Strategies and Management Practices for Improving Protein Content of Wheat Grain in the Canadian Prairies (July 4, 2014)

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Background:

Factors Affecting Protein Content in Wheat Grain:

- Protein in wheat grain makes an important contribution to diets for poultry, pigs and other livestock, and food for human consumption. Production and export of wheat in western Canada is a multi-billion dollar industry.
- Protein content of grain is an important quality factor for wheat, which also affects economic returns, because producers are now rewarded with premiums for producing wheat with high protein content in grain (i.e., > 13.5%), and discounts for low protein.
- There are many factors which affect the protein content of wheat grain, such as supply of available N in soil (which is linked to soil type/soil organic matter, tillage/summer fallow) in relation to N requirement, cultivar, moisture/precipitation and temperature during crop growing season.
- High levels of N are required for economical wheat grain yields, and levels of protein content in wheat grain are also directly related to N fertilizer rates as well in most cases (more than 60% of the protein yield variation is due to N fertility).
- Nitrogen has a large influence on both yield and quality of wheat grain. In general, there is an inverse relationships between wheat seed yield and protein content, depending upon the rate of applied N and amount of moisture available in soil which is linked to precipitation and temperature conditions. For example, in field experiments conducted from 1967 to 1983 in Saskatchewan (**Selles and Zentner 1998**), on average protein content of wheat grain was 14.6% with grain yield of 921 kg/ha, while the protein content reduced to 13.2% when average grain yield was 1936 kg/ha. Differences in grain yield and protein content of wheat can be greater under optimum environmental conditions, as growing conditions also influence yield potential of cultivars. For example, low N

fertilizer applications in western Canada corresponded with low wheat grain yield and higher protein content, while higher N fertilizer applications resulted in higher grain yields but lower protein content.

- Wheat cultivars can differ markedly in seed yield and protein content, depending on their yield potential and response to applied N fertilizers and climatic conditions (**Table 1**). For example, semi-dwarf wheat cultivars due to their high grain yield potential show a smaller increase in grain protein content than tall growing cultivars with low grain yield potential.
- Nitrogen is the most limiting nutrient required by wheat (or other crops) and its adequate supply throughout the growing season is necessary for both high grain yield and protein content. Nitrogen is normally supplied by fertilization and mineralization of soil organic matter, which depends on environmental conditions.
- Mineralization of N from soil organic matter is also affected by tillage/summer fallow. For example, in four long-term tillage studies in the Brown and Dark Brown soil zones of Saskatchewan, **McConkey et al. (1998**) found significantly lower soil nitrate-N under no-till (NT) than conventionally tilled (CT) soils for both Fallow-Oilseed-Wheat and Wheat-Oilseed-Wheat rotations, resulting in additional requirement 25 kg N/ha/yr for NT. Compared to CT soils, N fertilizer applications based on soil test nitrate-N were often insufficient under NT crop production systems. They suggested that this may lead to N deficiencies and lower protein content of wheat grain, and sometimes lower grain yield of wheat.
- If grain yield of wheat is limited by lack of N in soil, small additions of N fertilizer usually increase grain yield without any significant increase in protein content. This suggests that protein content will be increased by N fertilization only above the point where N is no longer the factor most limiting to grain yield.
- If N supply remains constant, increase in wheat grain yield due to improved soil moisture usually results in a decrease in protein content because of dilution of N from large biomass. In addition, at a given level of available N in soil, wheat cultivars with higher yield potential tend to contain lower protein content of grain than cultivars with higher yield potential.

Methods for Increasing Protein Content in Wheat Grain:

- Increasing protein content in wheat grain with increasing rates of N fertilizer applied prior to, near or at seeding is usually inefficient, as N use efficiency decreases with increasing N level particularly under rainfed/dryland conditions, which in turn reduces economic returns of N fertilization at higher rates. Application of high rate of N fertilizer at seeding also increases risk/potential of crop lodging, plus nitrate leaching/runoff and gaseous N loss from denitrification. To compensate for low N use efficiency at these N fertilizer rates, protein content in wheat grain can be improved by using following management practices.
- In addition to rate of N fertilizer, protein content in wheat grain is also affected by timing of N supply/application as N in grain comes through its re-translocation from plant leaves/stem as well as from soil. In Saskatchewan, protein content of wheat grain increased from 12.1% to 15.0% with late application of N fertilizer (anthesis), while application of N fertilizer prior to seeding increased the protein content in grain from 12.1% to 13.8% (**Hog and Ackerman 1998**). However, in their study, net returns of N fertilizer was greatest when it was applied prior to seeding in spring due to increase in both grain yield and protein. In a 7 site-year study on wheat, canola or barley (3-year trial at Star City in Saskatchewan and 4-year trial at Beaverlodge in Alberta, compared to all N fertilizer applied in spring at seeding (60 kg N/ha), split application of urea (half each at seeding and tillering for cereals ot bolting for canola) produced higher grain yield and total N/protein content in 4 site-years (**Malhi et al. 2010**), suggesting that split N application can be effective in increasing grain protein content.
- Late/split application of N fertilizer by topdressing at tillering, flag leaf or anthesis/flowering growth stages can be effective to increase protein content in grain, but this practice may not be an efficient and/or cost-effective way to improve protein content in wheat grain in certain agro-ecological regions, because the effectiveness of this practice depends of the amount of precipitation after topdressing N fertilizer.
- Under relatively dry conditions, uptake of N from topdressing N fertilizer on soil surface may be impaired, but late application of N fertilizer by foliar spray is expected to increase protein content of grain. For example, the results of field experiments in Manitoba indicated that late applications of liquid N to wheat foliage can increase protein content

of grain (0.7 to 1.0%), with only occasional improvement in grain yield (**Table 2**). Although foliar application of liquid N fertilizer at flag leaf growth stage can be more efficient in increasing protein content in wheat grain, its rate of application (because of the potential of salt/N toxicity to leaves to cause leaf damage) and absorption is restricted. For example, foliar application of liquid urea solution at flag leaf growth stage can increase protein content in grain, with little impact on grain yield.

- Application of controlled-release urea (CRU) or slow-release urea (SLU) N fertilizers, such as ESN (polymer-coated urea), or its blends of ESN and urea, are expected to enhance both grain yield and protein content. However, in a 7 site-years study on wheat, canola or barley (3-year trial at Star City in Saskatchewan and 4-year trial at Beaverlodge in Alberta, (**Malhi et al. 2010**), compared to spring applied urea at seeding (60 kg N/ha), ESN or a 50:50 blend of ESN and urea produced greater grain yield in 2 site-years under wetter than or about normal moisture conditions, but had little beneficial effect on grain total N/protein content of crops (except 1 site-year on canola, where total N in seed increased). In fact in a few cases, ESN had lower total N/protein content of grain (may be due to dilution of N from increased grain yield by ESN) compared to urea. In addition, there is extra cost involved in using ESN, and this should be taken into consideration for calculation of net economic returns from this practice.
- Application of animal manure (such as cattle manure or liquid hog manure – LHM) can also increase protein content of wheat grain. In a Saskatchewan study with LHM (8000 gallons/acre or about 90,000 L/ha) on spring wheat, **Schoenau et al. (1998)** reported an increase of both grain yield by 1.25 Mg/ha (from 2.08 Mg/ha in control to 3.33 Mg/ha with LHM) and protein content by 5.1% (from 11.3% in control to 16.4% with LHM). The large increase in both grain yield and protein content of wheat from LHM was through its effect on enhancing supply of available N in soil throughout the entire growing season. The economics of this practice depends on the cost of transporting manure from the source to long distances, and producers should take this into consideration while hauling LHM to long distances.
- Inclusion of legumes [for grain (pea, lentil – pulse crops), forage (alfalfa, clover), green manure (fababean, pea)] in the crop rotations with wheat can reduce input of N fertilizer and can have positive yield benefit as well as increase protein content of wheat grain, due

to both N gains from N fixation resulting in improvement of N-supplying power/capacity of soil (**Flaten and Greer 1998**), and non-N benefits from better root development and breaks in disease cycles. In Manitoba, **Forster and Entz (1998)** reported an increase of protein content of wheat grain by more than 1% in the fertilized rotations after alfalfa termination, and this rotational benefit to wheat protein lasted for up to 5 years. When fertilized, alfalfa-containing rotations produced wheat grain with a protein content of >15% more frequently than fertilized annual rotations.

- In Alberta, **Eyolfson (1998)** found a trend of increase in protein content of wheat when it was seeded into pea stubble (15.1% to 15.3%) compared to canola (13.8% to 13.9%) or wheat (13.1% to 13.4%) stubble at Sedgewick, with the highest net returns in the no-till pea stubble. In a number of crop diversification studies conducted in the Brown soil zone of Saskatchewan, **Campbell et al. (1992)** and **Miller et al. (1998)** concluded that inclusion of pulse crops (e.g., pea, lentil, or chickpea) and oilseeds (e.g., mustard, sunflower, or safflower) in crop rotations with wheat is the key to boosting protein content of wheat grain. In these studies, compared to wheat stubble, inclusion of oilseeds and pulse crops in the crop rotation resulted an average increase of wheat grain protein content by 0.6% to 1.6%.
- All N management practices (such as split application, foliar spray and use of slow-release N fertilizer ESN) that improve protein content in wheat grain, involve extra cost and this should be considered when using these N management methods on a commercial scale.
- In a review, **Smith et al. (1998)** suggested that protein premiums will increase total sales revenue from production of higher protein wheat and this should increase the application of optimum rates of N fertilizer. They further suggested that this increased N application could also cause environmental contamination/damage resulting in additional environmental costs, thus, effectively increasing the cost per unit of fertilizer N.

Conclusions

- Management practices, such as inclusion of legumes in the crop rotations, application of manure, split/late application of N fertilizer, foliar spray of liquid N fertilizer and use of controlled/slow-release N fertilizers (e.g., ESN), can improve protein content in wheat

grain. However, the extra cost of these practices should be considered when using these methods on a commercial scale. The findings also suggest the need for more research under different agro-ecological regions/soil-climatic conditions, to refine the use of liquid N products (through changes in formulation and/or solution concentration), that will not cause any leaf damage.

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Table 1. Effect of N fertilizer application on grain yield and protein content of 3 spring wheat cultivars under moderate moisture (mean of 5 site-years in 1985 and 1987), and protein content of 6 spring wheat cultivars under high moisture (mean of 4 site-years in 1985 and 1986) conditions in Manitoba (Gaur et al. 1992[z]; adapted from Grant and Flaten 1998[y])

Rate of N		Grain yield (kg N/ha)				Grain protein content (%)				Grain protein content (%)					
(kg N/ha)		Glenlea	HY320	Katepwa		Glenlea	HY320	Katepwa		Glenlea	HY320	Katepwa	Len	Marshall	Solar
0		1511	1953	1506		12.6	12.2	13.5		12.2	11.2	14.4	15.3	13.0	12.4
40		1990	2581	1991		2.9	12.3	13.3		12.4	11.0	14.3	14.9	12.6	11.7
80		2226	2784	2356		14.3	13.1	15.0		12.9	11.3	14.7	15.2	12.5	12.0
120		2418	2927	2408		14.8	14.0	15.7		13.8	11.9	16.1	15.9	13.2	12.6
160		2305	2938	2335		15.2	14.5	16.4		15.0	12.5	16.9	16.1	13.8	13.1
200		2318	2872	2444		15.7	15.0	16.4		15.8	12.9	17.2	16.5	14.0	13.5

Source: Gauer, L. E., Grant, C. A., Gehl, D. T., and Bailey, L. D. 1992. Effects of nitrogen fertilization on grain protein content, nitrogen uptake, and nitrogen use efficiency of six spring wheat (Triticum aestivum L.) cultivars, in relation to estimated moisture supply. Can. J. Plant Sci. 72: 235-241.

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Table 2. Effect of foliar application of urea-ammonium nitrate (UAN) solution at 17 kg N/ha to spring wheat at two growth stages (GS45 and GS69) on grain yield and protein content at different rates of spring applied N in 1994 and 1995 at three locations (adapted from Lafond and McKell 1998)[z]

Rate of N (kg N/ha)		Heavy clay soil – 1994 Wheat cv. Laura				Heavy clay soil – 1995 Wheat cv. CDC Makawa				Indian Head – 1995 Wheat cv. CDC Kestrel				Oxbow loam – 1994 Wheat cv. Laura		
		Check	GS45	GS69		Check	GS45	GS69		Check	GS45	GS69		Check	GS45	GS69
		Grain yield (kg/ha)														
0		1412	2152	1480		1681	1950	1883		1243	1356	1337		1883	2287	1883
56		2488	2556	2556		2825	2825	2892		2683	2944	2754		3026	3026	2892
84		2623	2757	2623		2825	2892	3026		3126	3157	3049		3228	2885	2959
112		2757	2690	2690		3094	2825	2959		3162	3239	3273		3363	3161	3026
Mean		2287	2556	2354		2623	2623	2690		2816	2938	2856		2892	2825	2690
SEM			55				37				81				90	
Foliar Effect																
None vs. Foliar			**				ns				ns				ns	
GS45 vs. GS69			ns				ns								ns	
		Grain protein content (%)														
0		12.5	12.8	13.1		11.7	13.0	13.0		10.5	11.5	11.6		12.0	12.3	12.3
56		12.7	13.2	12.7		12.7	13.8	14.0		9.4	10.3	10.4		12.1	13.1	12.1
84		13.1	14.1	13.6		13.7	15.0	15.4		9.8	10.8	10.8		12.8	13.6	13.2
112		13.8	14.7	14.2		15.1	16.0	16.2		10.3	11.3	11.6		13.7	15.0	13.8
Mean		13.0	13.7	13.4		13.3	14.4	14.6		9.9	10.9	11.1		12.7	13.5	12.9
SEM			0.09				0.08				0.2				0.1	
Foliar Effect																
None vs. Foliar			**				**				**				*	
GS45 vs. GS69			ns				ns								*	

[z]Source: Lafond, G. P. and McKell, J. 1998. Effects of foliar applied nitrogen on grain protein concentration in spring and winter wheat. Pages 298-304 in D. B. Fowler, W. E. Geddes, A. M. Johnston and K. R. Preston, eds. Wheat production and marketing. University Extension Press, University of Saskatchewan, Saskatoon, Saskatchewan, Canada.