Effect of Cropping Frequency, Wheat Classes and Flexible Rotations on Yield, Production and Nitrogen Economy in a Brown Chernozem

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Abstract

Producers in the semiarid Canadian prairies frequently summerfallow (F) to conserve water, control weeds, and to maximize soil N reserves; however, this practice often results in soil degradation. A crop rotation experiment was initiated in 1987 on a medium textured, Orthic Brown Chernozem at Swift Current, to determine the most ideal cropping frequency for this region and whether a fixed rotation such as fallow-wheat-wheat (F-W-W) would be more effective than flexible rotations in which fallowing is decided each spring based on criteria such as available soil water (if water), or the need to control perennial weed infestations (if weeds). The study also compares the production of traditional Canada Western Red Spring (CWRS) wheat class with the newer higher-yielding (Hy), Canada Prairie Spring (CPS) wheat class. The rotations included F-W-W, F-W-W-W, F-Hy-Hy, Continuous wheat (Cont W), Cont W (if weeds), and Cont W (if water). Over the study period (1987-1998), weather conditions were generally favourable and yields were above average for this region. Canada Prairie Spring wheat outyielded CWRS by 35% when grown on fallow and by 15% when grown on stubble; however, straw yields of the two wheat classes were similar on fallow and CPS was 7% less than CWRS on stubble. Harvest index (HI) averaged 45% for CPS and 40% for CWRS wheat. Grain N concentration averaged 25.5 g kg^{-1} for CWRS and 22.5 g kg^{-1} for CPS; straw N concentration averaged 4.0 g kg^{-1} for CWRS and 4.6 g kg^{-1} for CPS. Nitrogen yield for grain from CPS was 13% greater than from CWRS when grown on fallow, but class had no effect when wheat was grown on stubble. Nitrogen yield of straw was generally not affected by wheat class. Nitrogen yield of the above-ground plant parts generally mimicked grain N yield responses. Nitrogen harvest index (NHI) averaged 80% for both wheat classes, whether grown on fallow or stubble. On a rotation basis, F-W-W-W and Cont W (if weeds) produced 9% more grain than F-W-W, while Cont W (if water) produced 24% more grain, and Cont W and F-Hy-Hy produced 29% more grain than F-W-W. Nitrogen production in the grain, straw and above-ground plant material was lowest in F-W-W, highest in Cont W, and intermediate for other rotations.

Introduction

In the semiarid prairies of western Canada spring wheat is the main crop grown and crop rotations have a high proportion of summerfallow to conserve water, control weeds and increase available N. Summerfallow reduces economic risk but often promotes soil degradation. Crop rotation studies are useful for answering questions related to changes in soil quality, crop productivity and economic viability. Most rotation studies in the past have used “conventional production practices”. There have been recent technology advances in crop management and new crop types. Consequently, a “New Rotation” experiment was initiated in 1987 at the Semiarid Agricultural Research Centre (SPARC) at Swift Current to re-examine some of the issues related to crop rotations, but employing some of the “modern” production methods.

Our objective is to discuss agronomic performance of 6 of the 9 crop rotations in the New Rotation study”, using data from the first 12 years (1987-1998) of study.

Materials and Methods

Experimental Design and Crop Management

The “New Rotation experiment” was initiated in 1987 on Swinton loam, an Orthic Brown Chernozem at Swift Current. Nine rotations were established: four 3-yr, a 4-yr, one Cont W, two flex-cropping (if type) rotations, and a crested wheatgrass (CWG) system. We discuss 6 of these rotations (Table 1). All phases of each rotation were present every year and each rotation was cycled on its assigned plots. Plots were 15 m x 45 m, arranged in a randomized complete block design with three replicates. The plots were tilled only when necessary for proper weed control or seed placement (i.e., minimum- and zero-tillage was practiced).

Wheat received ammonium nitrate fertilizer midrow banded, based on NO_3-N levels in 0-60 cm depth of soil, measured on a per plot basis the previous fall, and the regional fertilizer recommendation guidelines of the Saskatchewan Advisory Council. Fertilizer N applied averaged 31-38 kg $ha^{-1}yr^{-1}$ for wheat grown on fallow and 47-51 kg $ha^{-1}yr^{-1}$ for wheat grown on stubble. But rates were lower in the 1988-1991 period (avg. 12-22 kg $ha^{-1}yr^{-1}$) for wheat grown on fallow compared to 38-46 kg $ha^{-1}yr^{-1}$ for this system in 1992-1998. All wheat plots received P (monoammonium phosphate) applied with the seed at 9.6 kg P ha^{-1}.

Wheat was harvested at full maturity with a conventional combine, equipped with a direct-cut header. The stubble was cut as high as possible (usually >30 cm) to enhance overwinter snowtrapping and soil water conservation. Three 1-m^2 aboveground plant samples were taken from all cropped plots prior to harvest for determination of plant biomass and kjeldahl N.

Weather Conditions

Weather data [growing season (May – August) precipitation and Class A pan evaporation] (Table 2) were measured at a meteorological station located 0.5 km east of the test site. Potential evapotranspiration (PET) was assumed to be 70% of the pan evaporation.

Statistical Analysis

Various characteristics were analyzed for the period 1987 to 1998 using a split plot design with rotation-phase as main plot and year as sub-plot (SAS Institute, Inc. 1985).

The characteristics assessed were yield, N concentration and N yield (mass x concentration) of grain, straw and above-ground plant material; harvest index (HI) (i.e., grain mass ÷ above-ground plant mass), and nitrogen harvest index (NHI) (i.e., N yield in grain ÷ N yield in above-ground plant parts).

Results and Discussion

Dry Matter Yields

Grain yields. In the 12-yr period, grain yields were above average for this region because of the generally favourable weather conditions (Table 2). For example, yields of CWRS wheat grown on fallow averaged 2350 kg ha^{-1} and wheat grown on stubble averaged 1795 kg ha^{-1} (Table 3). When grown on fallow, the CPS wheat (i.e., Hy) yielded significantly ($P<0.05$) more grain than CWRS wheat in 10 of 12 yr (data not shown), with CPS outyielding CWRS by 35% on average (Table 3). When grown on stubble, CPS outyielded CRWS by 15%, with the difference being significant ($P<0.05$) in 5 of 12 yr (generally the wetter years) (data not shown). These results were expected since CPS was developed to produce much higher yields, but lower grain protein and gluten strength than CWRS (Clarke and DePauw 1989). Cropping frequency had no effect on grain yields of CWRS wheat when grown on fallow or stubble (Table 3). Stubble-wheat yields of CWRS averaged 76% of fallow wheat yields. The influence of flexible rotations on yields is best discussed in terms of production for the complete rotation (see later discussion).

Straw yields. Because CPS wheat is normally shorter in stature than CWRS wheat (Clarke and DePauw 1989), it was not surprising that despite their higher grain yields they had similar straw yields to CWRS when grown on fallow, and had 7% less straw yield when grown on stubble (Table 3). Cropping frequency had no influence on straw yields of CWRS wheat grown on fallow or stubble. Straw yield of stubble-wheat averaged about 75% of wheat grown on fallow (Table 3).

Harvest index. When grown on fallow, the HI of CWRS ranged between 52% in a dry year (1987) and 32% in a wet year (1995) (data not shown) and averaged 38% (Table 3). For CPS wheat the range was between 57% in 1987 and 40% in 1995 with an average of 45%. The HIs for wheat grown on stubble were similar to those for wheat grown on fallow. Cropping frequency had no effect on HI. As expected, HI varied considerably with environmental conditions (years) (data not shown), as reported by Clarke et al. (1990). Our HI values were similar in magnitude to those obtained by Clarke et al. (1990) who reported average HIs of 45% for CPS, and 40% for CWRS and a standard durum cultivar grown at Swift Current under dryland and irrigation conditions.

Nitrogen in Plants

Grain N concentration. Canada Prairie Spring wheats are bred to produce medium quality protein, while CWRS wheats are generally bred for high protein (Clarke and DePauw 1989). Thus, it was not surprising that N concentration in grain on CWRS wheat was significantly higher ($P<0.05$) than that of CPS when grown on fallow in 11 of 12 yr and in 7 of 12 yr when grown on stubble (data not shown). Part of this difference due to wheat class was the result of N dilution because of the higher yields of CPS. The N concentration of CWRS grain averaged 25.5 g kg^{-1} for wheat grown on fallow or stubble and 22.5 g ha^{-1} for CPS, with values being highest in drier years (lowest yields) (data not shown). Like grain yield, cropping frequency had no effect on grain N concentration.

Straw N concentration. The N concentration in straw was similar for wheat grown on fallow and stubble, with values averaging 4.0 g kg^{-1} for CWRS and about 4.7 g kg^{-1} for CPS (Table 3).

Grain N yield. Grain N yield of CPS wheat grown on fallow was only 13% greater than that for CWRS (Table 3) despite a 33% advantage in grain yield, but also a lower grain N concentration. There was no difference in grain N yield due to wheat class when grown on stubble; both wheat classes contained about 43 kg N ha^{-1}, or about 70% as much grain N yield as F-(W)-W (Table 3). Grain N yield for wheat grown on fallow averaged 68 kg ha^{-1} for CPS wheat and 61 kg ha^{-1} for CWRS.

Straw N yield. Straw N yield in CPS wheat grown on fallow averaged 16.5 kg ha^{-1}, about 15% greater than for CWRS grown on fallow (14.5 kg ha^{-1}); however, CPS was only significantly ($P<0.05$) greater than CWRS in 2 of 12 yr (data not shown). Straw N yield for wheat grown on stubble averaged 9-10 kg ha^{-1} and was not affected by class of wheat. Cropping frequency did not influence straw N yield.

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Above-ground N yield. Nitrogen yield in the above-ground plant parts averaged 84 kg ha^{-1} for CPS wheat grown on fallow, about 8 kg ha^{-1} more than CWRS (Table 3); however, differences due to class of wheat were significant ($P<0.05$) in only 3 or 4 of the 12 yr (data not shown). Nitrogen yield in the above-ground plant parts for wheat grown on stubble averaged 52 kg ha^{-1} and was unaffected by wheat class. Cropping frequency had no effect on N yield in the above-ground plant parts.

Nitrogen harvest index. Nitrogen harvest index averaged 80% and was neither influenced by class of wheat nor cropping frequency in most years (Table 3). Further, like HI, NHI was generally similar for wheat grown on fallow and stubble.

Grain, Straw and N Production per Rotation

Grain production. Grain production of CWRS wheat for the F-W-W rotation averaged 1386 kg $ha^{-1}yr^{-1}$ over the 12-yr period (Table 4). The F-W-W-W and Cont W (if weeds) produced 9% more grain than F-W-W. Cont W (if water) produced 24% more grain, and Cont W and F-Hy-Hy produced 29% more grain than F-W-W.

Straw production. Straw production of CWRS wheat for the F-W-W rotation averaged 2307 kg $ha^{-1}yr^{-1}$ (Table 4). In contrast to grain production, this was 4% more than for the CPS. However, the straw production for the other rotations exceeded that for F-W-W by about the same proportion as they did for grain production.

N production. The production of grain N, straw N, and above-ground plant N, was lowest in F-W-W, highest in Cont W, and intermediate for the other rotations (Table 4).

Although we failed to observe effects of cropping frequency on the various characteristics when comparisons were made on a rotation-phase basis, the effect of cropping frequency was quite apparent when comparisons were made on a rotation basis.

Conclusions

The main objective of this study was to determine how, and to what extent, producers in the semiarid Brown soil zone of the Canadian prairies could extend their cropping frequency to achieve improved soil quality and economic benefits without incurring an unacceptable rise in the frequency of crop failures. The results of this study after 12 yr, based only on production and N economy, suggest that extending cropping frequency from F-W-W to F-W-W-W will only result in a 10% increase in grain production. However, a more flexible rotation in which available soil water in spring is used as the determining criterion as to whether to crop or fallow the land resulted in a 24% advantage in grain production. Thus, a preliminary conclusion favours the flexcropping treatment over the fixed 4-yr rotation. However, we must await economic analysis and assessment of soil quality changes before firm conclusions can be drawn.

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Table 1. Crop rotations[z] and abbreviations.

Rotation	Abbreviation
Fallow-wheat[y]-wheat	F-W-W
Fallow-CPS wheat[x]-CPS wheat	F-Hy-Hy
Fallow-wheat-wheat-wheat	F-W-W-W
Continuous wheat	Cont W
Continuous wheat (fallow if low spring soil water)	Cont W (if water)
Continuous wheat (fallow if weeds a problem)	Cont. W (if weeds)

[z] Only the rotations discussed in this paper are shown.
[y] Wheat is Canada Western Red Spring (CWRS) wheat class.
[x] CPS = Canada Prairie Spring wheat.

Table 2. Growing season (May-August) precipitation and potential evapotranspiration (PET)[z] for the period 1987-1998 at Swift Current.

Weather characteristics		May	June	July	August	Growing season
		(mm)				
Precip	Mean	50	82	53	52	237
	Range	15-96	43-165	16-107	19-153	172-335
	105 yr mean	44	72	52	42	210
PET	Mean	154	176	177	172	679
	Range	99-237	132-266	130-256	131-213	593-963
	40 yr mean	152	169	187	180	688

[z] The PET was assumed to be 70% of Class A pan evaporation for cropped system.

Table 3. Grain and straw yields, N concentration, N yield, harvest index (HI)[z] and NHI[z] for wheat grown on fallow and on stubble (values averaged over 1987-1998).

Treatment[y]	Yield ($kg\ ha^{-1}$)		HI	N Conc ($g\ kg^{-1}$)		N Yield ($kg\ ha^{-1}$)			NHI
	Grain	Straw	(%)	Grain	Straw	Grain	Straw	Above-ground	(%)
Wheat on fallow									
F-(W)-W	2362	4005	38	26.4	4.0	60.2	13.9	74.1	81
F-(Hy)-Hy	3211	3990	45	22.7	4.8	67.8	16.5	84.3	80
F-(W)-W-W	2442	4157	38	26.5	4.1	62.6	15.1	77.7	81
Mean	2675	4051	40	25.2	4.3	63.5	15.2	78.7	81
Wheat on stubble									
F-W-(W)	1797	2915	38	25.0	4.0	41.8	9.2	51.0	81
F-Hy-(Hy)	2155	2644	44	22.2	4.5	42.8	9.9	52.7	80
F-W-(W)-W	1782	2899	38	25.5	4.0	41.9	9.4	51.3	81
F-W-W-(W)	1798	3073	37	24.8	4.0	41.2	10.1	51.3	80
Cont (W)	1793	2985	38	25.3	4.2	42.2	10.3	52.5	80
Mean	1865	2903	39	24.6	4.1	42.0	9.8	51.8	80

[z] Harvest index = grain wt ÷ grain + straw wt and NHI = N in grain ÷ N in above-ground parts.

[y] Data for the two flexible Cont W rotations not shown. F = fallow, W = Canada Western Red Spring wheat (CWRS), Hy = higher yielding Canada Prairie Spring (CPS) wheat, and Cont = annual cropping.

Table 4. Average[z] wheat grain and straw yields and their N production per rotation (1987-1998).

Treatment	Grain yield (kg ha^{-1} yr^{-1})	Relative to F-W-W (%)	Straw yield (kg ha^{-1} yr^{-1})	Relative to F-W-W (%)	Grain N yield (kg ha^{-1} yr^{-1})	Relative to F-W-W (%)	Straw N yield (kg ha^{-1} yr^{-1})	Relative to F-W-W (%)	Above ground N yield (kg ha^{-1} yr^{-1})	Relative to F-W-W (%)
F-W-W	1386	100	2307	100	34.0	100	7.7	100	41.7	100
F-Hy-Hy	1789	129	2211	96	36.9	109	8.8	114	45.7	110
F-W-W-W	1505	109	2532	110	36.4	107	8.6	112	45.0	108
Cont W	1793	129	2985	129	42.2	124	10.3	134	52.5	126
Cont W (if water)	1722	124	2866	124	39.5	116	8.4	109	47.9	115
Cont W (if weeds)	1513	109	2445	106	37.2	109	9.0	117	46.2	111

[z] For each rotation = sum of 12-yr avg. yield for each crop phase ? number of phases in the rotation (e.g., for F-W-W- = avg. yield of F- (W)-W + avg. yield of F-W-(W) ? 3; for Cont W = avg. yield). In the flexible rotations fallow years are counted as zero yields.