Nitrogen Management for Enhanced Protein Content in Wheat in the Black Soil Zone

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Nitrogen in Important for Grain Yield and Protein

Nitrogen is the nutrient most commonly limiting to crop production in the prairies. As N comprises about 17% of protein, N is also the nutrient with the greatest effect on protein content. To produce a high-yielding, high quality wheat crop, the N supply must be balanced to the yield potential of the crop. Plant-available N is provided by mineralization of organic matter from summer fallowing, by release of N from high N residues or amendments such as legumes or manures, by accumulation of residual N in the soil, or through fertilizer application. If N in the soil is deficient, application of N fertilizer can increase both grain yield and protein content (Alkier et al. 1972, Grant and Flaten 1998).

Balance Yield Potential and Nitrogen Supply

The response of crop yield and protein to N applications depends on the balance between crop yield potential and N supply. If N supply is low relative to the yield potential of the crop, modest rates of additional N tend to have a large effect on grain yield and a lesser effect on protein concentration (Figure 1). As the N supply relative to grain yield potential increases, both yield and protein content can increase with N application. When N supply is high relative to yield potential so that N is no longer limiting to crop yield, yield will no longer increase with increasing N supply although protein content can continue to increase. If N supply is very high, neither yield nor protein content will increase with increasing N supply. Generally, a protein content less than 13-14 % in hard red spring wheat indicates that N supply was less than optimum for crop yield. Economically, payment of protein premiums provides a "buffer" in selection of optimum N application rates. Even where producers do not increase yield with additional N applications, they can still capture a higher return if they are paid for the higher grain protein content. However, as rate of N application increases, the efficiency of N use generally declines. High rates of N also lead to higher economic risk, increased danger of lodging and increased risk of nitrate leaching and gaseous N loss.

To optimize grain yield and protein content the N supply must be matched to the yield potential of the crop. Therefore, rates of application should consider the amount of N available in the soil, the available moisture and the target yield. Moisture supply may impact on crop yield potential and the capacity for plant utilization of available N (Gauer et al. 1992). Under optimum moisture conditions, high rates of N are required to support the yield potential and produce adequate protein content. With low moisture, N fertilization will have minor effects on crop yield, since yield is more limited by moisture than by N supply; however, N may still increase grain protein content. Different cultivars may also differ in their yield and protein response to N application (Gehl et al. 1990). Low yielding cultivars will usually have a lower N requirement for optimal yield, so protein content will increase at lower N levels. Cultivars with high yield potential generally require higher rates of N fertilizer to optimize both yield and protein content.

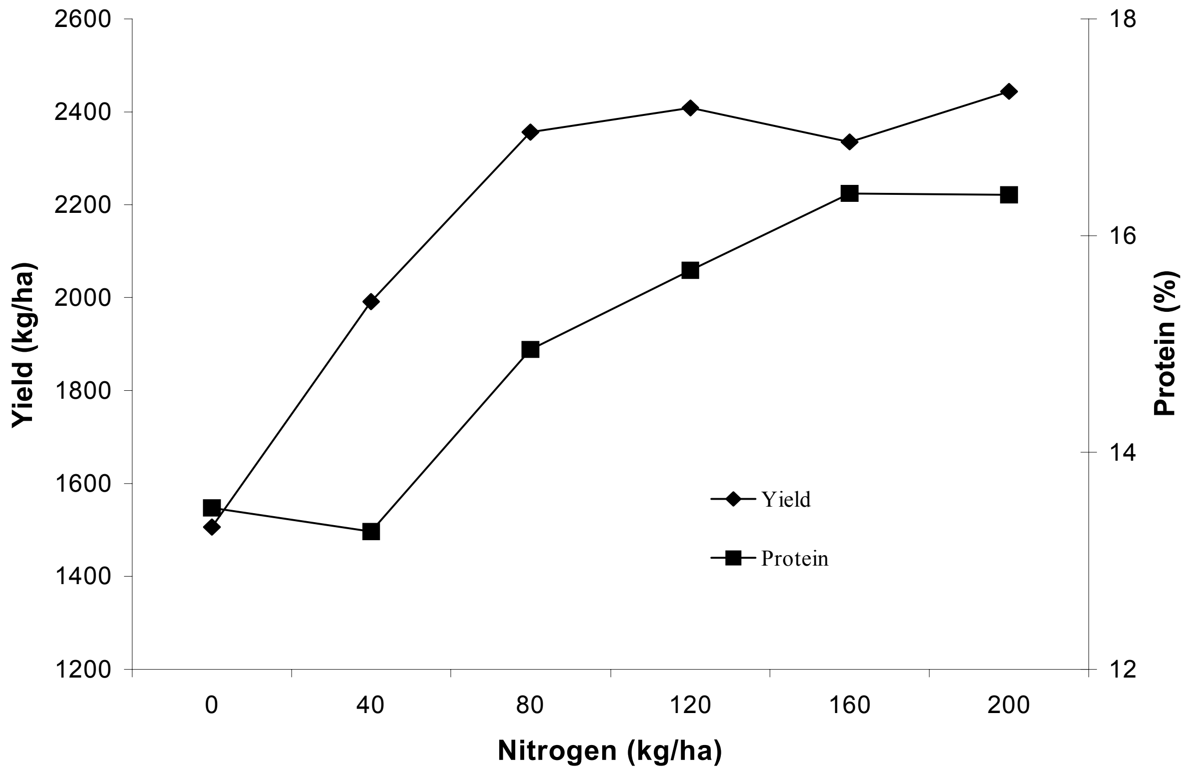

Figure 1: Response of wheat grain yield and protein content to nitrogen application

Manage for Efficient Nitrogen Use

Management practices should be used to improve the efficiency of N application. Both yield and protein content can increase with improved fertilizer efficiency. Therefore, it is important to use best management practices for N fertilization, suited to the environmental conditions of the area. This includes selecting a combination of N source, placement and timing that balances fertilizer use efficiency, agronomic benefits and logistical, economic and environmental considerations. For example, while banding generally results in improved fertilizer use efficiency, moisture loss from the banding operation may under some conditions negate any yield benefits from in-soil placement. Therefore, it is important to make fertilizer management decisions based on information from an area with a similar environment to your own.

Nitrogen Timing Influences Crop Response

Timing of N supply can also influence grain protein content. Nitrogen that is accessed by the crop early in the growing season generally has a major effect on vegetative growth and crop yield while the effect on grain protein content may be low, due to the biological dilution effect of the higher yield. Conversely, late season supplies of N generally affect protein more than yield. Since there is little impact of late N supply on crop yield, there is less dilution of the protein produced by the enhanced grain production. In addition, N accessed later in the season may be more effectively channelled to the grain, as it is not immobilized in vegetative parts.

Nitrogen may be supplied to the crop late in the season from mineralization of organic matter supplied through legume forage breaking, pulse crop residues, manure application, or a long history of balanced fertilization with return of crop residues. Long-term mining of the soil through fallow will reduce the potential for late-season mineralization and production of high protein wheat, unless N management is enhanced. Potential N supply from mineralization will be higher on soils with a high concentration of active organic matter and will be restricted in dry or cold soils.

Nitrogen may also be supplied late in the growing season through fertilizer applications. However, timing of N supply must still be early enough in plant development to allow sufficient time for plant uptake and translocation. Applications from the boot stage until slightly after anthesis have been effective in increasing protein content in wheat. In-crop N may be applied as foliar sprays, broadcast applications, surface dribble-bands, or as in-soil applications, if the equipment is available.

Foliar or Soil Applications?

In-crop "foliar" applications of urea ammonium nitrate or urea solutions are frequently used to increase grain protein content, in the belief that N is absorbed more efficiently through the leaf than from soil. In reality, very little of the foliar-applied N is normally taken up through the leaf and the majority of the "foliar-applied" N is accessed by roots once the fertilizer washes off and reaches the soil (Figure 2) (Alkier et al. 1972, Rawluk et al., 2000). Soil-applied dribble-banded or broadcast in-crop N tends to be more effective than foliar application, if there is sufficient moisture for the N to be dissolved and moved into the root zone. Soil application of in-crop N will also reduce the risk of crop damage due to leaf burn.

In spite of the limited absorption, foliar applications of N may be beneficial under some circumstances. The small amount of N that is absorbed through the leaf with foliar applications may still be able to increase protein content under dry conditions, where soil-applied fertilizer may be stranded at the soil surface. In studies conducted in the Black soil zone, protein content was increased to a greater extent with soil-applied than foliar-applied N through the boot stage. However, if applications were delayed until anthesis, protein content was increased more with foliar-applications than soil applications. Presumably, when application was delayed until anthesis, the soil-applied N was not available to the plant in time for uptake and translocation to the grain while the small amount of the foliar application that was absorbed through the leaf was sufficient to increase protein content.

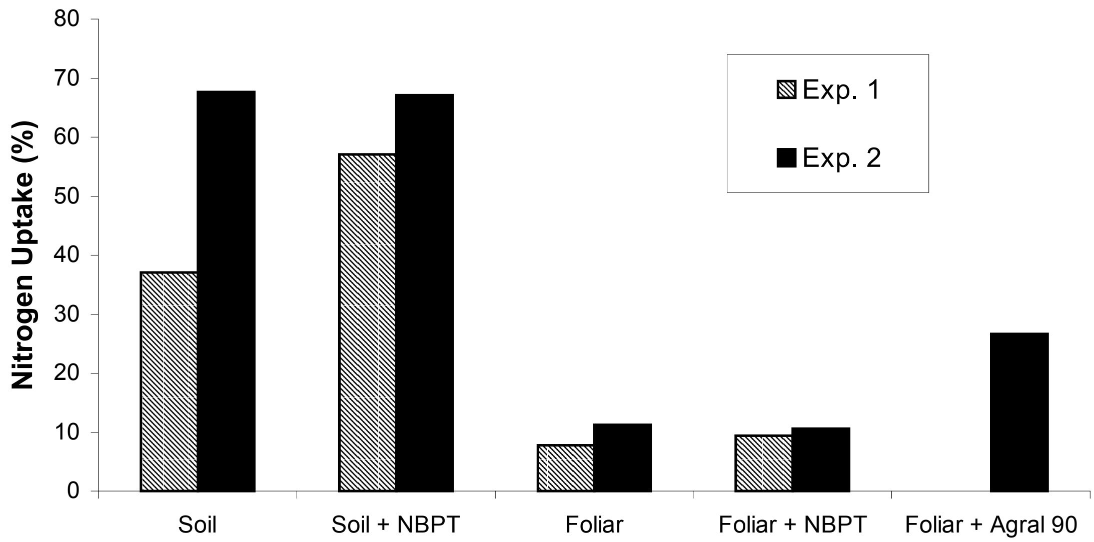

Figure 2: Effect of placement of urea solution and addition of NBPT or Agral 90 on absorption of nitrogen by wheat (Rawluk et al. 2000).

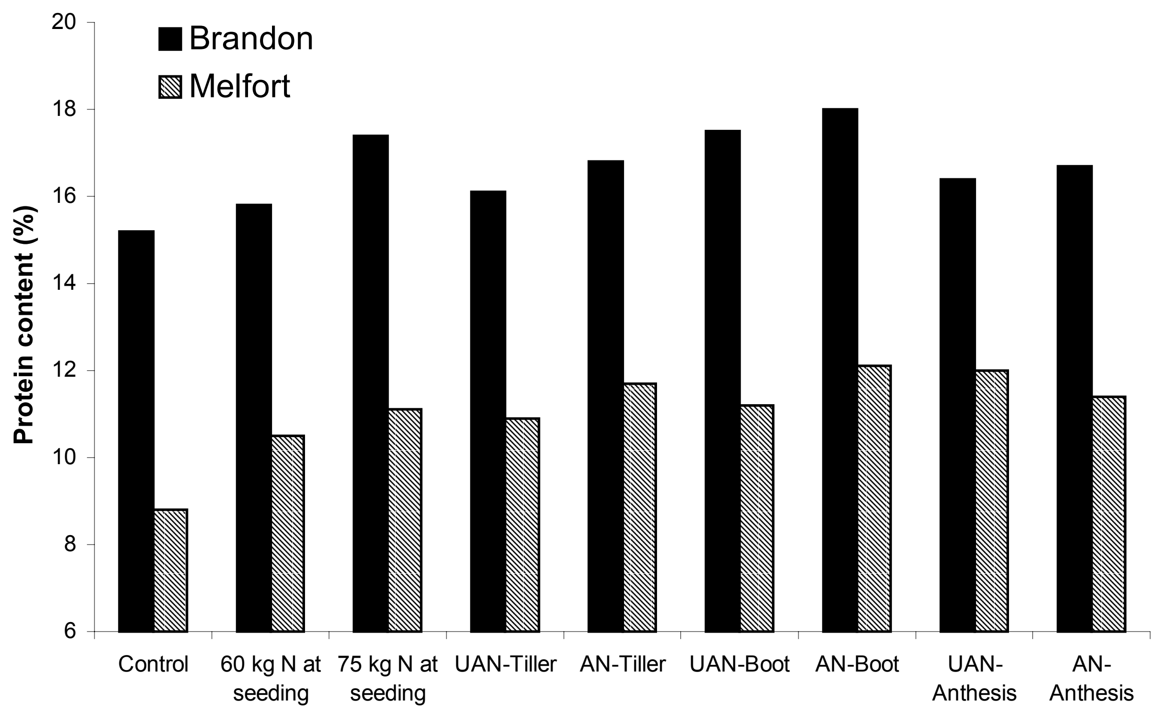

Figure 3: Effect of base application of 60 kg N ha^{-1} at seeding and the addition of 15 kg N ha^{-1} as ammonium nitrate or urea ammonium nitrate at various stages of growth at Brandon and Melfort.

For in-crop applications of N on the soil surface, ammonium nitrate may be a better source than urea or urea ammonium nitrate, as it is less subject to volatilization loss than ammonia- and ammonium-producing sources such as urea. Efficiency of broadcast urea can be improved by use of a urease inhibitor or with irrigation or significant rainfall after fertilizer application.

While in-crop applications of N can be used to increase protein content, there are some problems associated with this technology. In-crop applications of N will not always increase protein content. Increases are less likely when initial levels of N for the crop are relatively high or when growing conditions reduce the yield potential and hence the N requirements of the crop. Granular applications of N on dry soil will be ineffective if rainfall does not occur and the fertilizer is stranded on the soil surface. Foliar applications can cause leaf burn and lead to a yield decrease. In-crop applications also require another operation with extra labour and expense.

Remember "Best Management Practices"

If initial applications of N at or prior to seeding are high enough to ensure optimal yield, then protein concentrations should be in the range of 13-14%. If higher levels of protein are desired, it may be more beneficial to increase early season N application, where there may be an impact on yield and protein content, rather than to rely on in-crop N applications. This is especially true if protein levels have been low in this past, as this may be an indication that insufficient N has been applied to optimize crop yield. Fertilization for a reasonable target yield and use of "best management practices" for N management to minimize N loss and optimize fertilizer use efficiency are key steps in production of high protein wheat.

Breadmaking Quality - Protein Quantity and Quality

High protein wheat commands a premium because breadmaking quality generally increases with increasing protein content in the flour. The breadmaking quality of a wheat flour is a function of both dough and loaf properties. The ideal wheat flour for raised-bread has a high capacity for water absorption and forms a dough with the perfect combination of elasticity and resistance which will rise during baking as CO_2 is generated to produce a high volume loaf. Flour water absorption and gas production are highly correlated to the extent of damaged starch granules present in the dough (Williams 1997). Starch granules damaged during milling of hard wheats can absorb several times more water than undamaged starch and are a more ready source for fermentation by amylase enzymes to yield CO_2. During dough formation hydrated flour proteins join to form a strong and elastic gluten network that traps this CO_2, giving rise to high loaf volume. Increased water content of dough also translates to increased profit for the baker.

The abundance and quality of gluten storage proteins, which comprise about 80% of the total protein in flour (Fu et al. 1998), are most important for bread making. Wet gluten is strongly correlated to flour protein content at a ratio of 1:2.8 for CWRS wheat (Williams 1997). Gluten is largely made up of variable molecular weight glutenin and monomeric gliadin proteins which are associated with elasticity and viscosity, respectively. The relative proportions of gliadins and glutenins, and the size and structure of glutenins as insoluble high molecular weight subunits (positively related to loaf volume, well correlated to dough strength) or soluble low molecular weight subunits (negatively related to loaf volume, less related to dough mixing properties) are largely responsible for protein quality (Fu et al. 1998; Bushuk 1985).

The quality of dough is evaluated through mixing while baking parameters determine bread loaf quality. Farinograph, mixograph and extensigraph methodologies evaluate the physico-chemical properties of the CWRS wheat flour during mixing and dough formation on the basis of dough strength. The four main parameters of the farinograph indicative of flour mixing characteristics, are flour water absorption (FAB %), development time (FDT min), stability time (FST min), and mixing tolerance index (MTI BU). As protein content increases, a corresponding increase in quality would be observed as an increase in FAB, FDT and FST and a decrease in MTI. The mixograph assesses dough mixing strength on a basis similar to the farinograph but is more rapid and uses a smaller sample size. As the strength of the flour increases, the time to peak height also increases and the mixing tolerance decreases. The extensigraph measures the resistance and elasticity of the dough during stretching. The remix procedure for baking measures height after proofing and loaf volume after baking.

Protein quality is predominately a function of genetics but can also be affected by N management and environment conditions (Fowler et al. 1998; McKenzie and Williams 1997; Bushuk 1985). Protein content generally increases with increasing N. As changes in protein quality typically echo changes in protein content, protein quality should also be improved with additional N. In field studies near Brandon, MB in 1999 protein content increased with increasing N (ammonium nitrate) from 0 to 180 kg N ha^{-1} for Katepwa and AC Barrie wheat (12-16%). Dough quality improved with increasing protein content and N rate. Farinograph flour water absorption, dough development time and dough stability increased when protein increased with increasing N rate. Mixing tolerance index was more variable, tending towards increase for Katepwa and decrease for AC Barrie. However, at high levels of N fertilization, corresponding with high protein content, protein quality may be negatively affected due to possible imbalances in gliadin and glutenin protein ratios, glutenin structure, or high N:S ratio in the grain (Peltonen 1992; Salmon et al. 1990).

Timing N application to correspond with reproductive development may preferentially channel N to the grain for protein synthesis and storage, but delaying fertilization too long may restrict the amount of N that can be converted into quality protein. Applications of N at anthesis which have increased protein content have been shown to also increase protein quality (Ayoub et al. 1994; Peltonen 1992). Peltonen (1992) observed less protein was lost during milling when N was applied at GS 10 than at earlier growth stages, which he attributed to stimulated protein synthesis and protein storage in the endosperm by targeting N application to a growth stage where N would only be used for protein increases and not vegetative growth. Field studies near Brandon, MB in 1999 showed timing of supplemental N can affect both protein content and quality, depending on N source and growing conditions. However, protein quality was ultimately dependent on protein content, where dough strength increased when protein content increased, regardless of timing of N fertilization.

SUMMARY

Protein is a critical quality factor in wheat and it is important to maintain adequate protein levels in our crop to satisfy market demands. Improving protein content can help to maintain Canadian markets and also provide direct benefits to the producer in terms of protein premiums.

While environmental factors such as moisture and temperature have large effects on protein content, production practices such as cultivar selection, seeding date and fertility management can also influence protein content. Balancing N supply with yield potential can optimize both crop yield and protein content. Selection of an effective combination of nitrogen source, placement and timing can improve fertilizer use efficiency. In-crop nitrogen applications can increase protein content, but are not a substitute for adequate levels of N applied prior to or at seeding. Increasing protein content of wheat through N applications either at seeding or during the growing season can increase the milling and baking quality of the grain. Careful management can improve both the protein content of wheat and the economics of crop production.

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