EFFECT OF CROP ROTATIONS ON SOIL ORGANIC MATTER IN TWO BLACK CHERNOZEMS

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INTRODUCTION

A crop rotation is a planned sequence of crops grown in recurring succession on the same land. For more than 100 years, Agriculture Canada has carried out research on crop rotations. There have been 68 such studies conducted on the prairies and there are presently 20 ongoing. These are located at 10 Research Stations spanning the three prairie provinces and five soil zones. These studies have examined the effect of rotation length, crop sequence, summerfallow substitute crops, and N and P fertilization, on crop production, grain and forage quality, N and P uptake by plants, crop pests, soil moisture conservation and its efficient use, economic returns, non-renewable energy efficiency, and changes in physical, chemical, and biological properties of the soil.

The soils of western Canada have undergone serious degradation since the inception of arable agriculture in the early part of the 20th century. Of particular concern has been depletion of quantity and quality of soil organic matter. The concern about soil degradation has led to investigation into the effects of various rotations on soil quality in an attempt to identify rotations which preserve soil quality over the long term. Because crop residues are the primary substrate for organic matter replenishment, changes in crops and their sequence in rotation can exert significant influence on soil quality.

The most detailed research on the effect of crop rotations on soil quality has been carried out at Swift Current (Biederbeck et al. 1984; Biederbeck et al. 1986; Biederbeck and Campbell 1987) and Lethbridge (Janzen 1987a,b; Freyman et al. 1982; Dormaar and Pittman 1980; Dormaar 1983). Variables which have been examined include: fallowing frequency, inclusion of alternative crops (oilseeds, legumes, forages), the addition of fertilizer amendments, and the influence of time of cultivation.

The results of these studies were summarized in a soon to be released Rotation Bulletin by Campbell, Zentner, Janzen and Bowren of Agriculture Canada. The following is a quote from their summary of this topic:

> "The results consistently confirmed the degradative effects of frequent fallow on soil quality, evidenced by increased organic matter loss, depreciated organic matter quality, reduced microbial activity, and enhanced susceptibility to erosion. But they also showed that soil productivity can be effectively sustained over the long-term by adoption of stubble mulch techniques combined with proper fertilization and reduced fallow frequency. Application of fertilizer, particularly N, consistently benefitted the various parameters of soil quality, presumably by increasing the amounts of organic residues returned to the soil. Applications of N fertilizer lowered soil pH but the effect was not sufficient to warrant concern in the short term. The inclusion of legume green manure or legume-containing hay crops gener-

ally benefitted soil productivity although soil quality maintained by these rotations usually did not exceed that under adequately fertilized continuous wheat, perhaps due to the inclusion of fallow in the forage rotations. Organic matter was more likely to be enhanced in lower organic matter soils (Brown and Dark Brown) than soils with inherently high organic matter (Black soils)."

While we were preparing to write this bulletin, it became obvious that there was a paucity of this type of information on soil quality for soils in the Black soil zone where many of our rotations were located. Consequently, we initiated a study to determine what influence some of the more interesting rotations might have had on soil quality at Melfort (thick Black), Indian Head (thin Black), Somme (Dark Gray) and Scott (Dark Brown). The results reported here are very preliminary and are only presented for the thin Black soil (Indian Head) and the thick Black (Melfort).

MATERIALS AND METHODS

Soil samples were taken from the 0-7.5 and 7.5-15 cm depths of primarily the fallow phase of certain specified rotations at Melfort (thick Black) and at Indian Head (thin Black) in early June 1987 (Tables 1 and 2). Replicates 1-4 at Indian Head and the 4 replicates at Melfort were sampled. For more detailed description of these rotations we suggest you see Zentner et al. (1986). So far we have only determined total C (dry combustion) and total N (kjeldahl) analyses. In progress are the following analyses: potentially mineralizable N, microbial biomass, respiration, amino acids and certain soil enzymes. Aggregate stability, deep leaching of nitrates and other physical properties will also be analysed in future. Soils from Scott have been sampled, but have not yet been analysed.

RESULTS AND DISCUSSION

Indian Head

Application of fertilizer to F-W did not influence soil organic matter; fertilizer tended to increase organic matter content of F-W-W and it significantly increased organic matter content of continuous wheat (Table 3). The benefit of fertilizer application appeared to increase progressively with decline in fallowing frequency. Thus, increases in organic C concentrations amounted to 3%, 6% and 7% in the F-W, F-W-W and continuous wheat treatments, respectively. The corresponding increases in total N concentrations were 4%, 8% and 13%, respectively. There was no change in the C/N ratios due to fertilizers. This interaction of fertilizer and crop rotation length on soil organic matter changes can probably be attributed to higher yield responses for wheat grown on stubble than for wheat grown on fallow.

The degradative effect of summerfallowing on soil organic matter was evident at Indian Head. After 27 years of cropping soil organic C and N concentrations were approximately 10% higher in an unfertilized continuous wheat than in the comparable F-W rotation; there was no difference between unfertilized F-W and F-W-W. For the fertilized system, C and N concentrations of continuous wheat were 14% and 20% greater, respectively, than for the comparative F-W rotation, and for F-W-W they were 4% and 8% greater, respectively, than F-W, but the latter differences were again not significant.

Table 1. Mean yields‡ of wheat in rotations at Indian Head, Saskatchewan (1960-84) (From Zentner et al. 1987)

Rotation Sequence	Fertilizer+ N	Fertilizer+ P	25-yr mean yield (kg ha^{-1})
Wheat grown on fallow			
F#-<u>W</u> (check)	✓	✓	2459
F#-<u>W</u>	0	0	2239
F#-<u>W</u>-W	✓	✓	2551
F#-<u>W</u>-W (straw removed)	✓	✓	2615
F#-<u>W</u>-W	0	0	2268
GM#-<u>W</u>-W	0	0	2565
F-<u>W</u>-W-H (4 years)	0	0	2583
F-<u>W</u>-SC-O-H (4 years)	0	0	2619
F#-<u>W</u>-W-H#-H-H	0	0	2801
$S\bar{x}$			23
Wheat grown on stubble			
F-W-<u>W</u>	✓	✓	1840
F-W-<u>W</u> (straw removed)	✓	✓	1870
F-W-<u>W</u>	0	0	1103
GM-W-<u>W</u>	0	0	1491
F-W-<u>W</u>-H (4 years)	0	0	1433
F-W-<u>W</u>-H-H-H	0	0	1843
Cont. <u>W</u>#	✓	✓	1810
Cont. <u>W</u>#	0	0	1047
Flx-<u>W</u>-B	✓	✓	2334‡
Flx-<u>W</u>-B (high N fert)	✓	✓	2568‡
Flx-<u>W</u>-B	0	0	1338‡
$S\bar{x}$			20

+ During 1960-77 when fertilizer was applied using the general recommendations for the region, fertilized fallow wheat received 6 kg ha^{-1} N plus 27 kg ha^{-1} P_2O_5 while wheat grown on stubble received an average of 24 kg ha^{-1} N plus 21 kg ha^{-1} P_2O_5. Since 1978 when soil testing was started, fallow wheat received 5 kg ha^{-1} N plus 22 kg ha^{-1} P_2O_5, but stubble wheat received 82 kg ha^{-1} N plus 25 kg ha^{-1} P_2O_5. Wheat grown after flax with normal fertilizer application received an average of 49 kg ha^{-1} N plus 23 kg ha^{-1} P_2O_5; the high N fertilized wheat after flax received 72 kg ha^{-1} N plus 25 kg ha^{-1} P_2O_5.

Phase sampled.

‡ In Tables 1 and 2, yields correspond to rotation-years underlined.

Table 2. Mean yields of wheat in rotations at Melfort, Saskatchewan (1960-84) (From Zentner et al. 1986)

Rotation Sequence	Fertilizer[+] N	Fertilizer[+] P	25-yr mean yield (kg ha^{-1})
Wheat grown on fallow			
$F^{\#}$-$\underline{W}$ (check)	✓	✓	2784
$F^{\#}$-$\underline{W}$-W	✓	✓	2752
$F^{\#}$-$\underline{W}$-W	0	0	2409
$GM^{\#}$-$\underline{W}^{\#}$-W	✓	✓	2595
$F^{\#}$-$\underline{W}$-$W^{\#}$-H-H-$W^{\#}$	✓	✓	2838
$F^{\#}$-$\underline{W}$-$W^{\#}$-H-H-$W^{\#}$	0	0	2470
$S\overline{x}$			29
Wheat grown on stubble			
F-W-$\underline{W}$	✓	✓	2437
F-W-$\underline{W}$	0	0	1965
GM-W-$\underline{W}$	✓	✓	2236
F-W-$\underline{W}$-H-H-W	✓	✓	2259
F-W-W-H-H-$\underline{W}$	✓	✓	2412
F-W-$\underline{W}$-H-H-W	0	0	1922
F-W-W-H-H-$\underline{W}$	0	0	2057
Cont. $\underline{W}^{\#}$	✓	✓	1808
Cont. $\underline{W}^{\#}$	0	0	1327
F-C-$\underline{W}$	✓	✓	3174‡
F-C-$\underline{W}$-H-H-C	✓	✓	2678‡
F-C-$\underline{W}$-W	✓	✓	2848‡
F-C-W-$\underline{W}$	✓	✓	2498‡
$S\overline{x}$			33

+ During 1960-71, when fertilizer was applied using the general recommendations for the region, fertilized fallow wheat received an average of 7 kg ha^{-1} N plus 32 kg ha^{-1} P_2O_5, while fertilized stubble wheat received 27 kg ha^{-1} N plus 22 kg ha^{-1} P_2O_5. Since 1972, when soil testing was started, fallow wheat received 32 kg ha^{-1} N plus 40 kg ha^{-1} P_2O_5 and stubble wheat received 70 kg ha^{-1} N plus 40 kg ha^{-1} P_2O_5.

‡ 1977 to 1984 avg.

Phase sampled.

Table 3. Comparison of some rotational effects on soil organic matter at Indian Head (0-7.5 cm depth)

‡Treatment Compared (A)	vs (B)	% C (A)	% C (B)	% N (A)	% N (B)	C/N Ratio (A)	C/N Ratio (B)
Effect of Fertilizer							
F-W (No Fert)	vs F-W (Fert)	2.21	2.28	0.179	0.186	12.35	12.26
F-W-W (No Fert)	vs F-W-W (Fert)	2.25	2.38^{+}	0.186	0.200^{+}	12.10	11.93
Contin. W (No Fert)	vs Contin. W (Fert)	2.43	2.59*	0.198	0.223*	12.27	11.61^{+}
Effect of straw removal (Fert)							
F-W-W	vs F-W-W (removed)	2.38	2.35	0.200	0.191	11.93	12.30^{+}
Effect of rotation length							
F-W (No Fert)	vs F-W-W (No Fert)	2.21	2.25	0.179	0.186	12.35	12.10
F-W (No Fert)	vs Contin. W (No Fert)	2.21	2.43**	0.179	0.198*	12.35	12.27
F-W-W (No Fert)	vs Contin. W (No Fert)	2.25	2.43*	0.186	0.198	12.10	12.27
F-W (Fert)	vs F-W-W (Fert)	2.28	2.38	0.186	0.200	12.26	11.93
F-W (Fert)	vs Contin. W (Fert)	2.28	2.59**	0.186	0.223**	12.26	11.61^{+}
F-W-W (Fert)	vs Contin. W (Fert)	2.38	2.59*	0.200	0.223*	11.93	11.61
Effect of legumes in rotation							
F-W-W (No Fert)	vs GM-W-W	2.25	2.45^{+}	0.186	0.201^{+}	12.10	11.77^{+}
Contin. W (No Fert)	vs GM-W-W	2.43	2.45	0.198	0.201	12.27	11.77^{+}
F-W-W (Fert)	vs GM-W-W	2.38	2.45	0.200	0.208	11.93	11.77
Contin. W (Fert)	vs GM-W-W	2.59	2.45**	0.223	0.201*	11.61	11.77
GM-W-W	vs F-W-W-H-H-H	2.45	2.62*	0.208	0.221	11.77	11.86
F-W-W (No Fert)	vs F-W--W-H-H-H	2.25	2.62**	0.186	0.221**	12.10	11.86
Contin. W (No Fert)	vs F-W-W-H-H-H	2.43	2.62*	0.198	0.221*	12.27	11.86
F-W-W (Fert)	vs F-W-W-H-H-H	2.38	2.62**	0.200	0.221*	11.93	11.86
Contin. W (Fert)	vs F-W-W-H-H-H	2.59	2.62	0.223	0.221	11.61	11.86
GM-W-W	vs GM-W-W	2.45	2.36	0.208	0.201	11.77	11.74

‡ Means compared by linear contrast analyses. The values are means of 4 reps for LHS (A) and RHS (B) treatment comparisons. Values are for the rotation phases underlined.

+, *, ** denote significance of each pair of means compared, at $P < 0.20$, $P < 0.05$ and $P < 0.01$, respectively.

There were two types of legume-containing rotations studied at Indian Head, viz., a green manure (sweet clover)-W-W system and a 6-yr rotation involving three years of bromegrass-alfalfa forage, one year of fallow, and two years of spring wheat. No fertilizer was applied to these rotations. The green manure narrowed the C/N ratio and increased organic matter C and N in the surface soil by 5% and 8%, respectively, compared to the unfertilized F-W-W system. After 27 years the organic matter in the GM-W-W system (unfertilized) was equal to that of the F-W-W that had been fertilized as specified in Table 1 and also to unfertilized continuous wheat. The 6-yr forage-cereal rotation maintained organic matter at higher levels than the unfertilized GM-W-W and continuous wheat systems and the fertilized F-W-W, and had levels similar to those found in the fertilized continuous wheat system. There was no difference in organic matter between the GM phase and the wheat on GM phase of the 3-yr rotation.

Estimate of Effect of Straw Removal on Soil Organic Matter C and N at Indian Head

Baling the straw from a F-W-W (fertilized) rotation each year while not baling but returning straw to a like system allowed us to make a soil organic C and N balance in these systems after 27 years of cropping.

Case 1: Carbon

Known: % C in 0-7.5 cm depth of F-W-W (N, P), no bailing = 2.38% and when straw baled 2.35%. (The % C in 7.5-15 cm depths of the two systems were almost identical). This is equivalent to about 23800 and 23500 kg C/ha in the two systems (0-7.5 cm), respectively.

Assumptions:

1. Grain yield for fallow wheat = 2550 kg/ha and for stubble wheat = 1850 kg/ha for both systems.
2. Straw yield = 1.5 x grain yield (Nuttall et al. 1986).
3. Only 2/3 of straw yield removed by bailing.
4. Straw contains 33% C (Campbell's unpublished data).
5. Proportion of straw C lost by decomposition in first year = 67% and in second year 13%.

Calculations: Amount of straw baled each 3 years = (2550 + 1850) x 1.5 x 0.66 = 4400 kg/ha, and in 27 yr = 4400 x 9 = 39,600 kg/ha.
Amount of C baled as straw = 39,600 x 0.33 = 13,200 kg/ha.
Since 80% of C dissipated as CO_2 in decomposition and soil respiration, C left in soil = 13,200 x 0.20 = 2640 kg C/ha.
Since check plots have 23,800 kg C/ha per 7.5 cm, in theory straw baled plots should have 23,800 - 2640 = 21,160 kg C/ha.
We found 23,500 kg C/ha.

Case 2: Nitrogen

Known: Nitrogen, unlike C, could be located not only in the surface soil but also be mineralized and moved into the soil profile. The balance should therefore be done to depth but we only have the 0-7.5 and 7.5-15 cm depths and will use these as a first approximation.

		0-7.5 cm	7.5-15 cm	Total (kg/ha)
Check	% N	0.200	0.198	
	kg N/ha	2000	1980	3980
Straw baled	% N	0.191	0.186	
	kg N/ha	1910	1860	3770
	Difference after 27 years			210

Using assumptions from Case 1, yield of baled straw in 27 years = 39,600 kg/ha.
Assuming % N in straw = 0.45% (Campbell unpublished).

$$\text{Total N baled off land in 27 years} = \frac{39,600 \times 0.45}{100} = 178 \text{ kg/ha}$$

One can assume that all decomposed mineralized N entered the soil system and thus is within reasonable agreement with the difference found between the two F-W-W systems (i.e., 210 vs 178).

Explanation: The fact that the balance checks out for N and not for C would indicate that whatever organic C advantage that results to the check (unbaled) plots in the two crop years, tillage during the subsequent fallow year dissipates this C and brings the two systems back to the same level. This conclusion is corroborated by results of the F-W vs F-W-W (no fertilizer) systems where despite an extra 6 years of cropping (and thus extra C inputs) in the F-W-W system, there was no difference in soil organic C in the 0-7.5 cm depth (i.e., F-W = 2.21% and F-W-W = 2.25% C). In the case of N however, whatever N was mineralized during the fallow-year was used by subsequent crops or immobilized by microorganisms and thus re-entered the soil N pool.

Melfort

Since almost all tests except those that were annually cropped were sampled in the fallow phase, a sampling study was carried out on some rotations to determine if the cropping phase sampled influenced the soil organic matter (Table 4). There was a tendency for the cereal phase after GM (GM-W-W) and after wheat (F-W-W-H-H-W) to have a higher C concentration,

Table 4. Comparison of some rotational effects on soil organic matter at Melfort (0-7.5 cm depth)

‡Treatments Compared (A)	vs (B)	% C (A)	% C (B)	% N (A)	% N (B)	(A	atio (B)
Effect of Fertilizer							
F-W-W (No Fert)	vs F-W-W (Fert)	5.30	5.04	0.501	0.498	10	10.12+
Contin. W (No Fert)	vs Contin. W (Fert)	5.92	6.02	0.527	0.532	11	11.32
F-W-W-H-H-W (No Fert)	vs F-W-W-H-H-W (Fert)	5.67	5.67	0.527	0.535	10	10.59
Effect of Phase of Rotation Sampled							
GM-W-W (Fert)	vs GM-W-W (Fert)	5.34	5.65	0.508	0.509	10	11.10+
F-W-W-H-H-W (No Fert)	vs F-W-W-H-H-W (No Fert)	5.67	5.82	0.527	0.527	10	11.04
F-W-W-H-H-W (No Fert)	vs F-W-W-H-H-W (No Fert)	5.67	5.60	0.527	0.509+	10	11.01
F-W-W-H-H-W (Fert)	vs F-W-W-H-H-W (Fert)	5.67	5.92	0.535	0.536	10	11.04+
F-W-W-H-H-W (Fert)	vs F-W-W-H-H-W (Fert)	5.67	5.66	0.535	0.513*	10	11.02+
Effect of Rotation Length and Fertilizer							
F-W-W (No Fert)	vs Contin. W (No Fert)	5.30	5.92**	0.501	0.527*	10	11.22*
F-W (Fert)	vs F-W-W (Fert)	5.50	5.04*	0.499	0.498	11	10.12**
F-W-W (Fert)	vs Contin. W (Fert)	5.04	6.02**	0.498	0.532**	10	11.33**
Effect of Legumes in Rotation							
F-W-W (No Fert)	vs GM-W-W (Fert)	5.30	5.34	0.501	0.508	10	10.51
Contin. W (No Fert)	vs GM-W-W (Fert)	5.92	5.34*	0.527	0.508+	11	10.51**
F-W-W (Fert)	vs GM-W-W (Fert)	5.04	5.34	0.498	0.508	10	10.51+
Contin. W (Fert)	vs GM-W-W (Fert)	6.02	5.34**	0.532	0.508*	11	10.51**
GM-W-W (Fert)	vs F-W-W-H-H-W (Fert)	5.34	5.67+	0.508	0.535*	10	10.60
F-W-W (Fert)	vs F-W-W-H-H-W (Fert)	5.04	5.67**	0.498	0.535**	10	10.60*
Contin. W (Fert)	vs F-W-W-H-H-W (Fert)	6.02	5.67+	0.532	0.535	11	10.60**
Contin. W (No Fert)	vs F-W-W-H-H-W (Fert)	5.92	5.67+	0.527	0.535	11	10.60**

‡ Means compared by linear contrast analyses. The values are means of 4 reps for LHS and RHS (B) treatment comparisons. Values are for the rotation phases underlined.
+, *, ** denote significance of each pair of means compared, at $P < 0.20$, $P < 0.05$ an 0.01, respectively.

but for N concentration not to be affected, perhaps reflecting the recent addition of crop residue C from the wheat. On the other hand, organic C and N were sharply reduced by breaking the hay; however, while the C remained low even after a wheat crop (compare W after H and F phases) the N concentration recovered, reflecting the N gains from mineralization of bromegrass-alfalfa. These results suggest that we must be careful to sample comparable treatment phases in the rotations in order to make meaningful contrasts.

There were no unfertilized F-W treatments at Melfort. Although the organic C concentration of the fertilized F-W system seemed inordinately high (Table 4), generally organic C and N concentrations were greater for the continuous wheat system than for F-W or F-W-W whether fertilized or unfertilized. At the same time the C/N ratios tended to widen as would be expected from the much greater annual inputs of wide C/N ratio cereal residue material in the continuous cropping rotation.

Unlike Indian Head, the application of N and P fertilizers to wheat in monoculture or cereal-legume mixed rotations did not affect organic C, N nor C/N ratios (Table 4). This absence of significant benefit of fertilizer to the organic matter content of this thick Black soil contrasts with results obtained in the Brown (Biederbeck et al. 1984), Dark Brown (Jansen 1987) and thin Black (mentioned earlier) soil zones, and may be related to the comparatively high organic matter and fertility this soil enjoys.

At Melfort, as at Indian Head, there were two types of legume-containing rotations, a GM-W-W and two F-W-W-H-H-W rotations. The difference was that the GM rotation was fertilized with N and P as was one of the 6-yr mixed rotations. Unlike Indian Head, GM did not increase organic matter compared to the unfertilized F-W-W system. However, as at Indian Head organic C and N in the surface soil of the 6-yr mixed forage-cereal rotation was higher than in the 3-yr rotations and generally similar to those of the continuous wheat rotations.

SUMMARY

The main findings of this study to date are:

1. Summerfallowing (tillage) is the main factor causing loss of organic matter.

2. The longer the rotation the greater are the chances that soil organic matter will be increased.

3. Fertilizing according to soil test may lead to increases in soil organic matter, but (a) in direct proportion to rotation length and (b) inversely to the original level of soil organic matter.

4. Legumes such as sweet clover used for green manure in 3-yr rotations with wheat will increase organic matter in low fertility soils to the same extent as fertilizer applied at soil test rates; it may not increase organic matter in very fertile soils with high organic matter.

5. Six-yr mixed fallow-wheat-(legume-forage) rotations increased organic matter in thin and thick Black soils compared to shorter rotations; organic matter in mixed rotation systems was the same as for continuous wheat receiving soil test rates of N and P even though the land was fallowed once every 6 years.

6. The cropping phase sampled in the mixed or fallow-containing rotations may influence the organic matter values obtained; for example, organic matter crashed soon after the forage phase was broken.

7. Removal of straw by baling for 18 of the 27 years did not influence organic C, but reduced organic N by 5% in a fertilized F-W-W system on the thin Black soil. Apparently, any gains in organic C made during the two years of cropping were rapidly lost during the one year of fallow.

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