Short Rotation Forage Legumes Provide N Fertility for Wheat and Canola Crops

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Introduction

The agricultural region of Saskatchewan was developed from native prairie grasslands and Parkland mixed grassland and forest sites by plowing and cultivation during European settlement. Within 50 years after the start of cultivation, perennial forage crops were not recommended for rotation with annual crops in the Prairie region (Brown soil zone) of Saskatchewan but were recommended in the Parkland region (Black soils) (Campbell et al. 1990). Perennial forage crops in Brown soil zone rotations depleted soil moisture and subsequent annual crop yields. Alfalfa (*Medicago sativa* L.) utilized soil water to 3 m depth or more in the dry prairie region (Jefferson and Cutforth 2005) and the subsequent wheat (*Triticum aestivum* L.) yield was depressed in the first crop after alfalfa compared to wheat after wheat (Cutforth et al. 2010). Barley (*Hordeum vulgare* L.) grown after alfalfa/grass mixtures experienced drier soil conditions and lower grain yield than barley grown after grass monoculture (Jefferson et al. 2013). However, barley protein and N uptake was increased by alfalfa in the previous forage crop. As reported in other regions, legume forages can increase N fertility for subsequent crops in rotations (Entz et al. 2002). The amount of N fertility provided varies from modest (8 kg N ha^{-1}) (Jefferson et al. 2013) to larger amounts (62 kg N ha^{-1}) (Theissen Martens et al. 2005). It seems that soil zone and environmental conditions influence N fertility benefit of legumes forages. Soil drying may be reduced by shortening the stand life of the perennial forage legume (Cutforth et al. 1991).

The objectives of this project was to determine the N provided in crop rotations from short-lived (two-year) perennial forage legume crops in four sites representing different soil zones by:

1. Determining N uptake by cereal crops in the two years following the legumes
2. Calculate the N fertilizer replacement value by application of N rate subplots on the annual crop control rotation in 2012 and 2013

Materials and Methods

The rotation treatments are: A-A-W-C, RC-RC-W-C, B-P-W-C and B-F-W-C where A=Alfalfa, B=Barley, W=Wheat, C=Canola, RC=Red Clover, P=Pea, and F=Flax from 2010 to 2013 at Swift Current (Brown soil zone), Saskatoon (Dark Brown), Lanigan (Thin Black) and Melfort (Black). Certified seed of CDC Copeland barley, Belle Red Clover (inoculated), and 2065 Mf alfalfa (inoculated) was seeded 84 kg $ha^{-1}$for barley, and 9 kg ha^{-1} for alfalfa and red clover, except at Swift Current, where it was 4.5 kg ha^{-1} for alfalfa and red clover. Soil samples at 0-30 and 30-60 cm in 2010 and 2012 and at 0-15, 15-30 and 30-60 cm in 2012 and 2013 were taken in spring and fall at all sites. Seeding and harvest dates varied among the sites and years but were generally late May or early June and late August or September. In 2010 and 2011, all crops were fertilized according to soil test recommendation. In 2011, Golden Yellow peas (inoculated) and CDC Bethune flax were seeded in rotations three and four, respectively, at all four sites at recommended rates. In 2012, Unity wheat was seeded at recommended rates. In 2013, L-130 canola was seeded at all four sites at recommended rates. In 2012 and 2013 only rotation four subplots were fertilized with urea N (46-0-0) treated with Agrotain. The N rates were equivalent to 0, 40, 80, 120 and 160 kg N ha^{-1}. Pre-seeding weed control with glyphosate was done at Melfort, Lanigan and Swift Current. Post seeding weed control varied among the sites but followed recommendations for each crop.

All the sites experienced well above-average to near-record precipitation in 2010 (Fig. 1). Saskatoon, Lanigan and Melfort sites had about 200 mm of rain in April and May combined, which delayed seeding into June. The barley crop was not able to complete its grain filling period at Lanigan, so it was decided to harvest the whole crop as a greenfeed forage barley.

Wheat biomass and grain yield from 0 N rate subplot in Rotation 4 was compared to the other rotations in an ANOVA with JMP software (SAS Institute Inc. Cary NC). The other N rate results were not used in this analysis. This approach compares all four rotation treatments at 0 N fertilizer rate to determine the effect of rotation sequence.

The N rate subplots (including 0 N) were used to generate a wheat grain or canola seed yield response to N rate regression for each location. This equation was used to calculate the Nitrogen fertilizer Equivalent (NFE) based on the grain yield observed in rotations 1, 2 and 3. Any negative values calculated for NFE were treated as zero for the purpose of the analysis. The NFE values were then analyzed with ANOVA for 3 treatments (Rotations 1-3) and 4 replications.

Results and Discussion

Table 1. Forage yield, CP and TDN concentration for alfalfa and red clover hay harvested at four sites during 2010 and 2011 in Saskatchewan.

Site	Legume	2010 cut1	2011 cut 1	2011 cut 2	2011 cut 3
		Forage yield kg ha^{-1}			
Swift Current	Alfalfa	1726	8117	--	--
	Red clover	848	5357	--	--
Saskatoon	Alfalfa	3200	8924	3889	2832
	Red clover	3476	6415	3225	3002
Lanigan	Alfalfa	4726	3446	3479	3600
	Red clover	2104	3068	2692	3268
Melfort	Alfalfa	3374	6193	4273	--
	Red clover	5213	3993	5143	--
SE		621	463	166	143
P site		**0.0008**	**0.0001**	**0.0001**	**0.0047**
P legume		0.4397	**0.0001**	0.1728	0.5838
P site x legume		**0.0134**	0.0716	**0.0002**	0.1098
		CP %			
Swift Current	Alfalfa	19.63	15.00	--	--
	Red clover	14.76	15.47	--	--
Saskatoon	Alfalfa	19.89	16.78	23.84	22.51
	Red clover	19.33	15.68	23.88	21.23
Lanigan	Alfalfa	20.46	19.68	25.77	20.80
	Red clover	17.13	17.89	23.52	23.40
Melfort	Alfalfa	16.35	18.14	14.18	--
	Red clover	15.43	14.35	11.98	--
SE		0.90	0.63	0.60	0.98
P site		**0.0025**	**0.0001**	**0.0001**	0.8183
P legume		**0.0011**	0.0864	**0.0045**	0.5138
P site x legume		0.0837	0.3637	0.0760	0.0743
		TDN %			
Swift Current	Alfalfa	61.08	58.28	--	--
	Red clover	56.11	60.24	--	--
Saskatoon	Alfalfa	64.59	62.63	66.14	64.17
	Red clover	67.62	65.19	63.34	64.97
Lanigan	Alfalfa	64.05	62.55	61.75	65.85
	Red clover	66.28	60.29	59.70	66.70
Melfort	Alfalfa	61.62	62.34	59.79	--
	Red clover	64.35	61.58	61.22	--
SE		0.85	0.49	0.52	0.70
P site		**0.0001**	**0.0001**	**0.0001**	**0.0355**
P legume		0.2233	0.2940	**0.0086**	0.2688
P site x legume		**0.0003**	**0.0002**	**0.0007**	0.9710

Alfalfa produced more hay than red clover for all harvests at Swift Current and Lanigan but red clover produced more than alfalfa for two of three harvests at Melfort (Table 1). The site x legume interaction was significant for two of four harvests taken. Total yield combined over harvests (data not shown) indicate that 5 Mg ha^{-1} can be achieved with intensive harvest management.

The interaction was nearly significant (P=0.08) for CP concentration for three of four harvests (Table 1). Alfalfa CP was sometimes higher than red clover but in some sites and harvests (eg. Cut 1 in 2011 and Cut 3 in 2011) there was no difference. The CP concentrations exceeded the minimum requirements for beef cows in the mid and late gestation periods.

The site x legume interaction was significant for TDN concentration for three of four harvests (Table 1). Red clover TDN concentration was greater than alfalfa TDN at Melfort in cut 1 2010 while the opposite was observed at Swift Current. The TDN concentrations of both legumes exceeded the minimum requirements for beef cows during fall and winter.

Red clover is known for adaptation in the Parkland region but not in the Brown soil zone and this is evident in the yield observations in this trial. Alfalfa is better adapted in the Brown soil zone because its deep roots allow for greater soil water utilization. The nutritive value of hay harvested from either legume is suitable for blending with cereal straw or crop residues (chaff or straw/chaff or corn stover) to produce low cost but nutritious winter rations for pregnant beef cows.

Grain production was hampered by excessive rain at Lanigan and Saskatoon in 2010 and Lanigan and Swift Current in 2011 (Table 2). While we expected no differences in barley yield between Rotations 3 and 4, there was a significant difference at Saskatoon. Peas produced more grain than flax at Melfort, Lanigan and Swift Current in 2011 despite the poor growing conditions and low production at the latter two sites.

Wheat grain yield in 2012 was significantly greater after forage legumes at Saskatoon, Lanigan and Melfort (Table 3). At Swift Current however, the wheat grain yield was lower after alfalfa than after flax (rotation 4). Despite higher than average precipitation in 2010 and 2011 at Swift Current, the alfalfa dried the profile sufficiently that wheat production in rotation 1 was lower than rotations 2, 3 and 4 (data not shown). The barley yield results of Jefferson et al. (2013) at Swift Current were similar to the wheat yields in our study.

The canola yield was not different among the rotations at Swift Current or Saskatoon in 2013 (Table 4). Drier than normal conditions later in the growing season at the Swift Current site likely reduced canola yield potential. At Lanigan, canola yield in rotation 2 tended to be higher than in rotation 4 (P=0.0510). At Melfort, canola yield in rotation 1 was significantly greater than rotation 2, 3 or 4.

Table 2. Grain yield in two rotations at four sites in Saskatchewan during 2010 and 2011.

Year	Crop Rotation	Swift Current	Saskatoon	Lanigan	Melfort
		Grain yield kg ha^{-1}			
2010	B-P-W-C [z]	2177	1027	--[y]	2892
	B-Fl-W-C	2293	792	--	2744
	P>F	0.4514	**0.0422**	--	0.5660
	SE	150	77	--	258
2011	B-P-W-C	88	1969	511	3545
	B-Fl-W-C	25	1472	137	1717
	P>F	**0.0169**	0.1385	**0.0034**	**0.0049**
	SE	15	276	49	271

[z]A-A-W-C is alfalfa, alfalfa, wheat and canola in rotation; RC-RC-W-C is red clover, red clover, wheat and canola in rotation; B-P-W-C is barley, pea, wheat and canola in rotation; and B-Fl-W-C is barley, flax, wheat and canola in rotation. The underlined crop is the phase for that year.
[y] – Not harvested for grain due to immature growth stage.

Table 3. Wheat grain yield and N fertilizer equivalent for 4 rotations at 4 sites in Saskatchewan in 2012.

Rotation	Swift Current	Saskatoon	Lanigan	Melfort
		Grain yield kg ha^{-1}		
A-A-W-C[Z]	1546	2616	2174	3560
RC-RC-W-C	2098	2879	2425	3314
B-P-W-C	1981	2069	2405	3140
B-Fl-W-C	2281	1827	1626	2438
P>F	**0.0298**	**0.0212**	**0.0035**	**0.0001**
s.e.	186	275	158	88
		N fertilizer equivalent kg ha^{-1}		
A-A-W-C	--	48	107	274
RC-RC-W-C	--	76	140	193
B-P-W-C	--	5	168	140
B-Fl-W-C	--	--	--	--
P>F		0.1413	0.6301	**0.0351**
s.e.		30	61	38

[Z] A-A-W-C is alfalfa-alfalfa-wheat-canola, RC-RC-W-C is red clover-red clover-wheat-canola, B-P-W-C is barley-pea-wheat-canola and B-Fl-W-C is barley-flax-wheat-canola rotations from 2010-13. The underlined crop is the phase for 2012.

Table 4. Canola oilseed yield and N fertilizer equivalent for 4 rotations at 4 sites in Saskatchewan in 2013.

Rotation	Swift Current	Saskatoon	Lanigan	Melfort
		Canola grain kg ha^{-1}		
A-A-W-C [z]	1399	1908	1824	3274
RC-RC-W-C	1044	2269	2556	2610
B-P-W-C	861	1521	1946	1927
B-Fl-W-C	1154	1421	1448	2697
P>F	0.2562	0.1113	**0.0510**	**0.0165**
s.e.	234	314	336	300
		N fertilizer equivalent kg ha^{-1}		
A-A-W-C	35	29	37	56
RC-RC-W-C	0	94	72	8
B-P-W-C	0	2	26	0
B-Fl-W-C	--	--	--	--
P>F	0.0810	0.0654	0.2471	**0.0060**
s.e.	20	32	28	33

[z] A-A-W-C is alfalfa-alfalfa-wheat-canola, RC-RC-W-C is red clover-red clover-wheat-canola, B-P-W-C is barley-pea-wheat-canola and B-Fl-W-C is barley-flax-wheat-canola crop rotations from 2010-13.

N fertilizer equivalent (NFE) calculation depended on a positive yield response to N rates applied to the subplots in rotation 4 at each site (Theissen-Martens et al. 2005). There was no yield response at Swift Current in 2012 so NFE was not calculated (Table 3). At Melfort, rotation 3 had significantly more NFE than rotation 3 but the rotations did not differ in NFE at Saskatoon and Lanigan. In 2012, NFE tended to be greater in rotation 1 at Swift Current or rotation 2 at Saskatoon (Table 4) but the NFE did not differ among rotations at Lanigan. In Melfort, rotation 1 exhibited greater NFE than that of rotation 3.

The grain or seed yield results from 2012 and 2013 confirm the hypothesis that residual N after alfalfa or red clover hay crops will vary across the soil zones. Higher NFE at Melfort, especially in 2012, than at the Lanigan site suggests that producers with more productive soils will be better positioned to capture N benefits after alfalfa or red clover. At Swift Current, the drying of soil and perhaps the lack of drought tolerance of the red clover would limit their use as rotational crops for hay and N fertility benefit.

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Figure 1. Monthly precipitation totals by site from 2010 to 2013. Note the change in scale of the Y axis from year to year.