918	962	1391
Harrows		55ft	5590	11yr	40hr	813	26	115
Press Drill		26ft	27175	10yr	45hr	4121	228	344
Sprayer		60ft	7301	11yr	7hr	1058	10	21
Swather (PTO)		16ft	5600	10yr	61hr	845	46	176
First Tractor		171hp	72257	10yr	209hr	10573	320	
Second Tractor		80hp	32567	10yr	108hr	4697	39	
	Total		254776		436hr	38487	2767	3116
1600 acre base:								
Combine (SP)[b]		16ft	86288	9yr	149hr	13858	1818	1337
Cultivator		32ft	19091	8yr	192hr	3340	1226	2155
Harrows		55ft	5590	11yr	50hr	814	34	144
Press Drill		32ft	33134	10yr	46hr	5025	287	462
Sprayer		60ft	7301	11yr	9hr	1058	13	27
Swather (PTO)		16ft	5600	10yr	76hr	845	69	220
Primary Tractor		226hp	102945	9yr	238hr	15673	451	
Second Tractor		80hp	32567	10yr	135hr	4697	60	
	Total		292516		522hr	45309	3958	4345

(a) Note: total hours of use do not include hours of tractor operation.

(b) Note: combines have a capacity or "effective width" compatible with the swather.

Table A.2-3 Total Farm Fertilizer and Weed Control Chemical Costs for Conventional Tillage under a Crop fallow Cropping System (CT-CWF)

Item	Costs per acre			
	Canola	Wheat	Fallow	Total
Wild Oat	12.00	12.00	n/a	
Broadleaf	n/a	6.00	n/a	
Herbicide Cost	12.00	18.00	n/a	10.00
Nitrogen	7.50	15.00	n/a	
Phosphorus	8.40	8.40	n/a	
Fertilizer Cost	15.90	23.40	n/a	13.10
Material Cost				23.10

Table A.2-4 Summary of Costs for Conventional Tillage under a Crop fallow Cropping System (CT-CWF)

Item	Total farm basis			Per acre basis		
	960 acres	1280 acres	1600 acres	960 acres	1280 acres	1600 acres
Capital	36209	38487	45309	37.72	30.07	28.32
Repair	1806	2767	3958	1.88	2.16	2.47
Fuel	2405	3116	4345	2.51	2.43	2.72
Labour[a]	2429	3052	3654	2.53	2.38	2.28
Machinery Cost	42849	47422	57266	44.63	37.05	35.79
Herbicide	9600	12800	16000	10.00	10.00	10.00
Fertilizer	12576	16768	20960	13.10	13.10	13.10
Material Cost	22176	29568	36960	23.10	23.10	23.10
Total Cost	65025	76990	94226	67.73	60.15	58.89

(a) Note: labour costs are determined by multiplication of total machine hours by a labour rate of $7.00 per hour.

APPENDIX 3

Reduced Tillage under a Continuous Cropping System (RT-CWW)

This appendix section provides detail about the reduced tillage system under continuous cropping. A precise description of the option is given in Figure A.3-1. The specific machines used and the number of operations on each crop are outlined in Table A.3-1. Details of machinery cost components, including purchase price, replacement age, annual use as well as capital, repair and fuel costs are found in Table A.3-2. Costs of fertilizer and herbicide materials are detailed in Table A.3-3. Finally, Table A.3-4 provides a summary of the costs associated with the reduced tillage system under continuous cropping.

Figure A.3-1 Detailed Description of Reduced Tillage under a Continuous Cropping System (RT-CWW)

Fall cultivation: Fall cultivation by air seeder with chisels includes application of soil incorporated wild oat weed control chemical ($12.00 per acre) and fertilizer (nitrogen at 60 lbs per acre and phosphorus at 30 lbs per acre).

Spring cultivation: One spring cultivation by field cultivator followed by harrows.

Seeding: Seeding with air seeder during the period April 27 through May 31.

Weed spraying: Weed spraying of the wheat crop only, in June, for the control of broad leaf weeds ($6.00 per acre).

Table A.3-1 Machine Operations for Reduced Tillage under a Continuous Cropping System (RT-CWW)

Machine	Operations per acre		
	Canola	Wheat	Total
Air Seeder	2(1)	2(1)[a]	2.00(1.00)
Combine	1(0)	1(0)	1.00(0.00)
Cultivator	1(1)	1(1)	1.00(1.00)
Harrows	1(1)	1(1)	1.00(1.00)
Sprayer	0(0)	1(0)	0.67(0.00)
Swather	1(0)	1(0)	1.00(0.00)

(a) Note: brackets denote the number of operations during seeding.

Table A.3-2 Machine Sizes, Replacement Cycles, and Costs of Operation for Reduced Tillage under a Continuous Cropping System (RT-CWW)

Machine	size	purch price	repl age	annual use[a]	capital cost	repair cost	fuel cost
960 acre base:							
Air Seeder	30ft	46574	8yr	109hr	8066	2063	873
Combine (SP)[b]	16ft	86288	9yr	134hr	13648	1457	1203
Cultivator	28ft	16905	11yr	44hr	2460	152	351
Harrows	55ft	5590	11yr	22hr	814	12	65
Sprayer	60ft	7301	11yr	11hr	1058	16	32
Swather (PTO)	16ft	5600	10yr	69hr	845	57	198
First Tractor	161hp	67895	10yr	153hr	9893	162	
Second Tractor	80hp	32567	10yr	102hr	4697	34	
Total		268720		389hr	41480	3954	2722
1280 acre base:							
Air Seeder	36ft	41035	7yr	122hr	9465	2457	1031
Combine (SP)[b]	16ft	86288	9yr	179hr	14093	2666	1604
Cultivator	30ft	16859	11yr	55hr	2634	220	464
Harrows	55ft	5590	11yr	30hr	813	18	86
Sprayer	60ft	7301	11yr	15hr	1058	24	43
Swather (PTO)	16ft	5600	9yr	92hr	885	89	264
First Tractor	171hp	73705	10yr	176hr	10546	228	
Second Tractor	80hp	32567	10yr	136hr	4697	61	
Total		268945		493hr	44191	5762	3492
1600 acre base:							
Air Seeder	40ft	53148	7yr	137hr	10083	3310	1532
Combine (SP)[b]	16ft	86288	8yr	224hr	15247	3815	2005
Cultivator	32ft	19091	10yr	64hr	2895	283	718
Harrows	55ft	5590	11yr	37hr	813	24	108
Sprayer	60ft	7301	11yr	18hr	1058	32	53
Swather (PTO)	16ft	5600	9yr	114hr	885	133	331
First Tractor	226hp	102945	10yr	201hr	15039	351	
Second Tractor	80hp	32567	10yr	170hr	4697	96	
Total		312530		594hr	50717	8042	4747

(a) Note: total hours of use do not include hours of tractor operation.

(b) Note: combines have a capacity or "effective width" compatible with the swather.

Table A.3-3 Total Farm Fertilizer and Weed Control Chemical Costs for Reduced Tillage under a Continuous Cropping System (RT-CWW)

	Costs per acre		
Item	**Canola**	**Wheat**	**Total**
Wild Oat	12.00	12.00	
Broadleaf	n/a	6.00	
Herbicide Cost	12.00	18.00	16.00
Nitrogen	15.00	15.00	
Phosphorus	8.40	8.40	
Fertilizer Cost	23.40	23.40	23.40
Material Cost			39.40

Table A.3-4 Summary of Costs for Reduced Tillage under a Continuous Cropping System (RT-CWW)

	Total farm basis			Per acre basis		
Item	**960 acres**	**1280 acres**	**1600 acres**	**960 acres**	**1280 acres**	**1600 acres**
Capital	41480	44191	50717	43.21	34.52	31.70
Repairs	3954	5762	8042	4.12	4.50	5.03
Fuel	2722	3492	4747	2.84	2.73	2.97
Labour[a]	2723	3451	4158	2.84	2.70	2.60
Machinery Cost	50879	56896	67664	53.00	44.45	42.29
Herbicide	15360	20480	25600	16.00	16.00	16.00
Fertilizer	22464	29952	37440	23.40	23.40	23.40
Material Cost	37824	50432	63040	39.40	39.40	39.40
Total Cost	88703	107328	130704	92.40	83.85	81.69

(a) Note: labour costs are determined by multiplication of total machine hours by a labour rate of $7.00 per hour.

APPENDIX 4

Reduced Tillage under a Crop Fallow System (RT-CWF)

This appendix section provides detail about the reduced tillage system under a crop fallow program. A precise description of the option is given in Figure A.4-1. The specific machines used and the number of operations on each crop are outlined in Table A.4-1. Details of machinery cost components, including purchase price, replacement age, annual use as well as capital, repair and fuel costs are found in Table A.4-2. Costs of fertilizer and herbicide materials are detailed in Table A.4-3. Finally, Table A.4-4 provides a summary of the costs associated with the reduced tillage system under a crop fallow program.

Figure A.4-1 Detailed Description of Reduced Tillage under a Crop Fallow System (CWF)

Fall cultivation: Fall cultivation on canola stubble to be seeded to wheat in spring, by air seeder with chisels, includes application of soil incorporated wild oat weed control chemical ($12.00 per acre) and fertilizer (nitrogen at 60 lbs per acre and phosphorus at 30 lbs per acre). Fall cultivation on fallow land to be seeded to canola in spring, by air seeder with chisels, includes application of soil incorporated wild oat weed control chemical ($12.00 per acre) and fertilizer (nitrogen at 30 lbs per acre and phosphorus at 30 lbs per acre).

Spring cultivation: One spring cultivation with field cultivator followed by harrows.

Seeding: Seeding with air seeder during the period, April 27 through May 31.

Weed spraying: Weed spraying of the wheat crop only, in June, for the control of broad leaf weeds ($6.00 per acre).

Fallow operations: Four fallow operations consisting of one chemical operation in March ($1.50), and three tillage operations in July, August and October. The July and August tillage operations are with a field cultivator. The October fallow operation is by air seeder with chisels and includes the application of soil incorporated wild oat weed control chemicals and fertilizer as outlined above.

Table A.4-1 Machine Operations for Reduced Tillage under a Crop fallow Cropping System (RT-CWF)

	Operations per acre			
Machine	**Canola**	**Wheat**	**Fallow**	**Total**
Air Seeder	1(1)	2(1)[a]	1(0)	1.33(0.67)
Combine	1(0)	1(0)	0(0)	0.67(0.67)
Cultivator	1(1)	1(1)	2(0)	1.33(0.67)
Harrows	1(0)	1(0)	0(0)	0.67(0.67)
Sprayer	1(0)	1(0)	1(0)	1.00(0.00)
Swather	1(0)	1(0)	0(0)	0.67(0.67)

(a) Note: brackets denote the number of operations during seeding.

Table A.4-2 Machine Sizes, Replacement Cycles, and Costs of Operation for Reduced Tillage under a Crop fallow Cropping System (RT-CWF)

Machine	size	purch price	repl age	annual use[a]	capital cost	repair cost	fuel cost
960 acre base:							
Air Seeder	30ft	46574	9yr	73hr	7336	983	582
Combine (SP)[b]	16ft	86288	10yr	89hr	13022	685	802
Cultivator	28ft	16905	10yr	59hr	2564	221	468
Harrows	55ft	5590	11yr	15hr	813	7	43
Sprayer	60ft	7301	11yr	11hr	1058	16	32
Swather (PTO)	16ft	5600	11yr	46hr	812	29	132
First Tractor	161hp	67895	10yr	132hr	9877	119	
Second Tractor	80hp	32567	10yr	72hr	4697	17	
Total		268720		293hr	40178	2078	2059
1280 acre base:							
Air Seeder	36ft	50518	8yr	81hr	8450	1192	687
Combine (SP)[b]	16ft	86288	9yr	119hr	13461	1138	1069
Cultivator	30ft	17998	10yr	73hr	2729	319	618
Harrows	55ft	5590	11yr	20hr	813	10	57
Sprayer	60ft	7301	11yr	15hr	1058	24	42
Swather (PTO)	16ft	5600	10yr	61hr	845	46	176
First Tractor	171hp	72257	10yr	154hr	10528	174	
Second Tractor	80hp	32567	10yr	96hr	4697	30	
Total		278119		369hr	42582	2933	2649
1600 acre base:							
Air Seeder	40ft	53148	8yr	91hr	9037	1605	1021
Combine (SP)[b]	16ft	86288	9yr	149hr	13858	1818	1337
Cultivator	32ft	19091	10yr	85hr	2895	423	958
Harrows	55ft	5590	11yr	25hr	813	14	72
Sprayer	60ft	7301	11yr	18hr	1058	32	53
Swather (PTO)	16ft	5600	10yr	76hr	845	69	220
First Tractor	226hp	102945	10yr	177hr	15013	271	
Second Tractor	80hp	32567	10yr	119hr	4697	47	
Total		312530		444hr	48216	4279	3661

(a) Note: total hours of use do not include hours of tractor operation.

(b) Note: combines have a capacity or "effective width" compatible with the swather.

Table A.4-3 Total Farm Fertilizer and Weed Control Chemical Costs for Reduced Tillage under a Crop fallow Cropping System (RT-CWF)

Item	Canola	Wheat	Fallow	Total
	Costs per acre			
Wild Oat	12.00	12.00	n/a	
Fallow	n/a	n/a	1.50	
Broadleaf	n/a	6.00	n/a	
Herbicide Cost	12.00	18.00	1.50	10.50
Nitrogen	15.00	7.50	n/a	
Phosphorus	8.40	8.40	n/a	
Fertilizer Cost	23.40	15.90		13.10
Material Cost				23.60

Table A.4-4 Summary of Costs for Reduced Tillage under a Crop fallow Cropping System (RT-CWF)

	Total farm basis			Per acre basis		
Item	960 acres	1280 acres	1600 acres	960 acres	1280 acres	1600 acres
Capital	40178	42582	48216	41.85	33.27	30.14
Repairs	2078	2933	4279	2.16	2.29	2.67
Fuel	2059	2649	3661	2.14	2.07	2.29
Labour[a]	2051	2583	3108	2.14	2.02	1.94
Machinery Cost	46366	50747	59264	48.30	39.65	37.04
Herbicide Cost	10080	13434	16792	10.50	10.50	10.50
Fertilizer Cost	12576	16768	20960	13.10	13.10	13.10
Material Cost	22656	30202	37752	23.60	23.60	23.60
Total Cost	69022	80949	97016	71.90	63.24	60.64

(a) Note: labour costs are determined by multiplication of total machine hours by a labour rate of $7.00 per hour.

APPENDIX 5

Minimum Tillage under a Continuous Cropping System (MT-CWW)

This appendix section provides detail about the minimum tillage system under continuous cropping. A precise description of the option is given in Figure A.5-1. The specific machines used and the number of operations on each crop are outlined in Table A.5-1. Details of machinery cost components, including purchase price, replacement age, annual use as well as capital, repair and fuel costs are found in Table A.5-2. Costs of fertilizer and herbicide materials are detailed in Table A.5-3. Finally, Table A.5-4 provides a summary of the costs associated with the minimum tillage system under continuous cropping.

Figure A.5-1 Detailed Description of Minimum Tillage under a Continuous Cropping System (MT-CWW)

Fall cultivation: Fall cultivation by air seeder with chisels with application of soil incorporated wild oat weed control chemical ($12.00 per acre) and fertilizer (nitrogen at 60 lbs per acre and phosphorus at 30 lbs per acre).

Spring cultivation: No spring cultivation.

Seeding: Seeding with air seeder during the period April 27 through May 31.

Weed spraying: Weed spraying of the wheat crop only, in June, for the control of broad leaf weeds ($6.00 per acre).

Table A.5-1 Machine Operations for Minimum Tillage under a Continuous Cropping System (MT-CWW)

	Operations per acre		
Machine	**Canola**	**Wheat**	**Total**
Air Seeder	2(1)	2(1)[a]	2.00(1.00)
Combine	1(0)	1(0)	1.00(0.00)
Sprayer	0(0)	1(0)	0.67(0.00)
Swather	1(0)	1(0)	1.00(0.00)

(a) Note: brackets denote the number of operations during seeding.

Table A.5-2 Machine Sizes, Replacement Cycles, and Costs of Operation for Minimum Tillage under a Continuous Cropping System (MT-CWW)

	size	purch price	repl age	annual use[a]	capital cost	repair cost	fuel cost
960 acre base:							
Air Seeder	30ft	46574	8yr	109hr	8066	2063	873
Combine (SP)[b]	16ft	86288	9yr	134hr	13648	1457	1203
Sprayer	60ft	7301	11yr	11hr	1058	16	32
Swather (PTO)	16ft	5600	10yr	69hr	845	57	198
First Tractor	161hp	67895	10yr	109hr	9861	82	
Second Tractor	80hp	32567	10yr	80hr	4697	21	
Total		246225		323hr	38175	3697	2306
1280 acre base:							
Air Seeder	36ft	50518	7yr	122hr	9465	2457	1031
Combine (SP)[b]	16ft	86288	9yr	179hr	14093	2666	1604
Sprayer	60ft	7301	11yr	15hr	1058	24	43
Swather (PTO)	16ft	5600	9yr	92hr	885	89	264
First Tractor	171hp	72257	10yr	122hr	10504	108	
Second Tractor	80hp	32567	10yr	106hr	4697	37	
Total		254531		408hr	40701	5381	2942
1600 acre base:							
Air Seeder	40ft	53148	7yr	137hr	10083	3310	1532
Combine (SP)[b]	16ft	86288	8yr	224hr	15247	3815	2005
Sprayer	60ft	7301	11yr	18hr	1058	32	53
Swather (PTO)	16ft	5600	9yr	114hr	885	133	331
First Tractor	226hp	102945	10yr	137hr	14971	163	
Second Tractor	80hp	32567	10yr	133hr	4697	58	
Total		287849		493hr	46940	7510	3921

(a) Note: total hours of use do not include hours of tractor operation.

(b) Note: combines have a capacity or "effective width" compatible with the swather.

Table A.5-3 Total Farm Fertilizer and Weed Control Chemical Costs for Minimum Tillage under a Continuous Cropping System (MT-CWW)

Item	Costs per acre Canola	Wheat	Total
Wild Oat	12.00	12.00	
Broadleaf	n/a	6.00	
Herbicide Cost	12.00	18.00	16.00
Nitrogen	15.00	15.00	
Phosphorus	8.40	8.40	
Fertilizer Cost	23.40	23.40	23.40
Material Cost			39.40

Table A.5-4 Summary of Costs for Minimum Tillage under a Crop fallow Cropping System (MT-CWF)

Item	Total farm basis 960 acres	1280 acres	1600 acres	Per acre basis 960 acres	1280 acres	1600 acres
Capital	38175	40701	46940	39.77	31.80	29.34
Repairs	3697	5381	7510	3.85	4.20	4.69
Fuel	2306	2942	3921	2.40	2.30	2.45
Labour[a]	2261	2856	3451	2.36	2.23	2.16
Machinery Cost	46439	51880	61823	48.37	40.53	38.64
Herbicide	15360	20480	25600	16.00	16.00	16.00
Fertilizer	22464	29952	37440	23.40	23.40	23.40
Material Cost	37824	50432	63040	39.40	39.40	39.40
Total Cost	84263	102312	124863	87.77	79.93	78.04

(a) Note: labour costs are determined by multiplication of total machine hours by a labour rate of $7.00 per hour.

APPENDIX 6

Minimum Tillage under a Crop Fallow System (MT-CWF)

This appendix section provides detail about the minimum tillage system under a crop fallow program. A precise description of the option is given in Figure A.6-1. The specific machines used and the number of operations on each crop are outlined in Table A.6-1. Details of machinery cost components, including purchase price, replacement age, annual use as well as capital, repair and fuel costs are found in Table A.6-2. Costs of fertilizer and herbicide materials are detailed in Table A.6-3. Finally, Table A.6-4 provides a summary of the costs associated with the minimum tillage system under a crop fallow program.

Figure A.6-1 Detailed Description of Minimum Tillage under a Crop Fallow System (MT-CWF)

Fall cultivation: Fall cultivation on canola stubble to be seeded to wheat in spring, by air seeder with chisels, includes application of soil incorporated wild oat weed control chemical ($12.00 per acre) and fertilizer (nitrogen at 60 lbs per acre and phosphorus at 30 lbs per acre). Fall cultivation on fallow land to be seeded to canola in spring, by air seeder with chisels, includes application of soil incorporated wild oat weed control chemical ($12.00 per acre) and fertilizer (nitrogen at 30 lbs per acre and phosphorus at 30 lbs per acre).

Spring cultivation: No spring cultivation.

Seeding: Seeding with air seeder during the period April 27 through May 31.

Weed spraying: Weed spraying of the wheat crop only, in June, for the control of broad leaf weeds ($6.00 per acre).

Fallow operations: Four fallow operations consisting of two chemical operations in March ($1.50 per acre) and August ($14.00 per acre), and two tillage operations in July and October. The July tillage operation is with a field cultivator. The October fallow operation is by air seeder with chisels and includes the application of soil incorporated wild oat weed control chemicals and fertilizer as outlined above.

Table A.6-1 Machine Operations for Minimum Tillage under a Crop fallow Cropping System (MT-CWF)

	Operations per acre			
Machine	**Canola**	**Wheat**	**Fallow**	**Total**
Air Seeder	1(1)[a]	2(1)	1(0)	1.33(0.67)
Combine	1(0)	1(0)	0(0)	0.67(0.00)
Cultivator	0(0)	0(0)	1(0)	0.33(0.00)
Sprayer	1(0)	1(0)	2(0)	1.33(0.00)
Swather	1(0)	1(0)	0(0)	0.67(0.00)

(a) Note: brackets denote the number of operations during seeding.

Table A.6-2 Machine Sizes, Replacement Cycles, and Costs of Operation for Minimum Tillage under a Crop fallow Cropping System (MT-CWF)

Machine	size	purch price	repl age	annual use[a]	capital cost	repair cost	fuel cost
960 acre base:							
Air Seeder	30ft	46574	9yr	73hr	7336	983	582
Combine (SP)[b]	16ft	86288	10yr	89hr	13022	685	802
Cultivator	20ft	12533	11yr	21hr	1824	39	164
Sprayer	60ft	7301	11yr	17hr	1058	28	48
Swather (PTO)	16ft	5600	11yr	46hr	812	29	132
First Tractor	161hp	67895	10yr	93hr	9850	60	
Second Tractor	80hp	32567	10yr	62hr	4697	13	
Total		258758		246hr	38599	1836	1728
1280 acre base:							
Air Seeder	36ft	50518	8yr	81hr	8450	1192	687
Combine (SP)[b]	16ft	86288	9yr	119hr	13461	1138	1069
Cultivator	20ft	12533	11yr	27hr	1824	58	232
Sprayer	60ft	7301	11yr	22hr	1058	40	64
Swather (PTO)	16ft	5600	10yr	61hr	845	46	176
First Tractor	171hp	72257	10yr	108hr	10494	86	
Second Tractor	80hp	32567	10yr	83hr	4711	23	
Total		267064		310hr	40843	2582	2228
1600 acre base:							
Air Seeder	40ft	53148	8yr	91hr	9037	1605	1021
Combine (SP)[b]	16ft	86288	9yr	149hr	13858	1818	1337
Cultivator	20ft	12533	11yr	34hr	1824	79	383
Sprayer	60ft	7301	11yr	28hr	1058	54	80
Swather (PTO)	16ft	5600	10yr	76hr	845	69	176
First Tractor	226hp	102945	10yr	125hr	14960	137	
Second Tractor	80hp	32567	10yr	104hr	4696	36	
Total		300382		378hr	46278	3797	2997

(a) Note: total hours of use do not include hours of tractor operation.

(b) Note: combines have a capacity or "effective width" compatible with the swather.

Table A.6-3 Total Farm Fertilizer and Weed Control Chemical Costs for Minimum Tillage under a Crop fallow Cropping System (MT-CWF)

	Costs per acre			
Item	Canola	Wheat	Fallow	Total
Wild Oat	12.00	12.00	n/a	
Fallow	n/a	n/a	15.50	
Broadleaf	n/a	6.00	n/a	
Herbicide Cost	12.00	18.00	15.50	15.17
Nitrogen	15.00	7.50	n/a	
Phosphorus	8.40	8.40	n/a	
Fertilizer Cost	23.40	15.90	n/a	13.10
Material Cost				28.27

Table A.6-4 Summary of Costs for Minimum Tillage under a Crop fallow Cropping System (MT-CWF)

	Total farm basis			Per acre basis		
Item	960 acres	1280 acres	1600 acres	960 acres	1280 acres	1600 acres
Capital	38599	40843	46278	40.21	31.91	28.92
Repairs	1836	2582	3797	1.91	2.02	2.37
Fuel	1728	2228	2997	1.80	1.74	1.87
Labour[a]	1722	2170	2646	1.79	1.70	1.65
Machinery Cost	43885	47823	55718	45.71	37.36	34.82
Fertilizer	12576	16768	20960	13.10	13.10	13.10
Herbicide	14560	19413	24267	15.17	15.17	15.17
Material Cost	27136	36181	45227	28.27	28.27	28.27
Total Cost	71021	84005	100945	73.98	65.63	63.09

(a) Note: labour costs are determined by multiplication of total machine hours by a labour rate of $7.00 per hour.