Yield and Protein Response to N Fertilization by Different Cultivars of Spring and Durum Wheat

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Abstract

A field study to determine whether there were differences in the response of CWAD and CWRS wheat to N fertilization was conducted in two soils of southwestern Saskatchewan for four years. Using regression techniques we were able to establish that both wheat classes had the same grain yield and protein concentration response to N availability, and that the differences in grain yield and protein concentration between classes observed in the study arose from differences in the response of the classes to available water. Differences in response to water availability among cultivars within each class were too small to be of practical significance. Recommendations for N fertilization of CWAD and CWRS wheats should be based on an N response common to both wheat classes, and on the ratio of the price of wheat to the cost of fertilizer N for each class.

Introduction

Inefficient use of fertilizer N by crops has a negative impact on the economics of crop production, and also has strong adverse effect on the environment, mainly by contributing to contaminating of ground and surface waters with nitrate, and by contributing to enhanced emissions of NH_3 and N_2O to the atmosphere. It is important that we refine fertilizer management techniques and methodologies for forecasting N needs by crops in order to improve its efficient use by crops and to minimize any possible adverse environmental and economic impact.

Wheat cultivars have been developed to meet specifications of a particular wheat class. To be registered cultivars must meet the requirements of the grain grading system, and meet the end use suitability criteria for their class (DePauw et al. 1995). Additionally, plant breeders incorporate into new cultivars traits such as disease or insect resistance, improved grain yield, elevated grain protein, among others. As a result, wheat classes and cultivars have different grain yield and protein potential. The question before us is; do we need to prescribe specific N fertilization rates for each wheat class or cultivar to account for their differences in genetic potential?

The objective of this study was to determine if various cultivars of the Canada Western Amber Durum (CWAD) and Canada Western Red Spring (CWRS) wheat classes grown in the Brown soil zone have differences in their yield and protein responses to N availability so that they would require individual fertilizer N recommendations.

Materials and Methods

From 1998 to 2001 four CWAD and eight CWRS cultivars (Table 1) were grown with N fertilizer applied at seeding at rate of 0, 25, 50, 75, 100, and 125 kg N/ha in field tests at Swift Current and Stewart Valley. To ensure that no other nutrient would limit crop yield, all treatments received a blanket application of 35 kg P_2O_5/ha, 20 kg S/ha, and 55 kg K_2O/ha. Fertilizer P was applied in the seed row as 0-46-0, and S was applied in a mid-row band as 0-0-50-18. Fertilizer N was applied at seeding as 46-0-0; up to 20 kg N/ha was placed in the seed row together with P. N in excess of 20 kg N/ha was placed in the mid-row band together with S.

Table 1. Wheat Cultivars Used in the Study.

CWAD	CWRS
AC Avonlea	AC Barrie
AC Morse	AC Cadillac
AC Navigator	AC Elsa
Kyle	AC Intrepid
	AC Majestic
	Marquis
	McKenzie
	Neepawa

The field experiments were set up as complete randomized blocks with two replicates onto land that had been under summer fallow or cropped to spring wheat the previous year. At Swift Current the soil was a Swinton Silt Loam, an Orthic Brown Chernozem derived from medium-textured eolian deposits. At Stewart Valley the soil was a Sceptre Heavy Clay, a Rego Brown Chernozem derived from fine textured glacio-lacustrine deposits (Ayres et al. 1985). The crop was seeded onto 1 x 6 m plots with a small plot seeder equipped with offset double disk openers spaced 25 cm (Dyck et al. 1986, p A 5/86).

Prior to seeding, soil samples were removed at six to eight pre determined locations within each experimental area to a depth of 120 cm with a coring sampler. The samples were sectioned into 0-15, 15-30, 30-60, 60-90, and 90-120 cm depth increments. Gravimetric water content, bulk density, and the concentration of NO_3-N, Olsen-P, available K (Hamm et al. 1970), and SO_4-S (Hamm et al. 1973), and were determined for each depth increment and core. Gravimetric water content was converted to height of available water by subtracting the water content at 1.5 MPa and the bulk density for each depth increment.

At maturity the plots were trimmed to 4 m length and the crop was harvested with a plot combine. Grain yield was converted to kg/ha; grain protein was determined by NIR spectroscopy and normalized to 13.5% moisture.

Yield and protein response to N availability were evaluated for the entire dataset using regression with indicator variables (Freund and Littel 1986) with the least squares regression procedure of JMP 4.0.2 (SAS Institute 2000).

Independent variables for the regression analyses were available N, calculated as the sum of NO_3-N in the soil to 60 cm and N applied as fertilizer, and available water, calculated as the sum of soil available water to 120 cm at seeding plus precipitation from seeding to harvest.

Results and Discussion

Growing conditions varied substantially among site-years and cropping systems. Precipitation from seeding to harvest (GSP) ranged from a low of 80 mm at Stewart Valley in 2001 to 276 mm the previous year at Swift Current (Table 2). Although the two sites used in this experiment were only 30 km apart from each other, GSP in the same season was substantially different. In 1998, Stewart Valley received 12% more rain than Swift Current, but in 1999, 2000, and 2001 Stewart Valley received only 83% 71, and 67% of the rain received at Swift Current, respectively. As expected, spring soil available water (SSM) was higher in fallow than in stubble, and in both cropping systems it reflected GSP levels in the previous year.

Table 2. Water Available to the Crop.

Year	Sceptre			Swinton		
	SSM[1]		GSP[2]	SSM		GSP
	Fallow	Stubble		Fallow	Stubble	
	----------------------------------		(mm)	----------------------------------		
1998	93	14	224	84	11	190
1999	207	134	142	159	117	172
2000	60	89	198	93	14	263
2001	86	-8	80	72	36	120

[1] Available soil water in spring to depth of 120 cm.

[2] Precipitation between seeding and harvest.

Soil nutrients measured in the spring especially NO_3-N and PO_4-P, and to a lesser degree SO_4-S, showed the effects of cropping practices, with substantially larger amounts under fallow than under stubble. At Stewart Valley SO_4-S showed extremely large concentrations, especially in 1998, 1999, and 2000, reflecting the presence of low-level salinity at the sites where the tests were established those years. Extractable K reflected mainly the textural differences between the two soils used in this study (data not shown).

On average, CWAD had significantly higher grain yield and lower protein concentration than CWRS ($P \leq 0.01$) (Fig 1). Within the CWAD class there was no difference in grain yield among cultivars, although Kyle, the earliest released CWAD cultivar, tended to have lower yield than cultivars released later. Within the CWRS class Marquis, a cultivar released in the early 1900s showed the lowest yield and protein due to severe herbicide damage observed every year. Consequently, this cultivar was not included in further analyses; the newer cultivars in the test did not show the herbicide damage exhibited by Marquis. The rest of the CWRS cultivars were relative homogeneous in grain yield (Fig 1). All CWAD cultivars had the same protein concentration; within the CWRS class, there was no difference in protein concentration among the cultivars released by AAFC, but McKenzie, a high yielding cultivar released by the Saskatchewan Wheat Pool had the lowest protein of the class (Fig. 1).

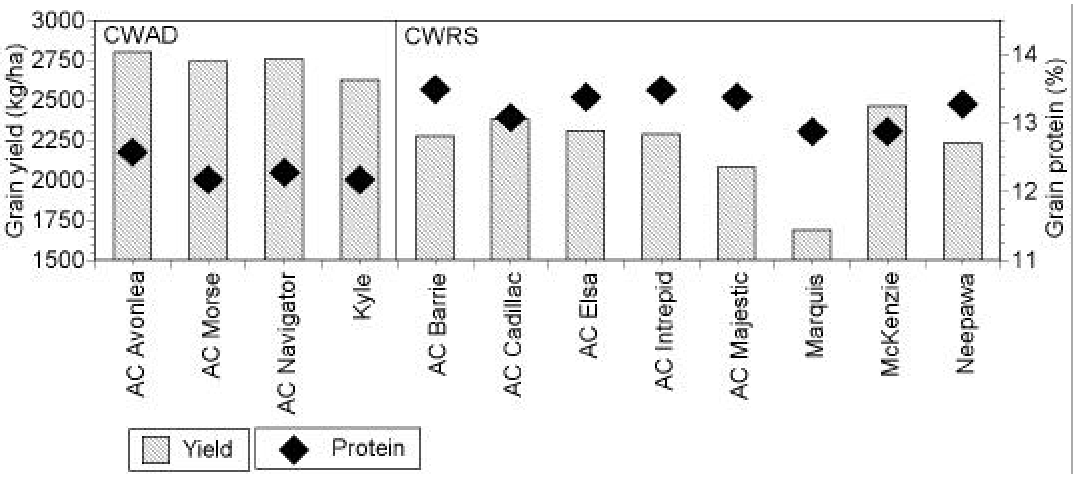

Figure 1. Average grain yield and protein concentration for CWAD and CWRS cultivars

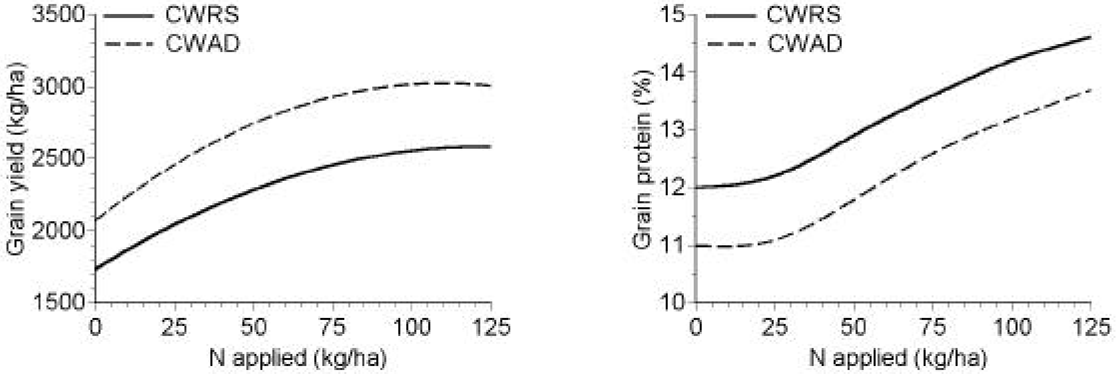

Figure 2. Overall yield and protein response to N fertilization

Based on the general shape of the overall grain yield and protein response to N fertilization (Fig. 2), and to water availability (data not shown), we estimated that a second degree polynomial function of available N and water with a NxW interaction term would be adequate to describe the crop response to N availability in all the environments tested. The basic model used was:

$$y = a + bN + cN^2 + dW + eW^2 + fNW \qquad [1]$$

Grain Yield Response

Stepwise regression indicated that the yield response to N and water availability of both wheat classes together was well described by the following model

$$y = a + bN + cN^2 + dW + fNW \qquad [2]$$

that explained 72% of the variability observed in grain yield of all the cultivars in all years across all locations, and cropping systems (Fig. 3). The terms on equation 2 can be rearranged to yield a second-degree polynomial response to N with linear functions of water as intercept and as slope for the first degree of N term. The response equation can the be written as:

$$y = (a + dW) + (b + fW)N + CN^2 \quad [3]$$

The coefficients of the fitted model (Table 3) indicate that as moisture conditions improve, the intercept and first-degree slope become larger, while the second degree slope remains constant. Based on the fitted model (Table 3), as water availability improves, the intercept becomes larger and the response to N becomes steeper, shifting the response upwards (Fig. 4a). Because the slope to the quadratic term of N is a constant, in higher moisture environments the maximum yield of the crop happens at higher levels of N availability.

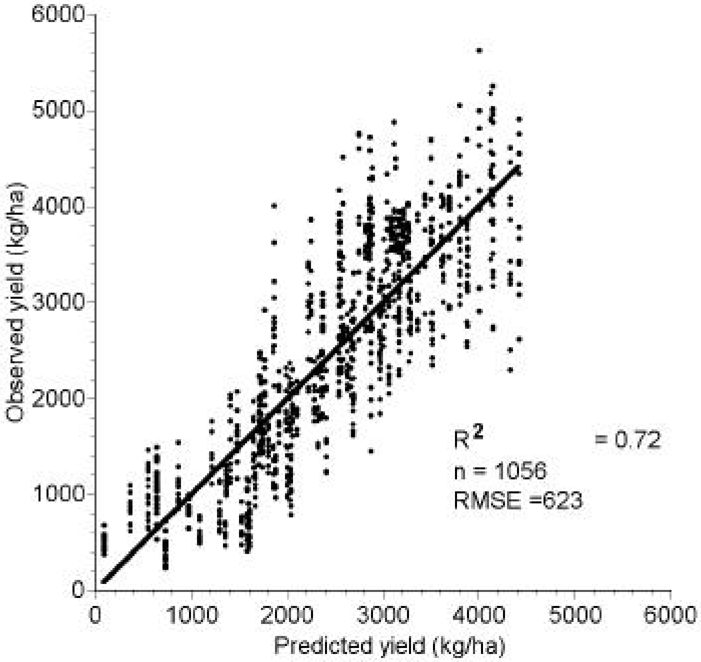

Figure 3. Observed yield as function of yield predicted by general yield model.

Table 3. Coefficients for the Parameters of the Fitted Yield Model

Parameter	Estimate	Shifters	
		CWAD	CWRS
Intercept	-559	ns[1]	ns
N	11.3	ns	ns
N^2	-0.07	ns	ns
W	7.3	0.89	-0.89
WxN	0.04	ns	ns

[1] Not significantly different from zero (P > 0.1)

Addition of indicator variables as shifters for the various parameter estimates of the model shown in equation 2 to separate the two wheat classes revealed that the response of the classes to N availability was the same (P > 0.01). However, CWAD was significantly more responsive to water availability than the CWRS class (P < 0.0001). Indeed, the slope for the water term was 8.2 for CWAD and 6.4 for CWRS. Using the model transformation described by equation 3, this translated in a larger intercept for CWAD that had its response parallel to that of CWRS, but shifted upwards by an amount directly proportional to water availability. Since no shifter for terms containing N was significantly different from zero, the maximum yield for both classes of wheat at equal water availability levels happened at the same level of N availability (Fig. 4b). The coefficient of determination of this model increased significantly from 0.72 to 0.75, evidencing the benefits of including wheat class as an indicator variable in the response model.

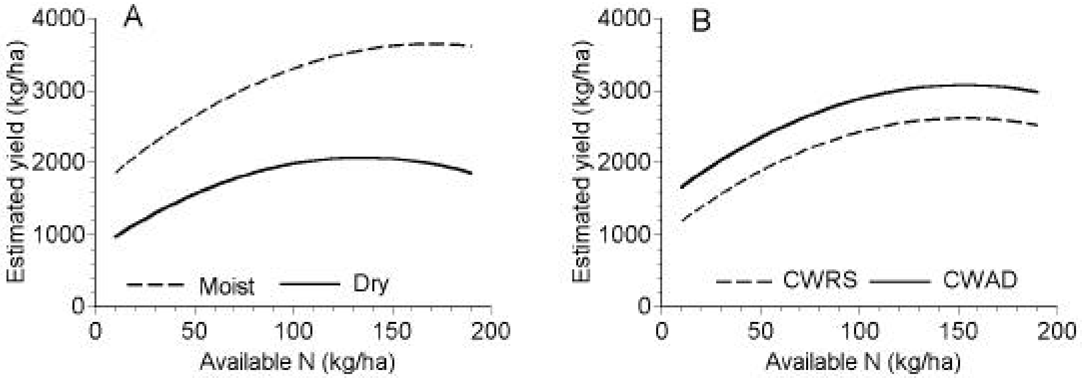

Figure 4. Effect of available moisture (A), and effect of wheat class (B) on estimated yields.

A similar result was achieved when wheat cultivars were used as indicator variables were used as shifter for the regression parameters. Just as determined for wheat class, the only term for which cultivars had an effect significantly different from zero ($P > 0.05$) was available water. The R^2 of this model increased only marginally from 0.75 to 0.76. This marginal increase indicated that nothing is gained by using cultivars instead of wheat classes to separate the yield responses because the shifters for the water term for cultivars within each wheat class are hardly different among themselves (Table 4).

Table 4. Cultivar Shifters for Slope Estimate of Water Term in Yield Model.

CWAD			CWRS		
Cultivar	Shifter Estimate	Prob > |t|[1]	Cultivar	Shifter Estimate	Prob > |t|
AC Avonlea	1.44^{f}	< 0.0001	AC Barrie	-0.68^{bc}	0.0012
AC Morse	1.24^{f}	< 0.0001	AC Cadillac	0.19^{cd}	0.37
AC Navigator	1.24^{f}	< 0.0001	AC Elsa	-0.52^{bcd}	0.014
Kyle	0.61^{e}	< 0.0001	AC Intrepid	-0.55^{bcd}	0.009
			AC Majestic	-1.61^{a}	<0.0001
			McKenzie	0.00^{d}	0.99
			Neepawa	-0.96^{b}	<0.0001

[1] Probability of obtaining a larger absolute value of ‘t’ by chance alone.
Estimates followed by different letters are significantly different ($P \leq 0.05$)

Grain Protein Response

Results of the stepwise regression analysis for grain protein indicated that the best model describing the response of grain protein to N availability was given by:

$$p = a + bN + cN^2 + dW \quad [4]$$

This model explained 55% of the variability observed in grain protein, compared to the 72% explained for grain yield. The absence of a NxW interaction term implied that changes in protein as result of variations in water availability produced response functions that differed only in their intercepts, shifting the response curves up or down according to water availability changes, but maintaining the same slopes. Unlike in the model defined for grain yield, where the water term had a positive slope, for grain protein the slope for the water term was negative, indicating that the yield gains obtained by improved moisture availability resulted in protein decreases, in agreement with the findings of previous studies (Terman 1979, Selles and Zentner, 2001).

Addition of indicator variables to separate the responses of the two classes of wheat indicated that only the slope of the available water term had a significant ($P \leq 0.05$) shifter, similarly to the results obtained for the yield response. This model increased the R^2 from 0.55, in the model where only N and W were considered, to 0.60, but only the slope of the water term was affected by wheat class. The shifter for CWAD was negative while that for CWRS was positive, reflecting the fact that the average protein of CWAD is lower than that of CWRS, but that both classes had a parallel response. On average, the water slope for CWAD was 0.004 units lower than for CWRS (data not shown).

As it was found in the case of the yield response, using wheat cultivars as indicator variables did not improve the resolution of the model. The R^2 did not increase, and the water slope shifters for each cultivar within a wheat class were not different from each other (Table 5).

Table 5. Cultivar Shifters for Slope Estimate of Water Term in Protein Model.

CWAD			CWRS		
Cultivar	Shifter Estimate	Prob > |t|[1]	Cultivar	Shifter Estimate	Prob > |t|
AC Avonlea	-0.0014^{ab}	0.013	AC Barrie	0.0021^{e}	<0.0001
AC Morse	-0.0028^{a}	<0.0001	AC Cadillac	0.0005^{cd}	0.30
AC Navigator	-0.0024^{a}	<0.0001	AC Elsa	0.0015^{cde}	0.004
Kyle	-0.0029^{a}	<0.0001	AC Intrepid	0.0020^{de}	0.0002
			AC Majestic	0.0017^{de}	0.0013
			McKenzie	0.0001^{bc}	0.80
			Neepawa	0.0015^{cde}	0.006

[1] Probability of obtaining a larger absolute value of 't' by chance alone.

Estimates followed by different letters are significantly different ($P \leq 0.05$)

Fertilizer Application Rates

The amount of N required for maximum crop yield can be obtained from the yield model (equation 3) by calculating the first derivative of yield with respect to N, equating it to zero and solving for N (Selles et al. 1992). The solution is given by:

$$N_{\max Y} = \frac{b + fW}{-2c} \quad [5]$$

To calculate the amount of N required for maximum economic yield (N_{econ}) one needs information of the price of wheat and cost of N. It can be demonstrated that for the yield model developed in this study (equation 3) this quantity is given by:

$$N_{econ} = N_{\max Y} - \frac{C_n}{P_w} \times \frac{Mrr}{-2c} \qquad [6]$$

where C_n is the cost of N, P_w is the price of wheat, and Mrr is the marginal return to marginal cost ratio (Selles et al. 1992). One complication with calculating the economic rate of N fertilization is that, with the protein price premiums, the price of wheat depends on protein concentrations (Fig 5), which in turn depend on the rate of N fertilization. Thus, solution to equation 6 can be obtained only through a process of successive approximations. Essentially, this process consists on using equation 6 to estimate N_{econ} at an initial price of wheat given by an arbitrary protein concentration value, then using equation 4 calculate a protein concentration that would result from this calculated N_{econ} value, and then finding the price of wheat corresponding to this newly calculated protein, and with it calculate a new value of N_{econ}. This process is repeated until the price of wheat obtained in two successive calculations converges into a single value.

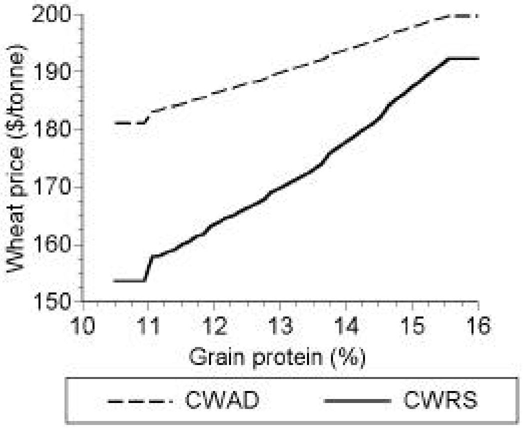

Figure 5. Initial payments for 2001-02 in stores Vancouver or St. Lawrence.

The amount of N required for maximum grain yield was the same for both wheat classes since they had no differences in yield and protein responses to N availability. The amount of N required for maximum economic yield was calculated for CWAD and CWRS growing with in two environments; one with 190 mm available water and with 310 mm, and using the Canadian Wheat Board 2001-02 initial payments with the January 4, 2002 adjustment, and the local cost of N of $ 628/tonne as urea. The two moisture levels were chosen as they corresponded to the 25th and 75th percentiles of the available water distribution in this study.

The amount of N required to produce the maximum physical yield was 131 and 165 kg/ha in he dry and the wet environment, respectively. The N_{econ} calculated here suggests than in spite of the current price differences between CWAD and CWRS wheat (Fig 5), there was not a large difference in the rates of N to be applied, and that the differences in N_{econ} increased as moisture availability became larger (Table 5). At the moisture levels chosen for this calculation CWAD required only 2 to 4 extra kg N/ha than CWRS in the low and high moisture, respectively.

Table 6. Estimates of Economic Rate of Nitrogen Fertilization (N_{econ}) for CWAD and CWRS wheat at Two Levels of Available Water.

	190 mm		310 mm	
	CWAD	CWRS	CWAD	CWRS
N_{econ} (kg N/ha)	97	95	130	126
Estimated Yield (kg/ha)	1819	1809	3297	3280
Estimated Protein (%)	13.8	14.5	12.1	13.2
Price ($/tonne)	192.6	181.3	186.6	170.35

Conclusions

Results from this study revealed that there were no differences in the grain yield and protein response of CWAD and CWRS wheat to N availability, and that any difference in grain yield and protein concentration observed between the two classes were related to the class specific response to available water. Differences in response to water availability among cultivars within each class were too small to be of practical significance. Hence, fertilizer recommendations for both wheat classes should be based on an N response function common to both wheat classes, and on the ratio of the price of wheat to the cost of fertilizer N. With the present wheat price and cost of N, CWAD requires less than 5 kg N/ha more than CWRS to achieve maximum economic yield.

References

Ayres, K.W., Acton, D.F. and Ellis, J.G. 1985. The soils of the Swift Current Map Area 72J Saskatchewan. Publ. 481 Extension Div. Univ. of Saskatchewan, Saskatoon, SK.

DePauw, R.M., Boughton, G.R. and Knott, D.R. 1995. Hard Red Spring Wheat. Chapter 2 *In* Slinkard, A.E. and Knott, D.R. (eds) Harvest of Gold the History of Field Crop Breeding in Canada. Univ. of Saskatchewan Extension Press, Saskatoon, SK.

Dyck, F.B. McLaughlin, N.B., Neudorf, B. and Stumborg, M.A. 1986. Directory of research equipment developed at the Swift Current Research Station. Public. No 379M0085 (Revised 1993), Agriculture Canada, Research Branch, Swift Current, SK.

Freund, R.J. and Littel, R.C. 1986. SAS System for Regression, 1986 ed. SAS Institute Inc., Cary, NC.

Hamm, J.W., Bettany, J,R, and Halstead, E.H. 1970. The simultaneous determination of nitrogen, phosphorus, and potassium in sodium bicarbonate extracts of soils. Pages 65-69 *In* Industrial Analysis, Vol. 2. Proc. Technicon Intl. Congr. Adv. Automatic Anal. Futura Publ. Co., Mt. Kisco, NY.

Hamm, J.W., Bettany, J,R, and Halstead, E.H. 1973. A soil test for sulphur and interpretative criteria for Saskatchewan. Commun. Soil Sci. Plant Anal. 4:219-231.

SAS Institute Inc. 2000. JMP Statistics and Graphics Guide, Version 4. SAS Institute Inc., Cary, NC.

Selles, F. and Zentner, R.P. 2001. Grain protein as a post-harvest index of N sufficiency for hard red spring wheat in the semiarid prairies. Can. J. Plant Sci. 81: 631-636.

Selles, F., Zentner, R.P., Read, D.W.L. and Campbell, C.A. 1992. Prediction of fertilizer requirements for spring wheat grown on stubble in southwestern Saskatchewan. Can. J. Soil. Sci. 72: 229-241.

Terman, G.L. 1979. Yields and protein content of wheat grain as affected by cultivar, N, and environmental growth factors. Agron. J. 71: 437-440.