EFFECT OF TILLAGE AND CROP ROTATION ON SOIL QUALITY FACTORS

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Traditional soil management in the Canadian prairies involves repeated cultivation for weed control and seedbed preparation. Tillage is also used to warm the soil in the spring and reduce surface compaction due to implement traffic and natural soil settling. However, tillage may also lead to breakdown of organic matter, loss of soil moisture, spread of salinity and increased susceptibility to wind and water erosion. Reduced tillage systems can therefore be valuable in combating soil degradation.

A well-planned crop rotation plays an important role in ensuring optimum productivity. The benefits of suitable rotations to the soil include improved resistance to soil erosion and degradation, improved soil fertility and soil tilth, enhanced aggregate stability, increased availability of stored moisture (Campbell et al. 1990). These benefits are in addition to the agronomic and economic benefits of crop rotations to the producer.

In spite of the importance of tillage method and crop rotation on soil quality, there have been few studies conducted on the interaction of rotation and tillage on soil quality factors. This is particularly true in the black soil zone, where cropping options are often greater than in the drier brown and dark brown soils. Therefore, when the Crop Management Study was established at Indian Head Experimental Farm, to evaluate tillage-rotation interactions, the effect on soil factors were considered an important part of the experiment.

MATERIALS AND METHODS

The design and general procedures of the experiment have been discussed in detail in the earlier paper by Lafond, Loeppky and Derksen, so only a brief description will be provided here. The study involves three management systems and three crop rotations. The management systems are conventional tillage, minimum tillage and zero tillage. Conventional tillage includes both fall and spring pre-seeding tillage. Minimum tillage only includes one pre-seeding tillage in the spring and zero tillage does not include any tillage operation. The only soil disturbance in the zero tillage system is during the seeding operation. Seeding is done with an Edwards hoe press drill and fertilizer is applied during seeding. The phosphate is placed with the seed and the N is applied as a band between every second seed-row. Soils are tested each fall and fertilizer rates based on provincial soil test recommendations for normal to moist conditions in the Thin Black soil zone. The same rate of fertilizer is applied to each tillage system, but rates differed for the crop. The three crop rotations are all four years in length and consist of the following:

Seq 1: Spring wheat, spring wheat, winter wheat, summerfallow (Sw-Sw-Ww-Fw)

Seq 2: Spring wheat, spring wheat, flax, winter wheat (Sw-Sw-Fx-Ww)

Seq 3: Spring wheat, flax, winter wheat, peas (Sw-Fx-Ww-P)

Under conventional tillage, weeds on summerfallow are controlled with tillage, while on the minimum tillage, both tillage and herbicides are used for weed control. On the zero tillage system, only herbicides are used for weed control in the summerfallow period. The study is designed to continue for 12 years and the first four year cycle was completed in 1990. Detailed soil studies were conducted at the end of the fourth year.

Bulk density measurements were taken in the winter wheat treatments, on August 9, 1990, using 5 cm diameter, 5 cm deep bulk density tubes. Soil samples from the tubes were weighed wet and dry and gravimetric moisture content calculated. At the same time, penetration resistance measurements were taken to the 45 cm depth, using a hand held recording penetrometer.

Soil samples were take prior to the initiation of the experiment and stored in airtight metal containers for future analysis. Further samples were taken on September 21 and 28, 1990. Both sets of samples were analyzed for total C and N, organic matter, and mineralizable nitrogen. Available N, P, K and S were measured on the samples taken in 1990. Only these later analyses are completed.

Statistical analysis was conducted using the GLM procedure of SAS (SAS Institute 1986). Mean separation was tested for significance using Student Newman Keuls' Test (Steel and Torrie 1980).

RESULTS

Soil Moisture

Soil moisture, measured in August after winter wheat production, was not influenced by tillage management or crop rotation (data not presented). However, as reported previously by Lafond, Loepky and Derkson, soil moisture in the spring tended to be about 10% higher on the average under zero tillage as compared to conventional tillage, under stubble conditions.

Bulk Density

Bulk density was lower in the surface 5 cm than at lower soil depths (Table 1). Density reached a maximum in the 10 to 15 cm depth and remained relatively constant from the 15 to the 45 cm depths. Tillage generally had no significant effect on bulk density, although density tended to be slightly lower under conventional tillage than under zero tillage in the 5 to 10 cm ($p<0.0795$) and 15 to 30 cm depths ($p<0.0535$). Crop sequence had little effect on bulk density, although surface density tended to be slightly higher in the spring wheat-spring wheat-flax-winter wheat rotation than in the other rotations (Table 2).

Penetration Resistance

Penetration resistance was measured in 1.5 cm increments to 45 cm. The data was broken into three 15 cm zones for statistical analysis. Penetration resistance increased with depth in all three zones. In the surface zone, penetration resistance was greatest under zero tillage and lowest under conventional tillage, with minimum tillage being intermediate (Table 3). In the middle and deepest soil zones, there was no significant effect of tillage on penetration resistance, however, there were significant sequence and tillage by sequence effects at all depths. Penetration resistance tended to be highest in sequence 2, the spring wheat-spring wheat-flax-winter wheat rotation and lowest in sequence 3, the peas-spring wheat-flax-winter wheat rotation. The higher resistance under sequence two was most evident under zero tillage, while under minimum and conventional tillage, the effect of sequence was more variable. Sequence 2, also tended to have higher bulk density values, while sequence 3 was numerically but nonsignificantly lower in bulk density than the other treatments. Moisture levels in the soil at the time of the penetration resistance readings did not differ among treatments, so this would not have influenced resistance.

Nutrient Content of the Soil

Amount and distribution of nitrate N through the soil profile was influenced by tillage management, cropping sequence and preceding crop. There was no difference among tillage systems for N content in the 0 to 5 or 5 to 10 cm depths, but conventional tillage had higher N levels than zero or minimum tillage in the 10 to 15, 15 to 30 and 30 to 60 cm depths (Table 4). Differences were particularly great between 15 and 60 cm. In the 60 to 120 cm depth, there was no difference among tillage treatments. Therefore, the residual N available under conventional tillage tended to accumulate in the middle soil zones, from 15 to 60 cm. Total soil nitrate level (kg/ha) measured either to 60 cm, the normal sampling depth for soil testing, or to 120 cm, the "rooting depth", was higher under conventional tillage than zero tillage. Repeated cultivation would increase the rate of mineralization of organic matter, increasing N release under conventional tillage. Also, crop yield was generally lower under conventional tillage than under zero or minimum tillage, so crop removal of N was lower under conventional tillage. These factors would increase the amount of N left in the soil.

Nitrate accumulation in the surface 15 cm and in the 60 to 120 cm depth was higher in sequence 1, which included summerfallow, than in the other sequences (Table 5). In the 30 to 60 cm depth, accumulation was highest in sequence 2, which received fertilizer N for each crop. Presumably mineralization of N during the fallow period increased the nitrate level in the surface soil zones, which contain the highest amount of organic matter. Accumulation of N in the 60 to 120 cm zone would result from downward movement of N with water during the fallow period. The relatively high concentration of N present in the 30 to 60 cm depth in sequence 2 may be due to fertilizer N which was not utilized by the crop due to the dry growing conditions experienced during this cropping cycle. Moisture may not have been sufficient under continuous cropping conditions to move the N to the 60 to 120 cm depth. Total nitrate accumulation in the 0 to 60 cm depth was highest in sequence 2, but if measured to 120 cm, nitrate accumulation was similar in sequence 2 and sequence 1 and lower in sequence 3. Under the fallow system, half of the residual N present in the profile was located in the 60 to 120 cm depth.

Nitrate content was higher in all soil depths in the fall after a fallow period than after any crop was grown (Table 6). The surface 10 cm of soil had higher levels of N after spring wheat and winter wheat than after flax or peas. In the 15 to 120 cm depth, however, flax, peas and spring wheat had comparable levels N, while winter wheat had slightly lower levels in the 30 to 120 cm depths. Winter wheat was effective in utilizing N and preventing its accumulation in the deeper soil zones, while fallow led to a build-up of nitrate below 60 cm. Risk of contamination of groundwater by nitrates would be greater under the fallow system than in the other cropping sequences, especially immediately following fallow. In contrast, winter wheat production would be effective in reducing the risk of ground water contamination.

Sulfur level did not differ with tillage management in the surface 5 cm, but was slightly higher under zero tillage than under conventional or minimum tillage in the 5 to 10 and 10 to 15 cm depths (Table 7). In the 15 to 30 and 30 to 60 cm depth, sulfur was higher under conventional tillage, but at the 60 to 120 cm depth, it was higher again under zero and minimum tillage. As with N, accumulation of S in the middle soil zones was greater under conventional than reduced tillage, but unlike N, S tended to be higher in the surface 15 cm under zero tillage than under disturbed soil conditions. Sulfate content in the surface 60 cm was higher under conventional tillage, but total to 120 cm did not differ significantly among tillage treatments. As with N, the greater accumulation of S to 60 cm under conventional tillage as compared to reduced tillage is likely due to increased mineralization of organic matter and lower crop uptake of applied S.

Cropping sequence did not influence S level in the upper 30 cm, however S level in the 30 to 60 cm level was higher in sequence 2 and 3 than sequence 1 (Table 8). This is reflected in a higher total S level both to 60 cm and to 120 cm under sequence 2 and 3. The flax and peas in sequence 2 and 3 received S fertilization, which may have accumulated in the lower soil profiles. However, total S tended to be highest after flax, winter wheat and spring wheat and lowest after fallow and peas (Table 9).

Phosphate content in the 0 to 15 cm depth was not influenced by tillage, crop sequence, or preceding crop species (Tables 9 to 11).

Potassium tended to accumulate in the surface to a greater extent under reduced tillage conditions, as compared to conventional tillage (Table 10). As no K was applied as fertilizer, the K accumulation in the surface was apparently due to uptake of K from deeper soil zones into the plant. The higher levels of K found in the soil surface under zero and minimum tillage may be due to the higher crop yields attained under these tillage systems as compared to under conventional tillage. Higher yields would lead to greater crop uptake of K, resulting in a greater movement of K from lower to upper soil zones. Potassium content in the soil surface was not influenced by cropping sequence or preceding crop (Tables 9 and 11).

CONCLUSIONS

Penetration resistance in the soil surface was highest under zero tillage and lowest under conventional tillage. Below 15 cm, tillage did not influence penetration resistance significantly. Growth of peas in place of spring wheat led to a lower penetration resistance throughout the soil profile to 45 cm, and a lower surface bulk density, even after three succeeding crops. Fallow in place of spring wheat also reduced penetration resistance. Soil moisture in the fall was not influenced by tillage or crop sequence.

Nitrate accumulation in the soil was greater under conventional than reduced tillage. Inclusion of fallow in a rotation led to accumulation of high amounts of N, particularly in the 60 to 120 cm depth. Nitrate accumulation in the 0 to 60 cm depth was also high in a spring wheat-spring wheat-flax-winter wheat rotation, where fertilizer was applied to each crop. Inclusion of a non-fertilized legume, field peas, in the rotation reduced N carry-over. Nitrogen accumulation was highest immediately after fallow and lowest after winter wheat and field peas. Winter wheat was effective at reducing N content in the lower soil zones. Potential for nitrate contamination of groundwater would be increased by fallow systems and decreased by production of winter wheat.

Sulfur content in 0 to 60 cm depth was higher under conventional tillage and where fertilizer S was used in the rotation. Phosphate was not influenced by tillage, crop sequence or preceding crop. Potassium content of the soil surface was higher under reduced than conventional tillage, possibly because the greater crop production under the reduced tillage systems led to increased removal of K from lower depths and deposition at the soil surface. Crop sequence did not influence potassium distribution in the profile.

REFERENCES

Campbell, C.A., Zentner, R.P., Janzen, H.H. and Bowren, K.E. 1990. Crop Rotation Studies on the Canadian Prairies. Publication 1841/E. Research Branch, Agriculture Canada. Ottawa. 133 pp.

Statistical Analysis Systems Institute, Inc. 1986. SAS User's Guide. Statistics. Version 5 Edition. SAS Institute, Inc. Cary, N.C. 957 pp.

Steel, R.G.D. and Torrie, J.H. 1980. Principles and Procedures of Statistics. A Biometrical Approach. McGraw-Hill, Inc. Toronto. 633 pp.

Table 1. Effect of management on bulk density of soil

	0-5 cm	5-10 cm	10-15 cm	15-30 cm	30-45 cm
	$g\ cm^{-3}$				
Zero tillage	1.08	1.26	1.33	1.32	1.27
Minimum tillage	0.98	1.25	1.33	1.32	1.29
Conventional tillage	1.02	1.20	1.30	1.24	1.28
p value	0.2061	0.0795	0.5786	0.0535	0.9302

Table 2. Effect of crop sequence on bulk density of soil

	0-5 cm	5-10 cm	10-15 cm	15-30 cm	30-45 cm
	$g\ cm^{-3}$				
Fallow-spwht-spwht-wwht	1.01	1.26	1.32	1.31	1.28
Spwht-spwht-flax-wwht	1.10	1.24	1.33	1.29	1.25
Peas-spwht-flax-wwht	0.96	1.21	1.31	1.28	1.31
p value	0.0704	0.3448	0.8738	0.7051	0.3234

Table 3. Effect of tillage and cropping sequence on penetration resistance (KPa) after winter wheat production, averaged over three soil depths

	0-15 cm			15-30 cm			30-45 cm		
	Seq 1	Seq 2	Seq 3	Seq 1	Seq 2	Seq 3	Seq 1	Seq 2	Seq 3
Zero tillage	1101	1259	923	1944	2469	1976	3065	3508	3163
Minimum tillage	982	1015	1075	2119	2445	2103	3513	3270	3063
Conventional tillage	988	1080	798	2268	2185	2240	3287	3340	3055

Table 4. Effect of management on N concentration (mg kg^{-1}) in various soil depths and N accumulation in the soil (kg ha^{-1})

	0-5 cm	5-10 cm	10-15 cm	15-30 cm	30-60 cm	60-120 cm	0-60 cm	0-120 cm
	mg kg^{-1}						kg ha^{-1}	
Zero tillage	13.2	8.7	7.1 B	5.0 B	7.9 B[1]	6.1	64.1 B	115.0 B
Minimum tillage	15.4	10.4	8.4 AB	6.3 B	8.6 B	6.4	73.5 B	126.8 AB
Conventional tillage	13.9	10.7	9.0 A	11.1 A	14.4 A	5.2	107.6 A	151.3 AB

[1] Numbers within a column followed by the same letter do not differ at the 5% level of significance.

Table 5. Effect of crop sequence on N concentration (mg kg^{-1}) in various soil depths and N accumulation in the soil (kg ha^{-1})

	0-5 cm	5-10 cm	10-15 cm	15-30 cm	30-60 cm	60-120 cm	0-60 cm	0-120 cm
	mg kg^{-1}						kg ha^{-1}	
Fallow-spwht-spwht-wwht	18.6 A[1]	13.9 A	10.7 A	7.3	7.2 B	8.8 A	75.7 B	149.7 A
Spwht-spwht-flax-wwht	12.5 B	8.3 B	7.0 B	8.1	14.8 A	5.1 B	98.5 A	141.1 A
Peas-spwht-flax-wwht	11.3 B	7.6 B	6.8 B	7.0	9.0 B	3.8 B	70.9 B	101.8 B

[1] Numbers within a column followed by the same letter do not differ at the 5% level of significance.

Table 6. Effect of preceding crop on fall nitrate-N content (mg kg^{-1}) in various soil depths and N accumulation in the soil (kg ha^{-1})

	0-5 cm	5-10 cm	10-15 cm	15-30 cm	30-60 cm	60-120 cm	0-60 cm	0-120 cm
	mg kg^{-1}						kg ha^{-1}	
Fallow	27.3 A[1]	21.0 A	16.3 A	13.4 A	12.2 A	15.7 A	124.7 A	256.2 A
Spring wheat	14.6 B	10.6 B	7.8 C	5.9 B	12.3 A	6.4 B	87.4 B	141.6 B
Flax	4.9 D	2.8 C	3.2 D	7.1 B	13.6 A	5.5 BC	79.5 B	125.9 B
Winter wheat	16.6 B	11.6 B	11.0 B	9.2 B	4.5 B	2.4 C	65.8 B	86.0 B
Peas	9.7 C	5.0 C	3.5 D	5.1 B	9.6 AB	4.2 BC	63.7 B	99.3 B

[1] Numbers within a column followed by the same letter do not differ at the 5% level of significance.

Table 7. Effect of management on SO_4-S (mg kg^{-1}) content in various soil depths and SO_4-S accumulation in the soil (kg ha^{-1})

	0-5 cm	5-10 cm	10-15 cm	15-30 cm	30-60 cm	60-120 cm	0-60 cm	0-120 cm
	mg kg^{-1}						kg ha^{-1}	
Zero tillage	5.5	4.61 A[1]	4.1 A	4.1 B	5.3	10.6 A	40.9 B	129.8
Minimum tillage	5.2	4.12 B	3.1 B	4.2 B	5.4	11.3 A	40.3 B	134.9
Conventional tillage	5.1	4.04 B	3.7 AB	5.4 A	6.6	9.0 B	48.1 A	123.8

[1] Numbers within a column followed by the same letter do not differ at the 5% level of significance.

Table 8. Effect of crop sequence of SO_4-S content (mg kg^{-1}) in various soil depths and SO_4-S accumulation in the soil (kg ha^{-1})

	0-5 cm	5-10 cm	10-15 cm	15-30 cm	30-60 cm	60-120 cm	0-60 cm	0-120 cm
	-----	-----	-----	-----	mg kg^{-1}	-----	------kg	ha^{-1}-----
Fallow-spwht-spwht-wwht	5.1	4.3	3.5	4.3	4.3 B[1]	9.8	36.1 B	118.4 B
Spwht-spwht-flax-wwht	5.6	4.3	3.8	4.6	7.1 A	10.9	48.8 A	140.2 A
Peas-spwht-flax-wwht	5.1	4.2	3.7	4.9	6.0 A	10.2	44.4 A	130.0 AB

[1] Numbers within a column followed by the same letter do not differ at the 5% level of significance.

Table 9. Effect of crop on P, K and SO_4-S accumulation in the soil ($kg\ ha^{-1}$)

Crop	P (0-15 cm)	K (0-15 cm)	S (0-60 cm)	S (0-120 cm)
	$kg\ ha^{-1}$			
Fallow	25.6	619.5	37.3 B[1]	108.9 B
Sp wht	22.6	610.9	41.0 B	127.8 AB
Flax	20.6	565.4	50.7 A	136.7 A
W wheat	19.7	610.2	45.6 AB	138.1 A
Peas	17.7	586.5	36.6 B	119.9 AB

1 Numbers within a column followed by the same letter do not differ at the 5% level of significance.

Table 10. Effect of management on P and K content (mg kg^{-1}) in various soil depths and accumulation in the soil (kg ha^{-1})

	P (0 - 5 cm)	K (0 - 5 cm)	P (5 - 10 cm)	K (5 - 10 cm)	P (10 - 15 cm)	K (10 - 15 cm)	P (0 - 15 cm)	K (0 - 15 cm)
	mg kg^{-1}						kg ha^{-1}	
Zero tillage	19.3	385 AB[1]	6.4	283 A	4.5	218	21.2	619.7 A
Minimum tillage	16.8	411 A	10.7	271 A	4.8	208	22.6	622.9 A
Conventional tillage	17.9	370 B	7.1	239 B	4.3	195	20.5	562.9 B

[1] Numbers within a column followed by the same letter do not differ at the 5% level of significance.

Table 11. Effect of crop sequence on P and K content (mg kg^{-1}) in various soil depths and accumulation in the soil (kg ha^{-1})

	P (0 - 5 cm)	K (0 - 5 cm)	P (5 - 10 cm)	K (5 - 10 cm)	P (10 - 15 cm)	K (10 - 15 cm)	K (0 - 15 cm)	P (0 - 15 cm)
	mg kg^{-1}						kg ha^{-1}	
Fallow-spwht-spwht-wwht	18.1	392	1.9	265	4.8	200	24.3	600.3
Spwht-spwht-flax-wwht	19.9	392	6.6	267	4.9	213	22.0	610.8
Peas-spwht-flax-wwht	16.0	382	5.6	260	3.9	207	17.9	594.4