Effects of tillage systems and crop rotations on soil water conservation, seedling establishment and crop production of a thin black soil at Indian Head.

Guy P. Lafond, Heather Loeppky and D.A. Derksen
Indian Head Experimental Farm, Indian Head, SK. S0G 2K0

ABSTRACT

The long term sustainability of agriculture for much of Western Canada is dependent on the development of economically viable crop production systems that alleviate wind and water erosion. The systems required must be capable of making full use of the benefits of surface residues and standing stubble. A study was initiated in 1986 at Indian Head to examine the interactions of tillage systems and crop rotations on soil water conservation, soil characteristics, seedling establishment, crop production, plant diseases, weed populations and production economics. Three four year rotations were then superimposed on the three tillage systems.

Spring soil water under stubble conditions was significantly greater for the zero and minimum tillage than conventional tillage system for the 0-60 and 0-120 cm soil layer. Under fallow conditions, soil water conserved was similar for all three tillage systems. Seedling establishment, as measured by the number of plants emerged per meter square was similar for all crops and tillage systems. Plant development in spring wheat, as measured by Haun stage was not affected by tillage system. This implies that the perceived differences in soil temperature at seeding depth between the various tillage systems did not significantly delay plant emergence under zero and minimum tillage. Tillage system had a significant effect on grain production. Zero and minimum tillage outyielded conventional tillage by 22% for flax, 20% for spring wheat on stubble and 8% for field peas. There was no difference between tillage systems for winter wheat.

1.0 INTRODUCTION

The long term sustainability of agriculture in many parts of Western Canada will be dependent on our ability to reverse the devastating effects of wind and water erosion and excessive tillage on soil quality. DeJong and Kachanoski (1988) found that erosion was the major factor contributing to the observed loss in organic carbon. The long term implication of not addressing these problems will result in loss of production potential as well as substantial increases in production costs. Verity and Anderson (1990) have shown that the addition of 50 mm of topsoil on an eroded knoll resulted in a 45-58% yield increase.

Smika and Unger (1986) did an extensive review of the benefits of surface residues in terms of water conservation and protection against wind and water erosion. Their findings indicated very definitely that if crop production systems could be developed that made full use of the benefits of surface residues and standing stubble, the risk of wind and water erosion would be greatly diminished which in turn would increase the production potential and make agriculture more sustainable.

A study was initiated in 1986 at Indian Head to investigate the interactions of tillage systems and crop rotations on soil water conservation, seedling establishment, plant diseases, weed communities, crop production and economics. This report will summarize the results as they pertain to soil water conservation, seedling establishment and crop production.

2.0 DESCRIPTION OF STUDY

The objectives of the study were to examine the interaction of tillage systems and crop rotations on soil water conservation, seedling establishment and crop production. The rotations incorporate spring wheat, winter wheat, flax and field peas. The three tillage systems are zero, minimum (only one preseeding tillage operation using a heavy duty cultivator one day prior to seeding), and conventional till (fall and spring tillage). The three crop rotations are:

R1: Spring wheat ← Spring wheat ← Winter wheat ← Fallow
└──────────────────────────────────────↑

R2: Spring wheat ← Spring wheat ← Flax ← Winter wheat
└──────────────────────────────────────↑

R3: Spring wheat ← Flax ← Winter wheat ← Field peas
└──────────────────────────────────────↑

The minimum tillage system defined in this study is very different than other forms of minimum tillage such as seeding directly into stubble with a discer, or seeding into standing stubble with an air seeder equipped with wide sweeps followed by two or three harrow-packer operations. In both these situations, very little surface residue or standing stubble remains after the seeding operation is complete, and it is felt therefore, that many of the advantages of surface residues and standing stubble are lost.

In order to avoid the confounding effect of seeding implement and fertilizer placement between the various tillage systems, the same seeding implement is used for each tillage system and as well, the same method of fertilizer placement.

A commercially available seeder (Edwards HD 812 hoe press drill) was modified such that all fertilizer could be applied during the seeding operation. This was done by mounting an extra fertilizer box on the drill. The fertilizer from one box is applied with the seed via the hoe openers. Fertilizer from the extra box is directed into double offset disks placed between every second hoe opener. Consequently, a seed row is never more than 10 cm away from a fertilizer band. The row spacing on the machine is 20 cm. The plots were fertilized yearly according to soil test recommendations. Soil tests were done on every plot.

In the case of winter wheat, the crop was always direct seeded into standing stubble to ensure winter survival regardless of the tillage system used.

3.0 SOIL WATER

Availability of water is the major yield determinant in dryland crop production. This factor alone accounts for much of the observed year to year variations in yield. Increasing yield through plant breeding and innovative crop production practices has a major impact on water use. Consequently, it is important that soil water recharge before the next growing season is maximized and that water during the growing season be used efficiently. In order to guarantee sufficient soil water recharge, the practice of summerfallow is used. However, this practice has been shown to be very inefficient. Efficiencies range from 10% in the black soil zone to < 10% in the gray soil zone (Bowren, 1984).

The present study has a rotation which includes summerfallow one out of four years. The various tillage systems offer the opportunity of determining the impact of tillage system on soil water recharge during the fallow period. The zero till system uses herbicides for controlling weeds, the minimum till system uses a combination of tillage and herbicides and the conventional till only uses tillage. The results are given in Table 3.1. After four years, each fallow system conserved the same amount of water regardless of the soil depth measured. Estimation of the efficiency in storing precipitation averaged 33%. This is substantially higher than the 10% value reported by Bowren (1984). The reason for the discrepancy could be a function of the length of the rotation and as well, the crop preceding the fallow period. Bowren used a three year fallow-spring wheat-spring wheat rotation. In this study, a four year fallow-spring wheat-spring wheat-winter wheat rotation was used. In the present study, winter wheat preceded the fallow period and was always harvested by the beginning of August or shortly thereafter. Consequently, it is very likely that the winter wheat crop stopped using water by the third week of July or maybe earlier. The higher efficiency observed in this study may be related to the longer effective recharge period prior to freeze-up before the first winter of the fallow period.

The zero and minimum till systems provide the opportunity for snow trapping and better water holding efficiency because of the reduction in soil water loss through evaporation. The relative effects of tillage systems on total stubble spring soil moisture is given in Table 3.2 for each crop. The first observation is that when total spring soil moisture is determined as a % of full saturation of the 0-120 cm soil profile, the values range from 81-92% with a mean of 86%. This fact alone indicates that during the last four years, recharge was adequate to justify stubble cropping.

In the case of field peas, flax and spring wheat, the recharge was significantly greater on zero and minimum tillage than conventional till. The actual difference between zero and minimum till vs conventional till for the 0-120 cm soil profile was 4.2 cm for field peas, 3.6 cm for flax, and 1.2 cm for spring wheat. These differences help to explain the observed yield differences for the various crops reported in Section 7.0. Note that field peas follow winter wheat in this study.

In summary, a zero and/or minimum tillage system can have a positive impact on spring soil moisture and this impact can actually tip the balance in favor of continuous cropping.

Table 3.1 The effects of tillage systems on soil water recharge (cm) during the fallow period. Values are averaged over four years.

	Soil Depth (cm)					
Tillage System	0-30	30-60	60-120	0-60	0-120	% Full Profile
	---------	---------	---cm---	---------	---------	
Zero	11.9	13.6	25.5	25.5	51.0	106
Minimum	11.2	13.4	24.7	24.7	49.4	103
Conventional	11.5	13.3	24.3	24.8	49.1	102
Standard error	*0.5*	*0.6*	*0.8*	*0.7*	*1.2*	
CV (%)	*17.9*	*16.9*	*12.7*	*11.5*	*9.5*	

Note: A full profile of water in the 0-120 cm soil layer is 48 cm.

Table 3.2 The effects of tillage systems on total spring soil water (cm) under stubble cropping conditions. Values are averaged over four years.

Tillage System	Soil Depth (cm) 0-30	30-60	60-120	0-60	0-120	% Full Profile
	---------	---------	---cm---	---------	---------	0-120 cm
			Field Peas			
Zero	11.7	10.5	20.3	22.2	42.5	89
Minimum	11.8	10.9	21.6	22.7	44.3	92
Conventional	10.1	9.5	19.7	19.6	39.2	82
Contrasts:						
ZT + MT vs CT	**	**	*ns*	**	*	
ZT vs MT	*ns*	*ns*	*ns*	*ns*	*ns*	

Tillage System	Soil Depth (cm) 0-30	30-60	60-120	0-60	0-120	% Full Profile
	---------	---------	---cm---	---------	---------	0-120 cm
			Flax			
Zero	11.7	11.0	20.4	22.7	43.0	90
Minimum	11.3	10.7	19.9	22.0	41.9	87
Conventional	10.5	9.5	18.9	20.0	38.9	81
Contrasts:						
ZT + MT vs CT	**	**	*	**	**	
ZT vs MT	*ns*	*ns*	*ns*	*ns*	*ns*	

Tillage System	Soil Depth (cm) 0-30	30-60	60-120	0-60	0-120	% Full Profile
	---------	---------	---cm---	---------	---------	0-120 cm
			Winter wheat			
Zero	10.3	10.2	20.7	20.5	41.2	86
Minimum	10.1	10.6	20.0	20.7	40.7	85
Conventional	10.2	9.9	20.3	20.1	40.4	84
Contrasts:						
ZT + MT vs CT	*ns*	*ns*	*ns*	*ns*	*ns*	
ZT vs MT	*ns*	*ns*	*ns*	*ns*	*ns*	

Tillage System	0-30	30-60	60-120	0-60	0-120	% Full Profile
	---------	---------	---cm---	---------	---------	0-120 cm
			Spring wheat			
Zero	11.3	10.8	20.3	22.1	42.3	88
Minimum	11.4	10.3	19.9	21.7	42.3	88
Conventional	10.5	10.1	19.6	20.5	40.1	84
Contrasts:						
ZT + MT vs CT	**	*ns*	*ns*	**	*	
ZT vs MT	*ns*	*ns*	*ns*	*ns*	*ns*	

*Note: The preceding crops for field peas is winter wheat, for flax, spring wheat, for winter wheat, spring wheat and flax, and for spring wheat, peas, spring wheat and winter wheat. The symbols ** and * indicate significance at the 0.01 and 0.05 level respectively.*

4.0 SEEDLING ESTABLISHMENT

A common concern with zero till production systems has been crop establishment. The two most common questions are:

1) Do seeding rates need to be increased because of greater difficulty in seedling establishment under zero till?

2) Will the cooler soil conditions delay emergence and/or maturity of the crops?

With regards to the first question, equivalent plant populations were obtained for the three tillage systems and crops (Table 4.1). However, the plant populations were significantly lower under zero and minimum till than conventional till for flax, but in absolute terms, the difference was only 9%. The plant populations, even for zero and minimum tillage, were more than adequate to ensure maximum yield (see Section 5.0). In the case of spring wheat and field peas, equivalent plant populations were obtained. The important consideration is to ensure good seed to soil contract during the seeding operation. This can be ensured by using equipment that clears residues effectively, penetrates and packs the soil properly to ensure good seed to soil contact and as well, avoids the problems of "hairpinning".

Table 4.1 The effects of tillage systems on seedling establishment of spring wheat, flax and field peas.

	Seedling Establishment		
Tillage System	Spring wheat	Flax	Field peas
	------plants per meter square--		--------------
Zero	297	490	70
Minimum	291	513	70
Conventional	302	547	68
Contrasts:		*Probability Level*	
ZT + MT vs CT	*ns*	*0.05*	*ns*
ZT vs MT	*ns*	*ns*	*ns*

The second question concerns cool wet soils under zero tillage. The implication is that it will delay emergence which could in turn delay maturity. To answer this question, seedlings were removed from the spring wheat plots each year and the actual seeding depth and Haun stage measured for each plant. Haun stage is a measure of plant development (Haun, 1974) and is highly correlated with speed of emergence at early growth stages (Lafond and Boher, 1986). If plants have the same Haun stage or number of leaves, then they must have emerged at the same time. After four years of investigation, the differences for Haun stage in spring wheat were not significantly different among the three tillage systems (Table 4.2). This means that the anticipated delay in emergence between tillage systems was not observed in any of the years of the study. However, examination of observed seeding depth shows that shallower planting was always obtained with zero tillage than conventional tillage, with minimum till being intermediate. It should be noted that the seeding equipment adjustments were not changed between tillage systems. The resulting deeper planting under conventional than zero tillage is due to the more extensive "caving in" of the furrow as a result of rain action. Under a zero tillage system, soil is held together more firmly by the still intact plant roots from the previous crop. It was shown that the consistently shallower planting obtained under zero till could easily offset some of the disadvantages associated with cooler, wetter soils. It was also observed that under zero till, there was usually adequate moisture to get the crop emerged without the need for rainfall which was not always the case in the conventional till system.

Table 4.2 The effects of tillage systems on Haun stage (plant development) and seeding depth (mm) in spring wheat.

Tillage System	Haun Stage	Seeding depth
		------mm------
Zero	4.8	43
Minimum	4.8	46
Conventional	4.8	51
LSD (.05)	*not significant*	*3.0*

Note: Each value represents the mean of 400 observations.

In summary, equivalent plant populations can be obtained in most cases with zero tillage with seeding rates similar to those used in conventional tillage providing good seed to soil contact is ensured. The anticipated delay in emergence under zero tillage due to cool wet soils may be offset by other factors such as shallow seeding depth and moist soil.

5.0 CROP PRODUCTION

The major determinant of the value of a new production system is the final yield as it affects the short and long term economics of the system.

Table 5.1 summarizes the yield results for each tillage system and crop. As well, the yield results for the tillage systems are expressed as a % of conventional tillage for each crop. In all crops, except winter wheat, the yields of zero and minimum till were significantly higher than conventional till. There were no yield differences between zero and minimum till. Zero and minimum till averaged 109, 123 and 121% of conventional till for field peas, flax and spring wheat on stubble. There were no yield differences between tillage systems for spring wheat grown on fallow. Spring wheat yields on stubble as a percent of fallow averaged 74, 72 and 61% for zero minimum and conventional till, respectively. There were no differences in the yield of winter wheat between tillage systems. An interesting point to note is the similar yielding potential of zero and minimum till. This implies that a certain amount of soil disturbance can be tolerated providing that some stubble is left standing and that most of the residues remain on the surface. However, seeding with a tillage implement equipped with wide shovels followed by 2-3 harrow packing operations will not have the same results. In that situation, the advantages offered by standing stubble and surface residues are lost.

The next factor of interest is the effect of crop rotation on yield (Table 5.2). It should be noted that no interactions were detected between tillage systems and crop rotations, regardless of crop. This implies that the crop rotations performed in a similar fashion regardless of the tillage system used. Flax included in the second rotation yielded 8.2% more than flax in the third rotation. Winter wheat grown on flax stubble yielded 7.3% more than when grown on spring wheat stubble. In the case of spring wheat, fallow yielded more that stubble and there was no difference in yield between second year wheat and wheat grown in a continuous cropping rotation, between spring wheat grown on cereal and pea stubble or between spring wheat grown on spring wheat and winter wheat stubble.

Results obtained at Indian Head compare favorably with other locations. Wright (1990) reports yield increases of 5.3, 11.8, 6.6, 22.8, 16.4, 9.5, 13.1 and 6.9% for barley, spring wheat, fababean, lentil, field pea, Polish Canola and Argentine Canola for direct seeding over a system which employs spring tillage. In Manitoba, Stobbe reports yield increases of 5.2, 2.6, 14.0 and 8.6% for wheat, barley, canola and flax, respectively, for zero till over a conventional tillage system (Lafond et al, 1990). Brandt (1989) reports that zero till spring wheat yielded 13% higher than conventional till in a continuous cropping rotation, but canola yielded 8% less on zero till than conventional till. The lower canola yields were due to higher weed pressure under zero till.

Table 5.1 **The effects of tillage system on the yield of field peas, flax, winter wheat and spring wheat (fallow and stubble) from 1987-1990. Numbers in brackets represent % of conventional tillage.**

				Spring Wheat	
Tillage System	Field Peas	Flax	W. Wheat	Fallow	Stubble
	-----------	-----------	--kg/ha--	-----------	-----------
Zero till	1935(108)	1473(122)	2070(102)	2548(100)	1883(121)
Minimum till	1973(111)	1501(124)	2152(106)	2636(103)	1895(122)
Conventional till	1785(100)	1208(100)	2039(100)	2553(100)	1558(100)
Contrasts			*Probability Level*		
ZT + MT vs CT	*0.021**	*0.001***	*n s*	*n s*	*0.05**
ZT vs MT	*ns*	*ns*	*n s*	*n s*	*n s*

Table 5.2 **The effect of crop rotation on the yield of flax, winter wheat and spring wheat.**

Crop Rotation	Yield (kg/ha)
	Flax
Sw-Sw-Fx-Ww (2)	1449
Sw-Fx-Ww-peas (3)	1339
Probability Level (2 vs 3)	*0.001*
	Winter wheat
Fw-Sw-Sw-Ww (1)	1990
Sw-Sw-Fx-Ww (2)	2167
Sw-Fx-Ww-Peas (3)	2105
Contrasts	*Probability Level*
Wheat vs flax stubble	*0.016**
Flax stubble in 2 vs flax stubble in 3	*n s*
	Spring Wheat
Fw-Sw-Sw-Ww	2579
Fw-Sw-Sw-Ww	1745
Sw-Sw-Fx-Ww	1701
Sw-Sw-Fx-Ww	1843
Sw-Fx-Ww-Peas	1825
Contrasts	*Probability Level*
Fallow vs stubble	*0.001***
Second year stubble vs continuous stubble	*n s*
Cereal vs pea stubble	*n s*
Spring vs winter wheat stubble	*n s*

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