Response of Cereals to Fertilizer N on Pulse and Other Stubbles

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Abstract
To optimize cropping systems requires knowledge of effects of the preceding crop on the grain yield and protein and the response to N of a following cereal crop. To gain this knowledge, we grew hard red spring (HRS) wheat, durum wheat, Canadian Prairie Spring (CPS)-class wheat, Canadian Western Extra Strong (CWES)-class wheat, and barley on barley, bean, coriander, fenugreek, kabuli chickpea, lentil, mustard, and pea stubble at different N fertilizer rates over 9 site-yr: Swift Current (1998-2002), Redvers (2001-02) and Canora (1999 and 2002). N rates were medium (recommended rate based on fall soil nitrate in cereal stubble), low (15-30 kg ha^{-1} less than medium) and high (15-30 kg ha^{-1}). There was a significant effect of stubble on subsequent cereal grain yield. Cereal on cereal stubble was consistently lowest or second lowest yielding (typically 100 – 800 kg ha^{-1} lower than other stubbles) with the exception of 2001 at Swift Current when it was the highest yielding. This latter effect was attributed to the superior moisture conserving benefits of cereal stubble during this year with extreme early drought. No single cereal crop was consistently highest or lowest yielding. The trend was for greatest grain protein on pulse stubbles although stubble effects on protein were not as great as on yield owing to confounding yield dilution effects. Within this narrow range of fertilizer N rates, yield or protein response to N was weak. Generally, there were no significant interactions between stubble and cereal crop or stubble and fertilizer indicating the effect of stubble was consistent across cereal type and N rates. The cereal yield and protein response to N on the non-cereal stubbles was not significantly different than that on cereal stubble with the exception that barley protein responded more positively to N on lentil stubble than on cereal stubble. Cereals grown on pulse stubbles tended to have higher yields and protein than on other stubbles. For HRS wheat and durum, the chance of achieving high protein grain was greatest with high fertilizer N on pea stubble (>75% of years). Applying a high fertilizer N rate on cereal stubbles did not markedly increase the chance of attaining high

protein wheat or durum. For barley, where low protein is desired for malting, the best chance for low protein barley was on cereal and mustard stubble although barley protein appeared less affected by stubble and fertilizer N than wheat or durum.

Introduction

To optimize cropping systems, it is important to understand the interaction of different preceding crops on the grain yield, protein, and fertilizer N response of cereals. Miller et al., 2002a,b concluded that the positive benefits of pulse crops on wheat yield and protein resulted from increased soil N rather than increased available water. However, increased soil N may only increase grain protein (Zentner et al. 2001). Pulse crops have also been reported to reduce cereal disease incidence (Stevenson and van Kessel, 1996; Beckie and Brandt, 1997). Townley-Smith (1994) reported that pea, canola and spring wheat yielded similar on other crop stubbles but least when grown on their own stubbles in a subhumid region of Saskatchewan. In southwestern Saskatchewan, Miller et al. (2003) found that spring wheat yield and protein were depressed when grown on its own stubble compared with on non-cereal stubbles but that pulses and oilseeds were not significantly affected when grown on other pulse and oilseed stubbles. Gan et al. (2003) found that durum grain yield and protein were depressed when grown on spring wheat stubble compared to on pulse or oilseed stubbles with the larger increases in both yield and protein occurring on pulse crop stubbles. In the Black soil zone, fertilizer N additions on non-cereal stubble have also been reported to increase productivity of succeeding cereal crops (Wright, 1990a; 1990b; Badaruddin and Meyer, 1994) with the largest relative response to N on the oilseed compared to pulse stubble (Beckie and Brandt, 1997). In the latter study, regardless of N addition rate, spring wheat on spring wheat stubble never attained a yield equal to that of spring wheat on pea or canola stubble. The objective of this study was to compare the effects of different fertilizer N additions to bean, cereal, coriander, fenugreek, kabuli chickpea, lentil, mustard, and pea stubble on the yield, grain protein and grain N uptake of spring wheat (hard red, Canadian prairie spring, and extra strong classes), durum, and barley.

Materials and Methods

The study was conducted at three of the "Spoke" sites of the AgriArm program (www.agr.gov.sk.ca/DOCS/research/Agri-ARM.asp): East Central Research Farm (Canora), the South-East Research Farm (Redvers), and the Wheatland Conservation Area, Inc. (Swift Current). The Canora and Redvers sites are in the Black soil zone while Swift Current is in the Brown Soil Zone. All sites had medium-textured soils. Across all sites, a wide range of weather conditions occurred from very wet (e.g. Redvers 2002) to very dry (e.g. Swift Current 2001).

In the preceding year, seven different crops were grown (Table 1) with low-disturbance seeding directly into cereal stubble and using recommended fertilizer, weed, disease, and insect control practices. Although a legume, fenugreek was not inoculated with Rhizobium and was fertilized with equivalent amount of N as the mustard. The pea and lentil received no supplemental N fertilizer but were properly inoculated with the appropriate Rhizobium.

In the crop year, the stubble plots were split and seeded with two or three different cereal crops at two or three N fertilizer rates (Table 1). The uniform medium fertilizer N rate was based on soil-test recommendations (www.envirotest.com) for soil nitrate in upper 60 cm of soil in fall in the cereal stubble (Table 1). The low N rate was that recommended for drier-than-normal growing conditions while the high N rate was that for wetter growing conditions. Hence the small range of fertilizer rates were designed to fine-tune fertilizer recommendations for the different stubbles. (The low rate for Redvers in 2001 was no supplemental N due to anticipated low N response from N carried over from the previous year since the experiment site had had very low yields due to excessively wet conditions in 2000). The Redvers site also had a very high N rate to further investigate N response of cereals on different stubbles The cereals were all seeded with commercial seed drills: Seed Hawk (www.langbankcap.ca/seedhawk.htm) at Canora and Redvers, Flexi-Coil with "Stealth" single side-banding knives (www.flexicoil.com) at Swift Current directly into the stubbles with recommended amounts of P, K, and S fertilizer. Plots were harvested with a plot combine and grain subsamples analyzed for protein with a calibrated laboratory-quality near infrared reflectance analyzer. Grain yields are reported at ambient moisture content at time of mass determination (8-14%), protein was expressed for 13.5% moisture content (wet basis). Grain N uptake was calculated from protein using standard conversion from protein to N (i.e. N=protein/6.25 for barley and protein/5.7 for wheat) and then expressed on a dry basis. Protein was not measured for the Canora site in 1999.

Analysis of variance was performed using SAS Proc Mixed and regression with SAS Proc Reg.

Results and Discussion

In both 2001 and 2002 at Redvers, yields at very high N fertilizer rate trended lower than at lower N rates across stubbles (Table 2). Protein was also not generally different at very high fertilizer N rate than at the high rate, indicating the very high N rate provided excess N. Consequently, the very high rate N rate was not included in subsequent analyses. In 2001, the relatively high grain yield and protein at the low (zero) fertilizer N rate indicated the soil provided a good N supply in that year. Not surprisingly then, the high N rate also appeared to supply excess N as yields across the stubbles trended lower at the high N rate than the medium N rate without also clearly affecting grain protein. Because the high N rate was also appeared excessive in 2001, it was also excluded from subsequent analyses for Redvers. At Redvers, particularly in 2002, yields were low because of competition from weeds, especially wild oats. In the latter year, barley appeared to be the most competitive cereal as it has the most stable yield across stubble types. In contrast, under the same weedy conditions, low durum yield on several stubbles represented an economic crop failure.

The mean yield of the different cereals were statistically different at all sites in all years (Table 3). However, there was no consistent highest or lowest yielding cereal. Also at all sites in all years, there were significant differences among the different stubbles. Cereal grown on cereals had the lowest or second lowest yield in all site-yr with the exception of 2001 at Swift Current. In that year, there was an extreme early season drought and we attribute this yield effect to the better moisture conserving ability, both prior to seeding and in-crop, of cereal stubble compared with the other stubbles. Cereals on the legumes had the highest yield in eight of the nine site-yr: cereal on pea had the highest yield in four site-yr, cereal on fenugreek had the highest yield in three site-yr and cereal on chickpea had highest yield in one site-yr. However, cereal on chickpea stubble was also the lowest yielding at Canora in 1999. Cereal grown on lentil stubble was also generally high yielding and was not significantly different from highest yielding cereal on a legume stubble in five site-yr. We did not evaluate the nodulation of the fenugreek and there may have been some additional N fixed from the atmosphere due to infection with Rhizobium already in the soil. Cereal yield on coriander stubble was variable, sometimes being relatively low (e.g. Swift Current 1999) and sometimes relatively high (e.g. Canora 2002). Cereal yields on mustard stubble were invariably intermediate between the highest and lowest yielding stubbles. The general cereal yield rankings of pulse stubble > oilseed stubble > cereal stubble agrees with previous research.

In only one site-yr (Swift Current 2002) was there a significant crop x stubble interaction. This appeared to mainly because the durum yielded relatively poorer on durum stubble than did the barley whereas the barley yielded relatively poorer on the coriander stubble than did the durum (Table 4).

Within the relatively narrow range of fertilizer N rates, the yield response to N was generally weak. In three site years (Canora 1999, 2002, and Swift Current 2001), there was no significant effect of N. At Canora, unlike Redvers, there was no clear indication that N rates were excessimve as there was no trend for yields to drop at the high N rate (Table 5). There was no significant stubble x fert interaction in any site-yr indicating the crop yield response to N was similar for all stubbles. There was a significant crop x fert interaction at both years at Redvers. The latter is explained because the durum had an overall negative yield response to N while the barley and HRS wheat had a more expected positive responses (Table 2).

For protein, there were significant differences among the cereals in all site-yr. Because of yield dilution effects on grain protein, the effect of stubble and fertilizer were less consistent than was the case for yield (Table 6). Generally, cereal grown on legume stubbles had the highest or among the highest grain protein. Since these stubbles also often had higher yields, the generally good grain protein indicated that the legume stubble were providing better N supply to the cereal crop. This agrees with much other research. Grain protein generally increased as fertilizer N applied increased although this effect was not significant in some site-yr. A crop x fert interaction occurred in six of the eight site-yr. Much of this interaction can be explained because barley and CPS wheat grain protein was less affected by stubble type than either HRS wheat or durum at Redvers (Table 2) and Swift Current (Table 7). Crop x stubble or stubble by fert interactions were generally not significant for protein indicating that crop protein and N response are similar among the different stubbles.

Cereal grain N uptake integrates the combined impacts of treatments on both protein and grain yield. Generally, yield dilution (i.e. higher grain decreasing grain protein concentration) were not important. The latter was because many of the cereals grown on pulse stubble had both relatively high grain yield and protein. Therefore, grain N uptake followed similar ranking as grain yield indicating the different stubbles significantly impacted N availability to the cereals. In 2002 at Swift Current, there was a significant interaction between crop and stubble and grain N uptake. This occurred because the differential effects of stubble on the barley and durum were similar for both grain yield and protein. To illustrate, relative to the yield and protein on other stubbles, both durum yield and protein were high on coriander and mustard stubble whereas, relative to its yield on other stubbles, barley yields were low on coriander and mustard stubble (barley protein relatively unaffected by stubble in 2002 at Swift Current).

For barley, the mean grain yield, protein, and N uptake difference relative to cereal stubble for the medium N rate were not significantly different than zero (Table 9). Therefore, there was no a significant overall effect of stubble on agronomic performance of barley at medium N rate. The trend was for relative differences to be larger for the pulse stubbles. In contrast, for HRS wheat, the yield difference and grain N uptake difference for all stubbles common across site-yr were significantly greater than zero. Relative protein difference was also significantly greater than zero for HRS wheat for lentil and pea stubble. Hence, overall, it was clearly advantageous to grow HRS wheat on a stubble other than a cereal. For durum, the relative differences for grain yield, protein, and grain N uptake were all significantly greater than zero for pea and lentil stubble. In addition the relative yield difference was greater than zero for mustard stubble and the relative grain N uptake difference greater than zero for fenugreek stubble.

This large relative positive response of HRS wheat to stubble type other than a cereal was not fully expected since, in this study, it was never grown on wheat stubble (i.e. always grown on barley or durum stubble). Clearly, the HRS wheat was able to more effectively extract soil N when grown on a non-cereal stubble. There was no large advantage of legume stubbles compared to the coriander and mustard stubbles. The HRS wheat appeared to be responding primarily to the rotational benefit of a crop sequence with a preceding non-cereal crop. In contrast to HRS wheat, durum, and, to lesser extent barley, appeared to be responding more to N benefit from the pulse stubbles and less to the rotational benefit of production on a non-cereal stubble.

Regression analysis using indicator variables was used to determine the relative N response on non-cereal stubbles differed from that on cereal stubble. Over the narrow range of fertilizer rates, the response to fertilizer N was generally weak (Table 4). These overall results would suggest that the medium N rate are close to optimal as slight adjustments above or below the medium N rate do not greatly affect agronomic performance. In only one case did the N response on the non-cereal stubbles differ significantly from that on cereal stubble: barley grain protein had a greater positive response on lentil stubble than on cereal stubble. There was a trend, however, for lower slopes for grain yield and N uptake on pea stubble than other stubbles. In contrast with the regression slopes, the intercept was frequently significantly different for the non-cereal stubbles than the cereal stubble. This shows that the main effect of stubble was to increase mean cereal grain yield, protein, and/or N uptake compared with those on cereal stubble. Among cereals, barley was least affected by stubble type.

Since the cereal response to fertilizer N is similar among stubble types, a critical consideration as to what N rate to apply to a cereal grown on particular stubble will be grain price premiums for particular protein concentrations. For HRS wheat and durum, there is a price premium for higher protein, while for barley, grain protein below 130 g kg^{-1} (even below 120 g kg^{-1}) may be required to attain malting grade price premiums (for all cereals, protein affects value only if grain meets other grade quality parameters). For barley, the probability of achieving low protein was relatively unaffected by stubble type or fertilizer rate (Table 5). Achieving barley protein below 120 g kg^{-1} was slightly favoured by growing it on cereal or mustard stubble. The response of cereal on canola stubble has been found to be similar to that on mustard stubble (Miller et al. 2003). In contrast, HRS wheat and durum protein were strongly affected by stubble and fertilizer rate. Achieving HRS wheat and durum with high protein is least likely on cereal stubble and most likely on a legume stubble. Decreasing N fertilizer applied to legume stubbles to take advantage of any potential “pulse N benefit” is not wise if one desires high protein cereal grain. For example dropping from medium to low N rate on pulse stubble about halved the chance of achieving HRS wheat with more than 140 g kg^{-1} protein concentration. Similarly, increasing N fertilizer applied to cereal stubble to increase grain protein may not be effective. For example, increasing from medium to high N rate did not increase the chance of achieving HRS wheat with protein concentration over either 130 or 140 g kg^{-1}. The best combination of fertilizer N and stubble to produce high protein durum or HRS wheat was high fertilizer N on pulse crop stubbles.

Conclusions

The preceding crop had strong influences on the grain yield, protein and N uptake of the succeeding cereal crop. Generally, there were no interactions between stubble and cereal crop or between stubble and N fertilizer indicating the effect of stubble type was similar across cereals and N fertilizer rates. Growing a cereal on a cereal, even if not on the same cereal species, depressed both yield and protein. The chance of achieving high protein HRS wheat or durum grain was greatest with high fertilizer N on pulse stubbles. Applying a high fertilizer N rate on cereal stubbles does not markedly increase the chance of attaining high protein wheat or durum. For barley, where low protein is desired for malting, the best chance for low protein grain was on cereal and mustard stubble although barley protein appeared less affected by stubble and fertilizer N than wheat or durum.

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Table 1. Cultivars and N rates for the eight site-years

	Canora 1999	Canora 2002	Redvers 2001	Redvers 2002	Swift Current 1998	Swift Current 1999	Swift Current 2000	Swift Current 2001	Swift Current 2002
	---------- cultivar ----------								
<u>Stubble</u>									
Bean	--	Pintium	Camino	--	--	--	--	--	--
Barley	Robust	Viscount	--	--	--	--	--	--	--
Coriander	Common	Common	Common	Common	Common	Common	Common	Common	Common
Durum	--	--	Avonlea	Avonlea	Kyle	Kyle	Kyle	Kyle	Kyle
Fenugreek	Quattro	Quattro	Quattro	Quattro	Quattro	Quattro	Quattro	Quattro	Quattro
Chickpea	Sanford	--	--	Sanford	Sanford	Sanford	Sanford	Sanford	Sanford
Lentil	Glamis	Robin	Milestone	Milestone	Laird	Crimson	Milestone	Milestone	Laird
Mustard	Viscount	Viscount	Pennant	Pennant	Cutlass	Cutlass	Cutlass	Cutlass	Omus
Pea	Swing	Alfetta	Swing	Swing	Carneval	Carneval	Carneval	Carneval	Delta
<u>Cereal Crop</u>									
Barley	Metcalfe	Metcalfe	Harrington	Harrington	--	--	Harrington	Harrington	Harrington
HRS wheat	AC Barrie	McKenzie	AC Barrie	McKenzie	AC Barrie	AC Barrie	AC Barrie	AC Barrie	--
CPS Wheat	--	--	--	--	AC Karma	AC Karma	--	--	--
CWES Wheat	Bluesky	--	--	--	--	--	--	--	--
Durum	--	--	Avonlea	Kyle	Kyle	Kyle	Kyle	Kyle	Kyle
	---------- kg/ha ----------								
<u>N Rate</u>									
Low	39	45	0	--	28	34	34	34	34
Medium	56	62	67	67	45	50	50	50	50
High	73	78		78	73*	78	78	78	78
Very High	--	--			--	--	--	--	--

* no high N rate for durum

Table 2. Yield and protein of barley, and HRS wheat, and durum in 2001 and 2002 at Redvers as affected by stubble and fertilizer N rate.

		2001						2002					
		Barley		HRS Wheat		Durum		Barley		HRS Wheat		Durum	
Stubble	N Rate	Yield (kg ha^{-1})	Protein (g kg^{-1})	Yield (kg ha^{-1})	Protein (g kg^{-1})	Yield (kg ha^{-1})	Protein (g kg^{-1})	Yield (kg ha^{-1})	Protein (g kg^{-1})	Yield (kg ha^{-1})	Protein (g kg^{-1})	Yield (kg ha^{-1})	Protein (g kg^{-1})
Bean	Low	3534	134	2181	143	1681	150	--	--	--	--	--	--
	Med	3986	137	3209	166	1992	154	--	--	--	--	--	--
	High	3375	127	2756	150	1112	165	--	--	--	--	--	--
	Very High	3754	137	2493	145	2128	157	--	--	--	--	--	--
Coriander	Low	3350	144	1676	135	1945	148	--	--	--	--	--	--
	Med	3916	135	2899	161	1750	156	1699	118	1212	142	616	149
	High	3810	127	2800	148	1563	138	1393	118	1646	147	598	150
	Very High	3850	130	2498	146	2000	153	1479	123	1872	141	632	157
Durum	Low	3362	151	1660	128	1508	161	--	--	--	--	--	--
	Med	4010	153	2184	158	1252	160	1370	115	412	143	330	150
	High	3570	130	2303	148	1119	152	1506	114	1070	139	299	145
	Very High	3840	140	1864	150	1476	163	1622	116	1120	141	285	150
Fenugreek	Low	3374	144	1850	131	2047	152	--	--	--	--	--	--
	Med	3747	148	2904	164	1893	155	1635	122	1631	148	802	149
	High	3867	130	3128	146	1446	146	1680	118	2042	144	807	143
	Very High	3824	139	2693	133	2013	154	1637	115	1905	139	749	149
Chickpea	Low	--	--	--	--	--	--	--	--	--	--	--	--
	Med	--	--	--	--	--	--	1525	116	1004	149	525	145
	High	--	--	--	--	--	--	1614	113	1878	143	598	149
	Very High	--	--	--	--	--	--	1717	115	2229	138	660	155
Lentil	Low	3002	129	1766	131	1780	156	--	--	--	--	--	--
	Med	4045	150	2718	155	1664	159	1685	123	1146	150	1034	146
	High	3897	129	2582	146	1466	155	1305	117	2234	142	966	150
	Very High	3705	138	2395	131	1740	161	1271	117	2419	144	1134	151
Mustard	Low	3153	130	1786	137	1931	147	--	--	--	--	--	--
	Med	3997	133	2839	154	1617	161	1792	118	1430	145	651	145
	High	3666	128	2801	149	1449	153	1654	115	1481	146	869	146
	Very High	3795	134	2345	146	1953	158	1669	113	1482	142	777	148
Pea	Low	3808	136	2738	138	2586	152	--	--	--	--	--	--
	Med	4770	137	3449	159	2064	161	1423	115	862	147	285	152
	High	3572	130	3151	152	1596	161	1627	120	1328	143	370	151
	Very High	4144	135	2858	148	2377	160	1509	116	2003	143	376	158
LSD		656	8	460	7	395	8	569	9	631	17	303	16

Table 3. Effects of cereal, stubble, and fert. N and their interactions on grain yield in all site-yr.

	Canora 1999	Canora 2002	Redvers 2001	Redvers 2002	Swift Current 1998	Swift Current 1999	Swift Current 2000	Swift Current 2001	Swift Current 2002
	F statistic								
Cereal	21.07***	80.8***	197.58***	51.9***	9.38**	16.8***	21.38***	15.71***	3.65+
Stubble	5.09**	4.14*	7.81***	4.29**	6.24***	4.52**	12.16***	2.31*	4.75**
Fert	0.19	0.43	38.84***	5.39*	3.65*	7.39**	23.42***	1.34	9.74**
Cereal*Stubble	0.37	0.57	0.61	0.94	0.46	0.38	0.95	0.95	4.7**
Cereal*Fert	0.24	2.36	19.18***	5.86**	1.23	0.91	1.33	1.52	0.8
Stubble*Fert	0.1	0.26	0.31	0.29	0.27	0.71	1.07	0.72	0.45
Cereal*Stubble*Fert	0.14	0.12	0.57	0.51	0.44	0.48	0.53	0.83	0.85
	Yield (kg ha-1)								
Cereal									
Barley	2926	3160	3715	1565	--	--	--	1767	945
HRS Wheat	2656	4242	2418	1384	1921	3222	2240	1436	--
CWES Wheat	3751	--	--	--	--	--	--	--	--
CPS Wheat	--	--	--	--	2119	3564	2670	--	--
Durum	--	--	1836	625	--	2921	2706	1450	1012
LSD	314	468	302	264	163	177	106	78	67
Stubble									
Barley	2922	3116	--	--	--	--	--	--	--
Bean	--	3930	2764	--	--	--	--	--	--
Coriander	3299	3848	2585	1194	1805	2875	2248	1636	1019
Durum	--	--	2325	831	1790	3023	2040	1703	851
Fenugreek	3156	4132	2636	1433	1952	3629	2771	1394	900
Chickpea	2255	--	--	1191	2022	3149	2754	1584	1155
Lentil	3350	3691	2496	1395	2249	3340	2731	1423	995
Mustard	3220	3647	2554	1313	1968	3205	2451	1568	913
Pea	3576	3544	3236	983	2356	3430	2777	1549	1014
LSD	399	519	331	295	202	229	151	120	120
Fert									
Low	3051	3652	2413	--	1903	3024	2234	1505	925
Med	3124	3780	2900	1099	2045	3250	2627	1537	922
High	3158	3672	--	1284	2112	3433	2755	1612	1087
LSD	314	478	295	255	171	181	106	78	79

*** $p < 0.001$; ** $p < 0.01$; * $p < 0.05$; + $p < 0.1$

Table 4. Grain yield for barley, CPS wheat, HRS wheat, and durum by stubble and fert. N rate for 1998-2002 at Swift Current.

		1998			1999			2000			2001			2002	
Stubble	N Rate	CPS Wheat	HRS Wheat	Durum	CPS Wheat	HRS Wheat	Durum	CPS Wheat	HRS Wheat	Durum	Barley	HRS Wheat	Durum	Barley	Durum
		Yield (kg ha^{-1})													
Coriander	Low	1677	1802	1670	3538	2489	2730	1665	1618	1997	1827	1422	1415	811	1048
	Med	2088	1689	2070	2890	3133	2694	2343	1885	2676	1892	1438	1576	890	1061
	High	1874	1697	--	3358	2675	2420	2798	2405	2841	1702	1827	1625	985	1320
Durum	Low	1624	1649	1772	2940	2992	2299	1844	1464	1783	1666	1269	1589	802	686
	Med	1979	1649	1669	3123	2987	2967	2138	1955	2255	1846	1535	2243	984	701
	High	2018	1818	--	3815	2998	3078	2267	2382	2268	2236	1370	1573	1168	762
Fenugreek	Low	1797	1687	1987	4046	3195	3125	2873	2127	2807	1630	1258	1201	954	919
	Med	1999	1955	1929	3787	3360	3183	2591	2647	3235	1615	1267	1087	931	722
	High	2444	1829	--	4407	3912	3644	3179	2655	2824	1652	1416	1424	1030	847
Chickpea	Low	1924	1921	2078	3148	2572	2888	2594	1822	2395	1823	1668	1588	1006	1165
	Med	1920	2221	2045	3227	2866	3002	2879	2608	3218	1617	1414	1234	1039	1118
	High	2206	1942	--	3842	3628	3167	3509	2654	3105	2215	1600	1094	1072	1528
Lentil	Low	2333	2087	2332	3424	3225	2870	2821	1923	2531	1340	1496	1231	863	904
	Med	2483	2083	2241	3894	3507	2781	2814	2419	3272	1779	1151	1336	837	1060
	High	2481	2030	--	3729	3723	2908	2828	2455	3514	1797	1327	1354	1169	1139
Mustard	Low	2065	1709	1841	3201	2817	2579	2371	1706	2394	1587	1418	1365	742	1034
	Med	1951	1927	1926	3599	3588	3116	2652	2395	2755	1495	1502	1835	672	984
	High	2216	1938	--	3709	3408	2822	2762	2219	2803	1875	1472	1565	995	1054
Pea	Low	2239	2132	2289	3841	2769	2822	3074	2632	2471	1622	1801	1390	855	1165

	Med	2460	2225	2420	3770	3751	2973	2887	2718	2834	1908	1180	1322	924	986
	High	2721	2359	--	3620	4078	3247	3176	2347	2856	1993	1320	1408	1114	1040
LSD		444	274	305	858	554	651	489	417	396	415	310	362	212	183

Table 5. Grain yield and protein in 1999 and 2002 of barley, CWES wheat, HRS wheat at Canora by year, stubble, crop, and fert. N rate.

		1999			2002			
		Barley Yield	CWES Wheat Yield	HRS Wheat Yield	Barley Yield	Barley Protein	HRS Wheat Yield	HRS Wheat Protein
Stubble	N Rate	------ ($kg\ ha^{-1}$)	------		($kg\ ha^{-1}$)	($g\ kg^{-1}$)	($kg\ ha^{-1}$)	($g\ kg^{-1}$)
Barley	Low	2666	2547	3738	2433	128	3599	131
	Med.	2365	2807	3167	3088	125	3394	133
	High	2750	2948	3307	2438	132	3745	139
Bean	Low	--	--	--	3608	126	4379	137
	Med.	--	--	--	3611	126	4264	140
	High	--	--	--	3233	129	4484	142
Coriander	Low	3114	2233	4298	2766	134	4419	140
	Med.	3305	2547	4136	3553	132	4858	141
	High	3229	3024	3802	2858	135	4636	144
Fenugreek	Low	2756	2330	3921	3668	128	4690	143
	Med.	2621	3002	4115	3702	128	4530	143
	High	3141	2766	3964	3450	132	4751	145
Chickpea	Low	2083	1864	2714	--	--	--	--
	Med.	2202	2081	2478	--	--	--	--
	High	2002	2178	2693	--	--	--	--
Lentil	Low	2756	2612	4050	3223	128	4344	142
	Med.	3518	3089	3932	3407	133	4057	141
	High	3268	3013	3910	3107	131	4012	143
Mustard	Low	2983	2655	3824	2958	125	4140	141
	Med.	2902	2699	3996	3210	126	4070	139
	High	3254	2644	4018	3059	124	4442	143
Pea	Low	3536	3190	4201	2926	133	3976	142
	Med.	3626	2798	4223	3308	133	3865	142
	High	3377	2961	4276	2760	133	4429	143
LSD		925	970	1054	797	7	797	6

Table 6. Effects of cereal, stubble, and fert. N and their interactions on grain protein in all site-yr.

	Canora	------ Redvers ------		---------------- Swift Current ----------------------				
	2002	2001	2002	1998	1999	2000	2001	2002
Effect	------------------------------------F statistic ------------------------------------							
Cereal	87.69***	9.47**	245.44***	97.93***	19.47***	111.75***	20.86***	329.26***
Stubble	2.7*	0.45	0.7	3.91**	3.51**	45.16***	30.15***	3.13**
Fert	2.17	16.07***	1.48	46.05***	0.35	212.69***	101.57***	10.94***
Cereal*Stubble	1.21	0.62	0.41	0.88	0.52	2.19*	1.77+	1.82
Cereal*Fert	0.09	5.69*	0.3	5.36**	4.13**	3.6**	2.67*	4.33*
Stubble*Fert	0.24	0.13	0.5	0.33	0.78	1.19*	1.21	1.15
Cereal*Stubble*Fert	0.16	0.34	0.51	0.45	0.75	0.66	0.67	0.96
	------------------------------------Protein (g kg^{-1}) ------------------------------------							
Cereal								
Barley	130	140	117	--	--	--	142	118
HRS Wheat	141	147	145	150	127	122	152	--
CPS Wheat	--	--	--	131	109	105	--	--
Durum	--	155	148	--	116	110	147	134
LSD	2	4	3	7	6	1	7	1
Stubble								
Barley	131	--	--	--	--	--	--	--
Bean	133	147	--	--	--	--	--	--
Coriander	138	146	138	133	120	101	140	124
Durum	--	152	134	145	111	110	135	125
Fenugreek	137	149	137	138	123	114	152	126
Chickpea	--	--	136	141	112	111	155	123
Lentil	136	147	138	148	125	120	156	127
Mustard	133	144	136	139	112	104	141	128
Pea	138	147	138	136	117	125	151	129
LSD	3	6	4	8	8	2	7	2
Fert								
Low	134	142	--	132	116	101	137	125
Med	134	153	137	135	118	111	147	124
High	137	--	136	153	117	125	157	129
LSD	2	3	2	7	7	1	7	2

*** $p < 0.001$; ** $p < 0.01$; * $p < 0.05$; + $p < 0.1$

Table 7. Grain protein for barley, CPS wheat, HRS wheat, and durum by stubble and fert. N rate for 1998-2002 at Swift Current.

		1998			1999			2000			2001			2002	
Stubble	N Rate	CPS Wheat	HRS Wheat	Durum	CPS Wheat	HRS Wheat	Durum	CPS Wheat	HRS Wheat	Durum	Barley	HRS Wheat	Durum	Barley	Durum
		Protein ($g\ kg^{-1}$)													
Coriander	Low	122	128	125	115	137	124	89	102	89	125	134	128	117	134
	Med	112	144	128	105	135	123	88	113	95	132	147	134	119	126
	High	138	155	--	121	114	107	100	128	103	148	157	151	119	131
Durum	Low	135	141	154	107	129	102	93	104	95	114	134	117	116	134
	Med	129	151	157	96	116	115	102	118	106	136	140	122	117	128
	High	147	167	--	118	115	99	116	129	128	143	155	150	120	137
Fenugreek	Low	128	138	139	121	136	125	96	111	94	136	147	144	118	131
	Med	127	138	134	106	128	140	109	121	107	152	156	154	118	130
	High	136	163	--	114	131	110	118	140	132	156	163	161	120	142
Chickpea	Low	131	134	135	93	120	109	91	105	96	138	151	146	118	126
	Med	126	142	141	107	111	118	101	122	109	152	158	164	116	122
	High	146	169	--	104	134	111	114	136	122	157	162	171	119	139
Lentil	Low	138	146	143	115	134	114	113	116	103	141	154	150	116	133
	Med	129	159	153	108	134	145	113	130	111	151	162	159	117	136
	High	147	167	--	123	129	128	123	139	132	157	160	169	121	141
Mustard	Low	120	137	133	109	117	89	89	106	90	117	136	131	118	140
	Med	119	148	151	97	141	113	92	113	99	142	148	128	120	134
	High	146	167	--	109	127	109	107	127	117	147	162	154	120	137
Pea	Low	117	139	123	116	122	101	104	123	111	135	145	143	119	135

	Med	115	149	137	93	131	125	112	133	133	150	149	157	120	137
	High	134	163	--	114	126	121	125	143	144	155	162	165	119	141
LSD		13	12	12	18	11	25	6	6	8	8	10	14	15	8

Table 8. Effects of cereal, stubble, and fert. N and their interactions on grain N uptake in all site-yr.

	Canora	------ Redvers	----------------------	---------------------- Swift Current	----------------------			
	2002	2001	2002	1998	1999	2000	2001	2002
Effect				F statistic				
Cereal	193.14***	59.81***	44.79***	1.83	9.11**	4.47*	2.61+	59.7***
Stubble	4.86**	4.87**	5.79***	8.02***	4.3**	26.82***	1.07	4.42**
Fert	0.4	45.84***	8.67*	21.07***	4.07*	86.65***	14.17***	13.69***
Cereal*Stubble	0.82	0.98	1.53	0.47	0.4	0.54	0.75	4.64**
Cereal*Fert	2.33	19.8***	9.13**	1.02	2+	2.15+	1.6	0.59
Stubble*Fert	0.25	0.31	0.26	0.33	0.88	0.78	0.76	0.58
Cereal*Stubble*Fert	0.13	0.51	0.81	0.27	0.6	0.72	0.86	1.05
				Grain N (kg ha^{-1})				
Cereal								
Barley	58	73	28	--	--	--	36	16
HRS Wheat	93	57	32	45	64	43	34	--
CPS Wheat	--	--	--	43	61	44	--	--
Durum	--	44	14	--	53	47	33	21
LSD	9	5	6	2	5	2	2	1
Stubble								
Barley	62	--	--	--	--	--	--	--
Bean	79	60	--	--	--	--	--	--
Coriander	80	56	27	37	54	35	34	19
Durum	--	52	17	40	53	35	34	16
Fenugreek	85	59	30	41	69	49	32	17
Chickpea	--	--	22	44	55	48	37	22
Lentil	76	55	30	51	65	51	34	19
Mustard	74	54	27	43	57	40	33	18
Pea	74	71	20	50	63	54	35	20
LSD	11	7	6	3	6	2	2	2
Fert								
Low	74	51	--	39	56	35	31	17
Med	77	65	22	43	60	45	34	17
High	76	--	27	50	63	53	38	21
LSD	10	5	5	2	5	2	2	1

*** $p < 0.001$; ** $p < 0.01$; * $p < 0.05$; + $p < 0.1$

Table 9. Grain yield, protein, and N uptake difference relative to cereal stubble for all common stubbles pooled across site-yr (Canora 2002, Redvers 2001-02, Swift Current 1998-2002) for the medium fertilizer N rate.

Stubble	Number of site-yr	Yield (kg ha^{-1})	Protein (g kg^{-1})	Grain N (kg ha^{-1})
	------------------------- Barley ---------------------------			
Coriander	5	130	-2	0
Fenugreek	5	66	5	2
Lentil	5	91	6	4
Mustard	5	-26	-1	-2
Pea	5	207	2	4
LSD		246	6	6
	-------------------- HRS Wheat ----------------------			
Coriander	7	428	3	11
Fenugreek	7	597	5	15
Lentil	7	423	10	13
Mustard	7	519	4	13
Pea	7	562	7	15
LSD		243	5	6
	------------------------ Durum --------------------------			
Coriander	7	168	-4	2
Fenugreek	7	204	4	5
Lentil	7	305	9	9
Mustard	7	213	-1	4
Pea	7	220	9	8
LSD		211	6	4

Table 10. Regression slope and intercept of relative grain yield, protein, and N uptake (all relative to cereal stubble at medium N rate) against N rate for barley, HRS wheat, and durum pooled across Canora 2002, Redvers 2001-02, and Swift Current 1998-2002.

	------ Yield ------		------ Protein ------		------ Grain N ------	
Stubble	Intercept[1] kg ha^{-1}	Slope kg $(kg\ N)^{-1}$	Intercept g kg^{-1}	Slope $(g\ kg^{-1})(kg\ N)^{-1}$	Intercept kg N ha^{-1}	Slope (kg N) $(kg\ N)^{-1}$
			Barley			
Bean	251*	8.4	-2.5	0.39	2.3	0.27
Cereal	-108	8.5	-0.2	0.00	-2.1	0.22
Coriander	-50	4.7	0.7	0.51	-1.7	0.17
Fenugreek	53	6.1	4.4*	0.35	1.6	0.19
Chickpea	51	6.1	4.1	0.37	1.5	0.15
Lentil	-56	10.0	4.1	0.33	-0.4	0.33*
Mustard	-86	9.5	-2.4	0.00	-3.2	0.31
Pea	47	4.0	3.2	0.00	1.3	0.19
			HRS Wheat			
Bean	971*	13.2	41.3*	0.24	25.2*	0.41
Cereal	20	7.9	-3.0	0.36	0.6	0.27
Coriander	298*	9.3	15.4	0.32	8.3*	0.31
Fenugreek	524*	10.6	58.9*	0.39	13.8*	0.34
Chickpea	263*	13.7	40.0*	0.51	6.1*	0.43
Lentil	418*	9.4	83.3*	0.35	12.6*	0.34
Mustard	344*	9.1	29.3	0.37	8.9*	0.30
Pea	537*	2.6	65.1*	0.33	14.2*	0.16
			Durum			
Cereal	-119	-0.5	0.1	0.12	-2.1	0.00
Coriander	55	-2.4	-2.7	0.19	0.9	-0.04
Fenugreek	188*	-2.7	4.9	0.25	5.2*	-0.02
Chickpea	122*	2.6	2.9	0.37	2.7*	0.14
Lentil	208*	-0.7	9.8*	0.31	7.4*	0.07
Mustard	101*	-2.5	-1.4	0.27	1.6	0.02
Pea	186*	-8.3	7.8*	0.37	6.6*	-0.09

* indicates significantly different than cereal stubble at p=0.10

Table 11. Probability of achieving specific grain protein concentrations for barley, HRS wheat, and durum as affected by stubble type and fertilizer N rate for Canora 2002, Redvers 2001-02, and Swift Current 1998-2002

	Cereal								
	Barley			Hard Red Spring Wheat			Durum		
	Fertilizer N Rate								
Stubble	Low	Med	High	Low	Med	High	Low	Med	High
	Probability (%) >120 g/kg protein								
Cereal	40	50	50	71	63	75	50	71	83
Coriander	60	50	50	71	75	75	83	86	67
Fenugreek	60	67	67	71	88	88	60	60	75
Lentil	60	67	67	71	88	88	67	71	100
Mustard	40	50	50	57	75	88	67	71	67
Pea	60	50	50	86	88	88	67	100	83
	Probability (%) >130 g/kg protein								
Cereal	20	33	50	43	63	63	50	43	67
Coriander	40	50	33	57	75	63	33	43	67
Fenugreek	40	33	33	71	63	88	67	71	83
Lentil	20	50	33	71	75	75	67	86	83
Mustard	20	33	17	57	75	63	67	57	67
Pea	60	50	33	57	88	75	50	86	83
	Probability (%) >140 g/kg protein								
Cereal	20	17	17	14	38	38	33	43	50
Coriander	20	0	17	14	63	63	17	29	33
Fenugreek	20	33	17	29	50	75	33	57	67
Lentil	20	33	17	43	63	63	50	71	67
Mustard	0	17	17	14	63	63	33	43	83
Pea	0	17	17	29	63	75	33	43	83