TILLAGE SYSTEMS FOR SUMMERFALLOW PREPARATION IN NORTH-CENTRAL SASKATCHEWAN

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ABSTRACT

This paper examines the agronomic and economic performance of seven summerfallow - spring wheat tillage systems studied over a 18 year period on a highly fertile silty clay loam soil at Melfort, Saskatchewan. During 1969-76, areas planted to wheat had the seedbed prepared with a cultivator and harrow; since 1977 one-half of each plot area received conventional seedbed preparation, the other half was sprayed with herbicide and zero till seeded. Overall, wheat yields averaged 3239 kg ha^{-1} for tillage alone, 3280 kg ha^{-1} for reduced tillage (combinations of tillage and herbicides), and 3347 kg ha^{-1} for herbicides only. On an annual basis, method of summerfallow preparation significantly influenced grain yields in only 6 of 18 years. In 3 of these years yields were lowest for tillage alone and highest for herbicides only; in 2 years yields were lowest for reduced tillage, and in 1 year yields were lowest for herbicides only. During 1977-86, preparation of the seedbed by tillage significantly increased yields (compared to zero till seeding) in 6 of 10 years, but it resulted in significantly lower yields in 4 of 10 years. Volume weight, protein content, and %P concentration in the grain were unaffected by the method used for fallow or seedbed preparation. Results of the economic analysis showed that total costs for the complete rotation systems were lowest for the all tillage treatment (avg 109 \$ ha^{-1}), intermediate for reduced tillage (avg 129 to 158 \$ ha^{-1}), and highest for herbicides only (avg 179 \$ ha^{-1}). Although the substitution of herbicides for mechanical tillage provided resource savings in the range of 2 to 10 \$ ha^{-1}, this was more than offset by the increased expenditures for herbicides. Net returns (income above all costs) were highest for tillage alone (avg 129 \$ ha^{-1}) and lowest for the herbicide only treatment in which paraquat or glyphosate was used in combination with dicamba (avg 54 \$ ha^{-1}). The reduced tillage systems generally produced a net return that averaged 18 to 44 \$ ha^{-1} lower than the traditional system. The maximum expenditure that could be made for herbicides to break even with the traditional system ranged from 22 to 29 \$ ha^{-1} for the reduced tillage systems, and from 31 to 37 \$ ha^{-1} for the herbicides only treatments. The study concluded that although the substitution of herbicides for some or all of the mechanical tillage is attractive to producers from an agronomic and soil conservation perspective, the present economic conditions and in particular, the high cost of herbicides, remains a major deterrent to widespread adoption.

INTRODUCTION

Summerfallow continues to be an important component of the cropping systems used by producers in the Black soil zone of Saskatchewan. Traditionally, from 3 to 8 tillage operations are performed on these areas during the 21-month fallow period to control weeds, manage trash, incorporate herbicides and fertilizers, smooth the soil surface, and prepare the seedbed for the subsequent crop. In recent years, producers have become increasingly aware of the deleterious effects of excessive tillage on soil quality and on the loss of soil by wind and water erosion. Despite research which shows that herbicides can be substituted for some or all of the mechanical tillage used for weed control on summerfallow areas (Lindwall and Anderson 1981), most producers have been slow or reluctant to adopt this technology.

This paper, with financial assistance from the Saskatchewan Agriculture Development Fund, examines the agronomic and economic performance of seven tillage systems for summerfallow-spring wheat production over a 18 year period in north-central Saskatchewan.

MATERIALS AND METHODS

The experiment was established in 1969 on the Agriculture Canada Research Station at Melfort, Saskatchewan. The soil, mapped as a Melfort silty clay loam, is an Orthic Black Chernozem with an organic nitrogen content of 0.55% (0-15 cm depth) and a surface pH of about 6.0. Seven summerfallow-spring wheat systems (Table 1) were established on plots 6.7 m by 53 m in a randomized complete block design with 4 replicates. Both stages of each rotation system were present every year and each system was cycled on its assigned plots.

Table 1. Summerfallow Preparation Treatments Studied

	Number of Operations	
Treatment Description	Tillage	Spray
1. Tillage Alone[+]	3-7	0
2. Three Tillage Operations (Rest Herbicides[f])	3	0-2
3. Two Tillage Operations (Rest Herbicides[f])	2	1-3
4. One Tillage Operation (Rest Herbicides[f])	1	2-4
5. Herbicides Only (paraquat or glyphosate[§] used in combination with bromoxynil plus MCPA ester (1:1) @ 0.56-0.84 kg/ha)	0	2-6
6. Herbicides Only (paraquat or glyphosate[§] used in combination with 2,4-D ester @ 0.42-1.12 kg/ha)	0	2-6
7. Herbicides Only (paraquat or glyphosate[§] used in combination with dicamba @ 0.14-0.28 kg/ha plus 2,4-D ester @ 0.42-0.84 kg/ha)	0	2-5

[+] The heavy-duty cultivator was the main implement used for tillage operations.

[f] The herbicides used were those of treatment 7.

[§] Paraquat was applied at rates of 0.56 to 0.84 kg/ha, while glyphosate was applied at rates of 0.42 to 0.84 kg/ha. All herbicide rates are in units of active ingredient.

Most field operations associated with the management of the treatments were performed using field-sized equipment (Table 1). The heavy-duty cultivator, operated at depth of 5-6 cm, was the main implement used for tillage operations on summerfallow areas; in some years a rodweeder, operated at 3-4 cm depth, replaced one or more of the cultivation operations on the tillage alone (control) treatment. The first summerfallow tillage operation was performed usually in early June with subsequent operations performed (subject to treatment specifications) on an as needed basis usually at 2 to 3 week intervals. Treatments using herbicides only for weed control generally received a first spraying in late May or early June with repeat applications as required usually in July and August. Based on visual inspection of the plots prior to each spraying, herbicides that were not necessary because of the absence of target weeds were deleted from the tank mixes. In the early part of the fallow season, phenoxy herbicides were often applied alone to control broadleaf weeds such as stinkweed, flixweed, and shephard's purse, and annual weeds such as buckwheat, lamb's quarter, pigweed, and mustard. During the remainder of the fallow season, tank mixes that included paraquat or glyphosate were common for control of volunteer cereals and grassy weeds. Treatments that involved combinations of tillage and herbicides relied on tillage for early season weed control and on herbicides (paraquat or glyphosate plus dicamba) for summer and fall weed control. All herbicides were applied in 160 L ha^{-1} water using a plot sprayer equipped with flat fan nozzles and operated at 200 kPa.

During 1969-1976, areas being cropped had the seedbed prepared with a cultivator and harrow. Spring wheat (cv 'Manitou' or 'Neepawa') was planted at a rate of 100 kg ha^{-1} in mid May of each year using a hoe-press drill. Since 1977, the plots were split with half receiving conventional seedbed preparation and the other half was sprayed with herbicide (usually a tank mix of glyphosate plus a broadleaf weed herbicide) and zero till seeded with a triple disc press drill. The herbicide was applied prior to planting or a few days after planting before emergence of the wheat seedlings. All seeded areas received seed placed fertilizer (monoammonium phosphate) at an average rate of 10 kg ha^{-1} N plus 45 kg ha^{-1} P_2O_5. On areas with conventional seedbed preparation, triallate alone or in combination with trifluralin was applied after seeding and soil incorporated with a rodweeder and harrow. Zero tilled plots used diclofop methyl (plus bromoxynil in later years) for control of wild oats and green foxtail. Herbicides such as bromoxynil plus MCPA ester (1:1) or 2,4-D ester were used as required to supplement in-crop control of broadleaf weeds on both the prepared seedbed and zero tilled areas.

The wheat was swathed at the full-ripe stage (usually in late August or early September) and the yields determined by threshing the grain from an area 3 m by 53 m in the center of each plot. In a few years, yields were determined by direct combining an area 1.2 m by 53 m using a small plot combine. Subsamples of grain were collected from each plot for determination of N and P concentrations and volume weight. Protein concentration was taken as the %N concentration X 5.7. The straw was chopped and spread uniformly back on the plots with a straw chopper and spreader attachment on the combine. In some years the plots were harrowed after harvest to help spread the straw and crop residue.

In late September or early October of each year and again in early May prior to planting, soil cores were taken from each plot to a depth of 120 cm and the samples analyzed for NO_3-N (0-60 cm), bicarbonate extractable-P (0-15 cm), and gravimetric moisture content (0-120 cm). Precipitation was recorded at a meteorological station located less than 0.5 km from the test site.

Annual information on the types and frequency of field operations, amounts and types of herbicides and fertilizers applied, and wheat yields obtained in each treatment and replicate were used to assess the economic performance of the summerfallow and preseeding tillage treatments under 1989 cost conditions (University of Saskatchewan) (Table 2). The price for wheat was initially fixed at 147 $\$ t^{-1}$. Each summerfallow and preseeding tillage system was evaluated in regard to level of net return, resource needs, and total and average costs of wheat production. Net return was defined as the income above cash costs, labor, and ownership costs (depreciation and interest) for machinery. Since the rates of herbicide application for zero tillage, primarily paraquat and glyphosate, have declined from those recommended and used in the early years of the experiment, the economic analysis was repeated assuming the current lower recommended rates of application for these herbicides (Saskatchewan Agriculture 1989). Breakeven expenditures for herbicides were also computed for the reduced tillage and herbicides only treatments that equate the net return earned with that of tillage alone. No allowance was made in the analysis for differences in soil erosion protection. All economic data are expressed on a total rotation basis and thus include the costs and returns for both the fallowed and cropped areas.

Table 2. Summary of Selected Input Costs

Input Description	Cost	Units
Fertilizer		
N	0.60	$\$ kg^{-1}$
P_2O_5	0.60	$\$ kg^{-1}$
Herbicides+		
2,4-D ester	8.00	$\$ kg^{-1}$
2,4-D amine	7.50	$\$ kg^{-1}$
MCPA amine	8.77	$\$ kg^{-1}$
Bromoxynil & MCPA ester (1:1)	18.14	$\$ kg^{-1}$
Dicamba	48.01	$\$ kg^{-1}$
Triallate	19.45	$\$ kg^{-1}$
Trifluralin	18.39	$\$ kg^{-1}$
Diclofop methyl	43.19	$\$ kg^{-1}$
Dicolfop methyl + bromoxynil (23:8)	38.02	$\$ kg^{-1}$
Glyphosate	40.54	$\$ kg^{-1}$
Paraquat	33.00	$\$ kg^{-1}$
Labor	9.00	$\$ hr^{-1}$

+ All herbicide costs are in units of active ingredient.

All data for treatments receiving conventional seedbed preparation during 1969-86 were statistically analyzed using analysis of variance for split plot in time designs (SAS Institute 1975). The analysis was repeated for the 1977-86 period in which preseeding tillage was included as an additional factor to facilitate comparison of conventional and zero till seeding. In event of significant treatment by year interactions, further analyses were conducted by individual year. Significant differences among treatment means were determined using Duncan's New Multiple Range Test (Steel and Torrie 1960) at a 0.1 level of probability.

RESULTS AND DISCUSSION

Weather Conditions

Average growing season (May 1 to August 31) and total annual precipitation received during the 1969-76 period were higher, while those for 1977-86 were comparable to the long-term averages (Table 3). Growing season precipitation was lowest in 1969, 1972, 1981, and 1983 when it was less than 160 mm. In contrast, growing season precipitation was highest in 1971, 1973, 1974, and 1977 when it generally exceeded 290 mm.

Table 3. Weather Conditions at Melfort

	Precipitation							
Year	Jan-Apr	May	June	July	Aug	GS+	Sept-Dec	Total
				mm				
1969	57	14	18	71	21	124	186	367
1970	82	19	117	67	33	236	99	417
1971	39	4	84	142	58	288	113	440
1972	89	21	61	53	19	154	72	315
1973	50	64	172	131	64	431	131	612
1974	72	114	66	24	141	345	84	501
1975	107	41	55	64	98	258	75	440
1976	65	33	75	129	29	266	50	381
1969 - 76	70	39	81	85	58	263	101	434
1977	43	149	30	70	42	291	145	479
1978	61	28	116	43	82	269	150	480
1979	92	34	103	40	22	199	96	387
1980	71	9	82	36	90	217	64	352
1981	58	10	35	93	17	155	164	377
1982	54	80	29	79	38	226	59	339
1983	75	28	42	12	78	160	109	344
1984	59	131	82	40	15	268	164	491
1985	76	54	58	53	56	221	76	373
1986	74	44	25	89	58	216	94	384
1977 - 86	66	57	60	55	50	222	118	406
L.T. Ave#	72	38	71	64	54	227	112	411

+ Growing season = May 1 to August 31.

Long-term average.

Effect of Summerfallow Tillage on Wheat Yields, Grain Quality, and Soil Properties

Overall, wheat yields averaged 3239 kg ha^{-1} for tillage alone, 3280 kg ha^{-1} for reduced tillage (combinations of tillage and herbicides), and 3347 kg ha^{-1} for herbicides only (Table 4). On an annual basis, method of summerfallow preparation significantly ($P<0.1$) influenced grain yields in only 6 of 18 years (data not shown). In 1974, 1978, and 1986, yields were lowest for tillage alone (avg 2910 kg ha^{-1}), intermediate for reduced tillage systems (avg 3160 kg ha^{-1}), and highest for herbicides only treatments (avg 3257 kg ha^{-1}). In contrast, yields were lowest for reduced tillage in 1981 and 1982 (avg 2233 kg ha^{-1} vs 2376 kg ha^{-1} for other treatments), and lowest for herbicides only in 1985 (avg 4253 kg ha^{-1} vs 4454 kg ha^{-1} for other treatments). These trends in grain yield response to summerfallow tillage are not readily explained by spring soil water reserves or by growing season rainfall (Table 3), although the herbicides only treatments tended to have the highest spring soil moisture reserves (Table 5), particularly during droughty fallow periods. Further, in most years there was little difference in soil N or P accumulations over the fallow period among treatments (Table 5). In contrast to finding reported by Campbell et al. (1988), there was no evidence that soil nitrate-N accumulations were lower due to immobilization on this highly fertile soil for treatments that received little or no tillage. However, the greater levels of crop residue conserved on the soil surface with the reduced and herbicides only treatments afforded considerably better protection for the soil against wind and water erosion. Volume weight, protein concentration, and %P concentration in the grain were unaffected ($P>0.1$) by the method used for fallow preparation (Table 4).

Table 4. Wheat Yields and Grain Quality, 1969-86[+]

Summerfallow Treatment	Yield Mean	Yield CV[ƒ]	Volume Weight	Protein Conc.	Phos. Conc.
	(kg ha^{-1})	(%)	(kg hL^{-1})	(%)	(%)
1. All Tillage (control)	3239a	24	78.1	16.1	0.43
2. Three Tillage	3268ab	24	78.2	16.0	0.43
3. Two Tillage	32771b	23	78.1	16.1	0.44
4. One Tillage	3296bc	23	78.0	16.0	0.44
5. Herbicides Only-1	3360c	21	78.2	16.2	0.44
6. Herbicides Only-2	3388c	21	78.4	16.2	0.44
7. Herbicides Only-3	3294bc	22	78.0	16.0	0.43
Sx	26		0.13	0.06	0.003

[+] For conventionally prepared seedbeds.

[ƒ] Coefficient of variation calculated over years.

Table 5. Summary of Soil Characteristics, 1969-86

Summerfallow Treatment	Fall Soil[+] Nitrogen	Fall Soil[ƒ] Phosphorus	Spring Soil[§] Moisture
	(kg ha^{-1})	(kg ha^{-1})	(mm)
1. All Tillage (control)	78	59	522
2. Three Tillage	80	58	526
3. Two Tillage	73	57	519
4. One Tillage	71	56	527
5. Herbicides Only-1	74	55	521
6. Herbicides Only-2	84	58	541
7. Herbicides Only-3	81	54	540
Sx	3.7	1.8	4.7

[+] 0-60 cm depth measured in fall prior to planting.
[ƒ] 0-15 cm depth measured in fall prior to planting.
[§] 0-120 cm depth measured in fall prior to planting.

Effect of Seedbed Preparation on Wheat Yields

During 1977-86, preparation of the seedbed by tillage significantly increased ($P<0.1$) wheat yields (compared to zero till seeding) in 6 of 10 years (Table 6). However, it also resulted in lower ($P<0.1$) wheat yields than with zero till seeding in 4 of 10 years. This seemingly inconsistent effect of method of seedbed preparation on grain yields likely reflects a combination of factors including differences in seeders, soil edaphic factors, and weed infestations. In some years the zero-till seeder had difficulty cutting through heavy crop residues due to uneven spreading which may have resulted in less than optimum seed placement. The greater crop residue conserved with the reduced and herbicides only fallow treatments may have also kept soil temperatures lower on zero tilled areas compared to those that received tillage for seedbed preparation (Campbell et al. 1988) thereby delaying germination and seedling emergence. Further, in some years it was observed that weeds on zero till areas often emerged soon after the preseeding (or early postseeding) herbicides were applied, possibly because of lower soil temperatures, thus increasing the competition for moisture and nutrients. These factors could have contributed to lower wheat plant densities and possibly explain the lower yields that were obtained with zero tillage in some years.

Table 6. Effect of Method of Seedbed Preparation on Wheat Yield, 1977-86.

Year	Conventional Till+	Zero-Till#
	(kg ha^{-1})	
1977	3873*	3751
1978	3343*	2944
1979	2721	3129*
1980	3565*	3284
1981	2718*	2286
1982	2240*	2014
1983	2970	3245*
1984	2054	2324*
1985	4018	4717*
1986	3741*	3030
Mean	3124	3072

\+ Asterisk indicates that yields from conventionally prepared seedbed are higher ($P<0.1$) than from zero-tilled areas.

\# Asterisk indicates that yields from zero-tilled areas are higher ($P<0.1$) than from conventionally prepared seedbeds.

Effect of Method of Summerfallow and Preseeding Tillage on Economic Returns

Total variable plus fixed machine costs for the complete rotation systems were lowest for the traditional all tillage treatment, intermediate for reduced tillage, and highest for herbicides only (Table 7). Although the substitution of herbicides for mechanical tillage provided savings in expenditures for fuel and oil, machine repair, labor, and depreciation plus interest on machine investment in the range of 2 to 10 \$ ha^{-1}, this was more than offset by the increased expenditures for herbicides, in agreement with findings from other studies (Zentner and Lindwall 1982). Even when the rates of herbicides actually used in the experiment were reduced in the economic analysis to those currently recommended, total costs averaged 9 to 25 \$ ha^{-1} higher for reduced tillage (compared to tillage alone) and 26 to 52 \$ ha^{-1} higher for herbicides only systems. Method of seedbed preparation had relatively little affect on total costs since the savings in tillage were largely offset by higher costs of herbicides for control of weeds prior to planting (data not shown).

Net returns (income above all costs) were highest for tillage alone and lowest for the herbicides only treatment in which paraquat or glyphosate was used in combination with dicamba (Table 8). The reduced tillage systems generally produced a net return that averaged 18 to 44 \$ ha^{-1} lower than the traditional system. At the lower rates of herbicide application currently recommended, net returns were often similar for the traditional and reduced tillage systems, but those for herbicides only still remained significantly lower.

Table 7 Costs of Production For Complete Rotation Systems, 1969-86[+]

Summerfallow Treatment	Machine[ƒ] Operation	Herbicides	Variable[§] Cost	Machine Overhead	Total Cost
	($ ha^{-1})				
1. All Tillage (control)	30	19	74	35	109
2. Three Tillage	29	41	95	34	129
3. Two Tillage	28	55	108	33	141
4. One Tillage	26	74	125	32	157
5. Herbicides Only-1	25	96	146	31	177
6. Herbicides Only-2	25	88	138	31	169
7. Herbicides Only-3	25	106	156	31	187

[+] For conventionally prepared seedbeds.
[ƒ] Includes fuel, oil, machine repair, and labor.
[§] Includes machine operation, herbicides, seed, and fertilizer.

Table 8. Net Returns for complete Rotation Systems, 1969-86[+]

Summerfallow Treatment	Actual Rates[ƒ]	Reduced Rates[§]
	($ ha^{-1})	
1. All Tillage (control)	129	129
2. Three Tillage	111	120
3. Two Tillage	99	114
4. One Tillage	84	108
5. Herbicides Only-1	69	96
6. Herbicides Only-2	79	107
7. Herbicides Only-3	54	93
Sx	1.8	2.0

[+] For conventionally prepared seedbeds.
[ƒ] Calculations based on the actual rates of herbicides used in the experiment.
[§] Calculations based on (lower) rates of herbicide application currently recommended for zero-tillage.

The maximum expenditure that could be made for herbicides to break even with the traditional all tillage system ranged from 22 to 29 $ ha^{-1} for the reduced tillage systems, and from 31 to 37 $ ha^{-1} for the herbicides only treatments (Table 9). Changes in the expected price for wheat had little affect on net returns or the level of breakeven herbicide expenditures because of the relatively small differences in wheat yields among treatments.

Table 9. Breakeven Expenditures For Herbicides for Summerfallow and Preparation of Zero-Till Seedbed+

Summerfallow Treatment	Mean	Min.	Max.
a) <u>1969-76 (Conventionally Prepared Seedbed)</u>			
2. Three Tillage	19	4	32
3. Two Tillage	22	3	47
4. One Tillage	24	3	36
5. Herbicides Only-1	30	19	44
6. Herbicides Only-2	33	20	46
7. Herbicides Only-3	25	1	49
b) <u>1977-86 (Conventionally Prepared Seedbed)</u>			
2. Three Tillage	25	4	47
3. Two Tillage	27	-8	45
4. One Tillage	33	1	51
5. Herbicides Only-1	40	15	70
6. Herbicides Only-2	41	24	60
7. Herbicides Only-3	36	5	56
c) <u>1977-86 (Zero-till Seedbed)</u>			
2. Three Tillage	42	6	64
3. Two Tillage	40	2	74
4. One Tillage	49	15	81
5. Herbicides Only-1	53	13	94
6. Herbicides Only-2	56	25	92
7. Herbicides Only-3	50	8	95

+ The All Tillage treatment was used as the base.

CONCLUSIONS

Results of 18 years of study on a highly fertile Black Chernozem in north-central Saskatchewan have shown that although the substitution of herbicides for some or all of the mechanical tillage of summerfallow is attractive to producers from an agronomic and soil conservation perspective, the present economic conditions, and in particular the high cost of herbicides, is a major deterrent to widespread adoption. Systems involving combinations of tillage and herbicides have the greatest potential; however, additional research is still required to find new ways to lower herbicide expenditures through use of alternative combinations of tillage and herbicides, use of reduced rates of herbicide application, or use of herbicides with greater residual weed control properties.

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