# Nitrogen Management for Yield and Protein in Wheat in the Brown Soil Zone

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## Introduction

Protein is an essential factor that determines bread-making or pasta-making quality of wheat, and is an important component of the human diet (Lukow and Preston 1998). Buyers of Canadian wheat demand assurance of minimum protein levels in wheat shipments. However, in the past few years wheat protein levels have been below average, due to cooler and moister than normal growing season conditions. To ensure a consistent supply of high protein wheat, the Canadian Wheat Board has introduced a schedule of protein price premiums for CWRS and CWAD wheats (Smith et al. 1998).

In response to the introduction of protein price premiums, producers have been trying to capitalize on the potential extra economic return they may achieve from their crop. In some years, protein premium price can be realized by simply increasing fertilizer rates. However, because grain protein content (GPC) is determined by complex interactions between N nutrition and environment, it is important to understand how GPC responds to these factors. This knowledge will enable us to devise fertilizer management strategies that will maximize returns to investment in N fertilizer, and will minimize possible adverse effects of over-fertilization on the environment.

Yield and protein response to N availability

Because N is an essential component of plant growth and grain protein, its supply to the crop, whether from the soil or from fertilizer, plays an important role in determining GPC (Smika and Greb 1973, Grant et al. 1991). The response of protein to N fertilization is complex and controlled by many factors, which makes its response highly variable (Campbell et al. 1977, Fowler et al. 1989). In general, when the crop is highly deficient in N, or when the supply of N is low for the potential yield of the crop, small increases in N availability produce large yield increases (Fig. 1). At this point GPC does not increase, and often it may drop, because the increase in N taken up by the crop is small relative to the increase in grain yield (Terman 1979). In soils with adequate but not excessive N supplies, improvements in N availability produce moderate yield increases, and substantial GPC increases. In this region of N supply sufficiency, relative increases in grain yield are equal to or smaller than relative increases in N uptake by the crop. Finally, in soils with high N supply one normally observes modest increases in GPC as N availability increases, while yields normally do not respond or even decline (Schlehuber and Tucker 1967, Selles and Zentner 1998).

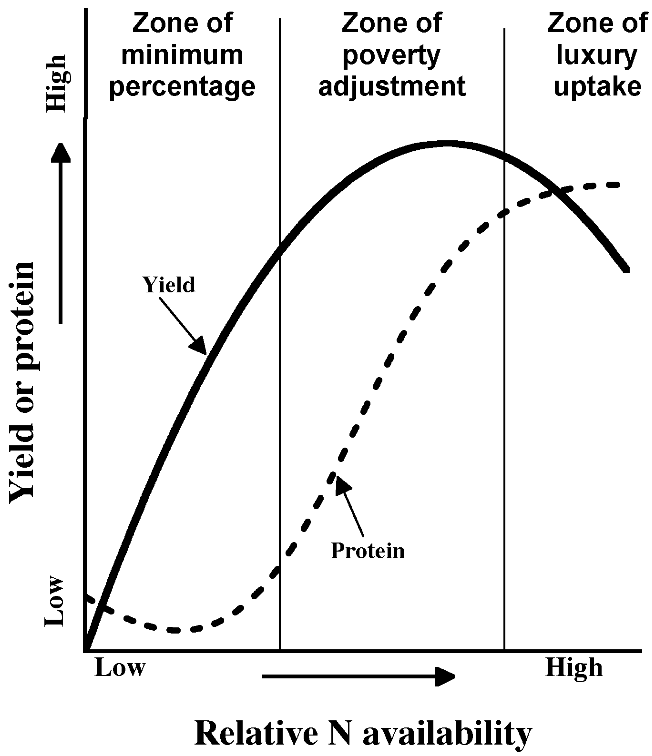


Figure 1**. Idealized grain yield and protein response to N availability.**

**Adequate fertilization is one of the most important factors for production of high protein wheat (Grant and Flaten 1998). When all N is applied at or near seeding, as is commonly done under dryland farming, the crop absorbs the largest proportion of N early in the growing season, decreasing the amount of available N in the soil (Fig. 2). Thus, later in the growing season when the crop is filling the grain, there may be little N available to the crop to maintain adequate protein levels when the weather is favourable for the production of high grain yields.**

The price incentive for high GPC wheat might prompt producers to fertilize with high rates of N in order to increase GPC and cash in on the protein premiums. While it may be possible to raise GPC with excessively high rates of N fertilization, as the supply of N to the crop improves, the fraction of available N used by the crop declines (Fig 3a), and increasingly less grain and protein are produced per unit of available N (Figs. 3b and 3c). This may lead to reduced profits (Grant and Flaten 1998), and to increased risk of nitrate leaching and ground water contamination. The efficiency of fertilizer use can be measured as conversion efficiency in terms of amount grain or protein produced per unit of available N (soil + fertilizer), or as nitrogen use efficiency (NUE) which estimates the proportion of available N used by the crop.

Effect of weather on grain protein

The GPC of CWRS wheat grown in western Canada from 1927 to 1994 (Fig. 4) has been highly variable from year to year, ranging from 11.5 to 15.25%. Despite large changes in production technology and crop varieties, GPC shows no time trend, but it fluctuates around the long-term mean. During periods of hot dry weather (during the thirties, late fifties and early sixties, and the eighties), GPC was consistently higher than the long-term mean. Conversely, during periods of cool wet weather GPC was below the long-term mean. Average grain yields for the same periods (data not shown) followed a trend opposite that of GPC; that is, yields were below the mean during periods of hot dry weather and above the mean during cool wet periods. This happens because there is, normally, an inverse relationship between grain yield and GPC. During wet cool growing seasons, the yield potential of the crop is high, and GPC tends to be low, because the amount of N taken up by the crop is diluted into a larger amount of grain. In some cases when yield increases due to fertilization are very high, protein content can drop with N fertilization if insufficient amounts of N are applied to the crop. In hot and dry growing seasons, yield potential is often low and protein content is high, as the N available to the crop is distributed into a smaller amount of grain.

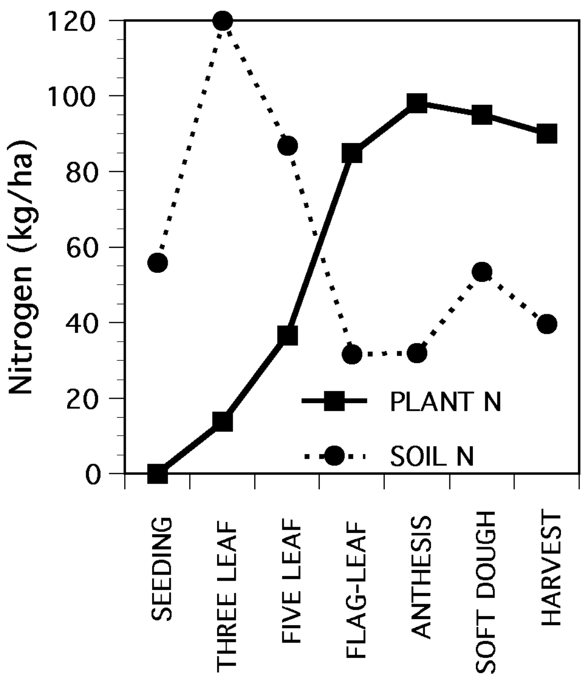


**Figure 2**. Evolution of plant and soil N during the growing season (wheat seeded on stubble and fertilized with 75 kg N/ha).

Because GPC is affected by N availability to the crop, it has been postulated that GPC could be used as a post-harvest index of N sufficiency as a means to evaluate the adequacy of fertilization programs (Goos et al. 1982, Grant and Flaten 1998). For the moister eastern prairies, it appears that a GPC of 13.5% is a critical level separating N-deficient from N-sufficient wheat crops. A study conducted using data from long-term fertility experiments conducted by SPARC throughout the Brown soil zone of Saskatchewan, indicates that wheat crops with GPC below 12.8% (range of 12.3 to 13.5%) have suffered enough N deficiency stress to severely reduce their grain yield. However in this area of the prairies, GPC above the threshold limit does not necessarily indicate sufficiency of N supply. Commonly, grain yields in the Brown soil zone are limited by water stress. Under these conditions grain yield and GPC are negatively correlated, and the observed high GPC may be the result of abnormally low grain yields due to water stress.

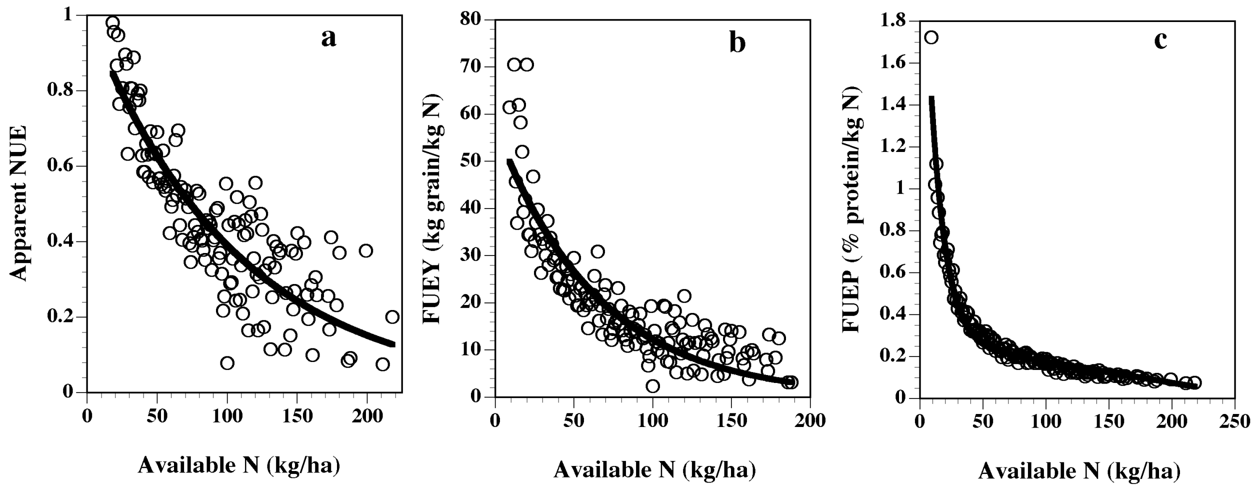


**Figure 3**. Effect of fertilizer N on apparent fertilizer N use efficiency (NUE) (a), effect of available N (fertilizer + soil N) on grain produced per unit N (FUEY) (b), and effect of available N on protein produced per unit N (FUEP) (c).

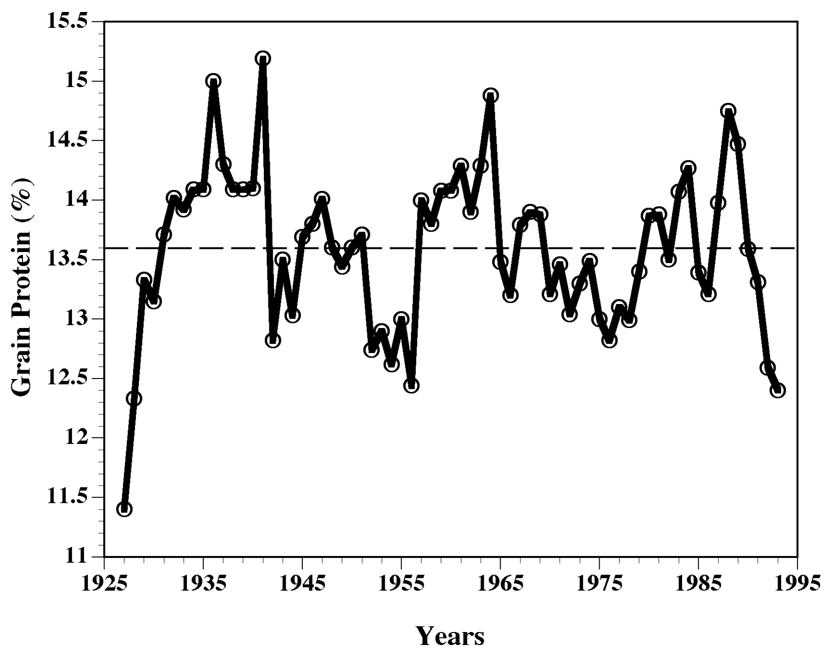


**Figure 4**. Average protein content of spring wheat produced in western Canada (data from Canadian Grain Commission).

Response to N applied at seeding.

Data from a multi-year (1998 to 2000), multi-site fertilization study revealed that wheat responded with yield and protein increases to N applied at seeding, under both stubble and fallow cropping. Wheat grown on fallow increased grain yields in response to N fertilization until 75 kg N/ha was applied; higher rates of N application failed to produce further yield increases (Table

1). Protein concentration responded nearly linearly with fertilizer rate from 11.5% for the unfertilized crop to 14.3% when 125 kg N/ha was applied. Under stubble cropping, grain yields and GPC were lower than under fallow, however, the relative yield increases were much larger under stubble cropping. Grain yields increased with N applications until a maximum was reached when 100 kg N/ha was applied. However, even the yields obtained at the highest application rates were lower than the yields of unfertilized wheat grown on fallow, revealing the limited water and N availability to crops grown on stubble land. Although the GPC of the unfertilized crops were identical in both cropping systems, application of 25 kg N/ha to wheat grown on stubble significantly lowered the GPC of the crop, and it required 75 kg N/ha to increase the GPC above the level of the unfertilized check. It is interesting to note that in both cropping systems GPC increased to just above 13% at the same N application rate at which the crop achieved its maximum yield.

As grain yield and GPC increased in response to higher fertilization rates, the efficiency of conversion of fertilizer into grain and protein decreased substantially (Table 1). Under fallow cropping, for example, the crop produced 69 kg of grain for each kg of N in the soil, but as fertilization was increased, the crop produced much less grain per unit of available N (soil + fertilizer N). A similar pattern was observed for GPC. Under stubble cropping with no fertilization, the N conversion efficiency of the crop was significantly ($P \leq 0.05$) higher than that of the fallow seeded crop, but as fertilizer rates were increased, the conversion efficiency decreased much faster than under fallow cropping, perhaps reflecting lower water availability under stubble cropping.

**Table 1**. Grain and protein responses, grain and protein produced per unit N, and fertilizer use efficiency of N applied at seeding.

| **Cropping System** | **Fertilizer N** | **Yield** | **Grain N[1]** | **Protein** | **NUEY[2]** | **NUEP[3]** |
|---|---|---|---|---|---|---|
| | -------------- (kg/ha) | | ----------------- | (%) | (kg grain /kg N) | (%Prot/kg N) |
| Fallow | 0 | 2801$^{f}$ | 57$^{g}$ | 11.5$^{b}$ | 69$^{h}$ | 0.29$^{g}$ |
| | 25 | 3079$^{g}$ | 66$^{g}$ | 12.1$^{c}$ | 46$^{g}$ | 0.18$^{e}$ |
| | 50 | 3285$^{h}$ | 73$^{h}$ | 12.5$^{d}$ | 36$^{e}$ | 0.14$^{d}$ |
| | 75 | 3415$^{j}$ | 79$^{i}$ | 13.2$^{e}$ | 29$^{d}$ | 0.11$^{i}$ |
| | 100 | 3495$^{j}$ | 85$^{j}$ | 13.8$^{f}$ | 25$^{c}$ | 0.10$^{b}$ |
| | 125 | 3510$^{j}$ | 88$^{k}$ | 14.3$^{g}$ | 21$^{b}$ | 0.09$^{a}$ |
| | Mean | 3264 | 75 | 12.9 | 37 | 0.15 |
| Stubble | 0 | 1178$^{a}$ | 23$^{a}$ | 11.5$^{b}$ | 88$^{i}$ | 0.95$^{h}$ |
| | 25 | 1636$^{b}$ | 32$^{b}$ | 11.2$^{a}$ | 42$^{f}$ | 0.30$^{f}$ |
| | 50 | 1924$^{c}$ | 38$^{c}$ | 11.6$^{b}$ | 30$^{d}$ | 0.19$^{e}$ |
| | 75 | 2147$^{d}$ | 45$^{d}$ | 12.5$^{d}$ | 24$^{c}$ | 0.14$^{d}$ |
| | 100 | 2318$^{e}$ | 52$^{e}$ | 13.2$^{e}$ | 20$^{2}$ | 0.12$^{c}$ |
| | 125 | 2375$^{e}$ | 54$^{e}$ | 13.7$^{f}$ | 17$^{a}$ | 0.10$^{b}$ |
| | Mean | 1930 | 41 | 12.3 | 37 | 0.30 |

1 N removed with grain.
2 Nitrogen efficiency with respect to grain produced (amount of grain produced per unit N).
3 Nitrogen efficiency with respect to protein produced (% protein produced per unit N).

This information shows that trying to achieve the highest GPC possible by increasing the rate of N fertilizer applied at seeding may not be practical or economical. As fertilization rates are increased, the fertilizer is used less efficiently, and at higher GPC levels the increase in GPC per unit N added to the crop becomes progressively smaller.

Split N applications

Maximum yield of spring wheat is normally achieved by applying all of the N fertilizer at or near seeding (Stark and Tindall 1992). However, a number of studies indicate that with this practice, grain yield and protein are inversely related (Langer and Liew 1973). This will lead to the usual production of high yield, low protein wheat in moist cool years; and low yield, high protein wheat in dry hot years.

Under irrigation, or in moist to wet rain fed areas, split N applications have proven effective in raising GPC of wheat (Finney at al. 1957, Stark and Tindall 1992, Tindall et al. 1995). With split N applications, a fraction of the crop N requirement is applied at or near seeding and the remainder is applied later during the growth period of the crop. In general, N applied early in the life cycle of the crop improves plant growth and grain yield. Nitrogen applied at later growth stages tends to influence protein more than grain yield (Terman et al. 1969, Oscarson et al.1995). Under dryland conditions, especially in semiarid areas, split N application is not a common practice for spring seeded cereals. The success of topdressing N as a tool to manage yield and GPC in these areas depends, largely, on adequate moisture conditions at the soil surface and on the occurrence of rains soon after topdressing. Water is required to move the fertilizer into the soil where it can be absorbed by the crop roots and to reduce N losses.

To determine the feasibility of topdressing N under dryland farming conditions, SPARC initiated a multi-site multi-year field experiment in 1996. This article reviews the most important findings from the first three years of this study.

The study was conducted under fallow and stubble conditions in soils of light, medium, and heavy texture. A single variety of CWRS wheat (Lancer in 1996 and 1997, AC Eatonia in 1998) was grown with various rates on N fertilizer applied at seeding (0, 20, 40, and 60 kg N/ha for fallow, or 20, 40, 60, and 80 kg N/ha for stubble cropping). Superimposed on these treatments, the crop was topdressed with 10 or 20 kg N/ha as 28-0-0 dribble banded (L10DB and L20DB) or as 46-0-0 broadcast (U10BC and U20BC), or 5 kg N/ha as 28-0-0 applied to the crop foliage (L5FS). The topdressing treatments were applied 5-leaf, flag leaf, and anthesis. An extra set of plots did not receive topdressing treatment (CK). All treatments received a blanket application of 25 kg $P_2O_5$/ha and 20 kg S/ha to ensure that the crop would not be deficient in these nutrients.

For the foliar application of 5 kg N/ha, 28-0-0 was diluted 6 times (i.e., one volume of product plus 5 volumes of water) to bring the concentration of N down to 6% from 36% in the fertilizer. Application was done with a field sprayer equipped with stainless steel 80° flat fan extended range 015 size spray tips, calibrated to deliver 84 L/ha (7.5 gal/ac).

The effects of topdressed N were highly variable from year to year and from site to site. This reflects the high dependency of the response to topdressing on weather events. Since the study provided a large number of observations (1944 experimental plots per year), we determined the probability of obtaining a yield increase or a GPC increase larger than a given threshold. The threshold for yield increase was 65 kg/ha, and for protein increase the threshold was 0.2% protein.

Results are expressed as the probability of obtaining a yield increase (PYI) or the probability of obtaining a protein increase (PPI), along with the mean yield and protein increases for the treatments that responded to topdressing. We also calculated the probability of obtaining a protein price premium as a result of topdressing (PCP). This last variable was calculated using Canadian Wheat Board's 1999-2000 protein price schedule for #1 CWRS. For example, the probability of obtaining a yield increase larger than 65 kg/ha when N was applied as a topdress at the 5-leaf stage is 61% (or 6.1 times out of 10). Similarly, the probability of obtaining a protein increase of more than 0.2% protein by topdressing at the 5-leaf stage was 47%, while the probability of capturing a protein price premium is 39%.

## Effect of cropping system

On average, yield and protein increases due to topdressing were 502 kg/ha and 1.28 GPC units, respectively, while the overall PYI was 53% and PPI was 54% (Table 2). However, PCP was only 34%. The responses to topdressed N in terms of protein and yield increase were significantly ($P \leq 0.05$) higher under fallow- than under stubble-cropping (Table 2). The PYI was the same for both cropping situations, but PPI was much higher under stubble (58%) than under fallow (49%). However, because a larger proportion of the protein increases for stubble were well below the 12% threshold level for a price premium, the PCP was significantly lower ($P \leq 0.05$) for wheat grown on stubble (29%) than for wheat grown on fallow (38%).

The difference in responses between both cropping systems probably reflects the fact that plant growth under stubble is often more limited by low N availability than when grown under fallow. Consequently, small additions of N to crops grown on stubble will produce proportionally larger yield increases that will tend to dilute protein increases.

**Table 2**. Effect of cropping system and time of topdressing on yield and protein increases, and probabilities of achieving the increases and cashing on protein premiums.

| Cropping system | Time of topdressing | Yield | | Protein | | |
|---|---|---|---|---|---|---|
| | | Increase | Probability of achieving increase | Increase | Probability: achieving increase | Probability: capturing premium |
| | | (kg/ha) | (%) | (% protein) | --------- (%) --------- | |
| **Fallow** | 5-Leaf | 610[d] | 61[c] | 1.22[ab] | 47[a] | 39[b] |
| | Flag-Leaf | 525[c] | 58[bc] | 1.55[c] | 52[a] | 34[b] |
| | Anthesis | 468[b] | 39[a] | 1.21[ab] | 48[a] | 37[b] |
| | Mean | 535 | 53 | 1.33 | 49 | 37 |
| **Stubble** | 5-Leaf | 484[bc] | 44[a] | 1.33[b] | 62[b] | 28[a] |
| | Flag-Leaf | 341[a] | 59[c] | 1.12[a] | 63[b] | 30[a] |
| | Anthesis | 579[d] | 53[ab] | 1.24[ab] | 49[a] | 26[a] |
| | Mean | 468 | 52 | 1.23 | 58 | 29 |

## Effect of time of topdressing

Under fallow cropping, delaying topdressing until anthesis significantly ($P \leq 0.05$) reduced the yield increases and probability of achieving them (Table 2). Protein increases were larger when the N fertilizer was topdressed at flag-leaf, where it reached its maximum. When topdressing at 5-leaf and anthesis, the increases were similar, but smaller than at flag leaf ($P \leq 0.05$). In spite of the changes in protein response, the PPI remained unchanged throughout the range of application times. Nevertheless, the PCP was highest when the topdressing occurred at the 5-leaf stage, and was significantly ($P \leq 0.05$) lower when it occurred later in the growing season. These results are similar to those reported in other studies (Terman et al. 1969); but in our study protein increases with late N applications were smaller. In southwestern Saskatchewan, by the time the crop reaches the flowering stage, the soil surface is often dry, and the frequency of rains and rain showers decrease towards the end of July.

Under stubble cropping, the responses to time of topdressing were different than those observed for fallow cropping. Larger yield increases were obtained with late topdressing, whereas largest protein increases were observed with early and late topdressing (Table 2). The probability of increasing yield was highest when the topdressing was done at flag leaf, and intermediate to low at anthesis and 5-leaf. Topdressing a stubble seeded crop at 5-leaf or flag leaf produced probabilities of increasing protein significantly higher than when at anthesis, or when topdressing wheat grown on fallow. Under stubble, a substantial portion of the protein increases happened at protein levels well below the protein price premium band. Thus, the PCP was not affected by time of topdressing, and these were significantly lower ($P \leq 0.05$) than for fallow cropping (Table 2).

These results suggest that under fallow cropping, the optimum time of topdressing for maximum yield and protein increase is when the crop is between the 5-leaf and flag-leaf stage. Under stubble cropping, the situation is not a clear, probably because of the higher nutrient and water stress, but it appears that a slightly later application may be more successful than a late application on fallow.

## Effect of method of topdressing

Under fallow cropping, all topdressing methods produced similar effects on protein and yield increases (Table 3). The exception was L20DB, which had lower ($P \leq 0.05$) yield increases than other methods. This treatment tended to produce substantial leaf burning in the crop, which may have lowered its relative effectiveness. The PYI and PPI were not affected by topdressing method. However, the PCP was significantly higher ($P \leq 0.05$) for topdressing methods that applied 20 kg N/ha, regardless of N source.

Under stubble cropping, dribble banding liquid N on the soil surface produced yield increases that were comparable to those observed under fallow, and were significantly higher ($P \leq 0.05$) than those obtained with foliar N application or by broadcasting granular urea. It appears that with the dry soil surface conditions under stubble, a larger proportion of N in the liquid fertilizer form was able to reach the crop roots than when granular fertilizer was used. However, the PYI was not affected by topdressing method. The PPI was much higher ($P \leq 0.05$) for the application of 20 kg N/ha to the soil, regardless of source, than for other methods. Topdressing by applying N to the soil had no effect on PCP, but foliar application significantly reduced ($P \leq 0.05$) PCP. This may be related to the substantially lower protein increases obtained with this method (0.2 to 0.3 units of GPC less) than with methods that rely on soil application.

**Table 3**. Effect of topdressing method on yield and protein increases, and probabilities of achieving the increases and cashing-in on protein premiums.

| **Cropping system** | **Topdressing method** | **Yield** | | *Protein* | | |
|---|---|---|---|---|---|---|
| | | *Increase* | **Probability of achieving increase** | **Increase** | **Probability** achieving increase | **Probability** capturing premium |
| | | (kg/ha) | (%) | (% protein) | --------- (%) --------- | |
| Fallow | L5FS | $574^{c}$ | $55^{ab}$ | $1.28^{bc}$ | $48^{ab}$ | $35^{c}$ |
| | L10DB | $555^{c}$ | $56^{b}$ | $1.39^{c}$ | $41^{a}$ | $30^{bc}$ |
| | L20DB | $456^{b}$ | $49^{a}$ | $1.40^{c}$ | $54^{b}$ | $41^{d}$ |
| | G10BR | $559^{c}$ | $52^{ab}$ | $1.27^{bc}$ | $45^{a}$ | $34^{c}$ |
| | G20BR | $527^{cb}$ | $54^{ab}$ | $1.28^{bc}$ | $56^{c}$ | $42^{d}$ |
| Stubble | 5-FSP | $406^{a}$ | $52^{ab}$ | $1.02^{a}$ | $49^{bc}$ | $19^{a}$ |
| | L10DB | $524^{cb}$ | $51^{ab}$ | $1.36^{b}$ | $62^{d}$ | $28^{b}$ |
| | L20DB | $537^{c}$ | $56^{b}$ | $1.20^{b}$ | $65^{d}$ | $33^{bc}$ |
| | G10BR | $430^{a}$ | $57^{b}$ | $1.28^{bc}$ | $55^{b}$ | $30^{bc}$ |
| | G20BR | $444^{a}$ | $48^{a}$ | $1.3^{bc}$ | $61^{d}$ | $31^{bc}$ |

## Effect of N applied at seeding

In general under fallow cropping, the amount of N applied at seeding had little effect on the magnitude of the yield increases, PYI, or PPI (Table 4). The largest yield increase was achieved when 60 kg N/ha was applied at seeding. Protein increases, however, were significantly smaller in the crop fertilized at seeding with 40 kg N/ha, or more. The PCP was significantly lower ($P \leq 0.05$) when the crop was fertilized at seeding with 60 kg N/ha than with the lower N rates.

Under stubble cropping, yield increases of the crop fertilized at seeding with 80 kg N/ha were as large as those obtained under fallow, and were significantly higher ($P \leq 0.05$) than those obtained with lower rates of N applied at seeding. Neither PYI, PPI, nor PCP were affected by rate of N applied at seeding.

These results suggest that part of the effect of topdressing may be related to the amounts of N available in the soil. Top dressing apparently produces a boost in crop growth that stimulates root growth and activity. Thus, topdressed crops would be able to explore a larger volume of soil, and would be able to absorb more nutrients than the crop fertilized only at time of seeding.
Effect of environment on yield and protein increases

Environmental conditions affect the magnitude of yield and protein increases in response to topdressing N, as well as the probabilities (or chances) of achieving them. In general, we have observed that the probabilities of achieving increases are mainly a function of timing, duration and intensity of water stress events during the growing season, and levels of N available to the crop.

**Table 4**. Effect of rates of N applied at seeding on yield and protein increases, and probabilities of achieving the increases and cashing on protein premiums.

| Cropping system | Seeding N (kg/ha) | Yield | | *Protein* | | |
|---|---|---|---|---|---|---|
| | | Increase | Probability of achieving increase | Increase | *Probability* achieving increase | *Probability* capturing premium |
| | | (kg/ha) | (%) | (% protein) | --------- (%) | --------- |
| Fallow | 0 | 600[de] | 43[c] | 1.72[b] | 43[ab] | 41[b] |
| | 20 | 595[bcd] | 39[abc] | 1.62[b] | 43[ab] | 40[b] |
| | 40 | 599[bcd] | 40[bc] | 1.46[a] | 38[a] | 37[b] |
| | 60 | 692[e] | 40[bc] | 1.49[a] | 39[a] | 29[a] |
| Stubble | 0 | 535[ab] | 36[ab] | 1.47[a] | 49[b] | 30[a] |
| | 20 | 563[ab] | 34[a] | 1.49[a] | 49[b] | 26[a] |
| | 40 | 524[a] | 34[a] | 1.41[a] | 47[b] | 28[a] |
| | 60 | 558[abc] | 37[ab] | 1.35[a] | 49[b] | 30[a] |
| | 80 | 620[cd] | 34[a] | 1.37[a] | 44[ab] | 27[a] |

Conceptually, we can state that under conditions of moderate to severe water stress, PYI and PPI are relatively independent of the amount of N available to the crop (Fig. 5). Under moist to wet conditions, the PYI increases sharply at low N availability levels, but decreases as N availability to the crop improves, and the drop in PYI is higher for high- than for moderate-moisture conditions. Similarly, the probability of achieving a protein increase is highest at low N supply and, at this point, there is little difference across moisture regimes. However, under moist to wet conditions, PPI decreases as N availability becomes more plentiful. The drop in PPI with N availability is proportional to the amount of available water.

Moisture and N availability also affect the size of the protein and yield increases. On stubble, the size of the yield and protein increases were often not greatly affected by the availability of N, while increases in water available to the crop resulted in larger yield increases, but did not influence the magnitude of protein increases. Under fallow, however, topdressing at low available N produced relatively large protein and yield increases, which became progressively smaller as the N supply to the crop improved. These results are in agreement with those of previous studies that demonstrated that the size of protein increases from topdressing wheat grown under irrigation were inversely proportional to the N status of the crop (Tindall and Stark 1995).

Under conditions of high N and water supply, the crop has a high yield potential. Additional N supplied by topdressing will have little effect on yield and protein of the crop. However, under low N supply, crop growth and yield are limited, and any increase in N supply will promote crop growth and yield, especially under conditions of high water availability. Under these conditions of plentiful moisture, PPI remains largely unchanged, and may even decrease, mainly because of the inverse yield/protein relationship.

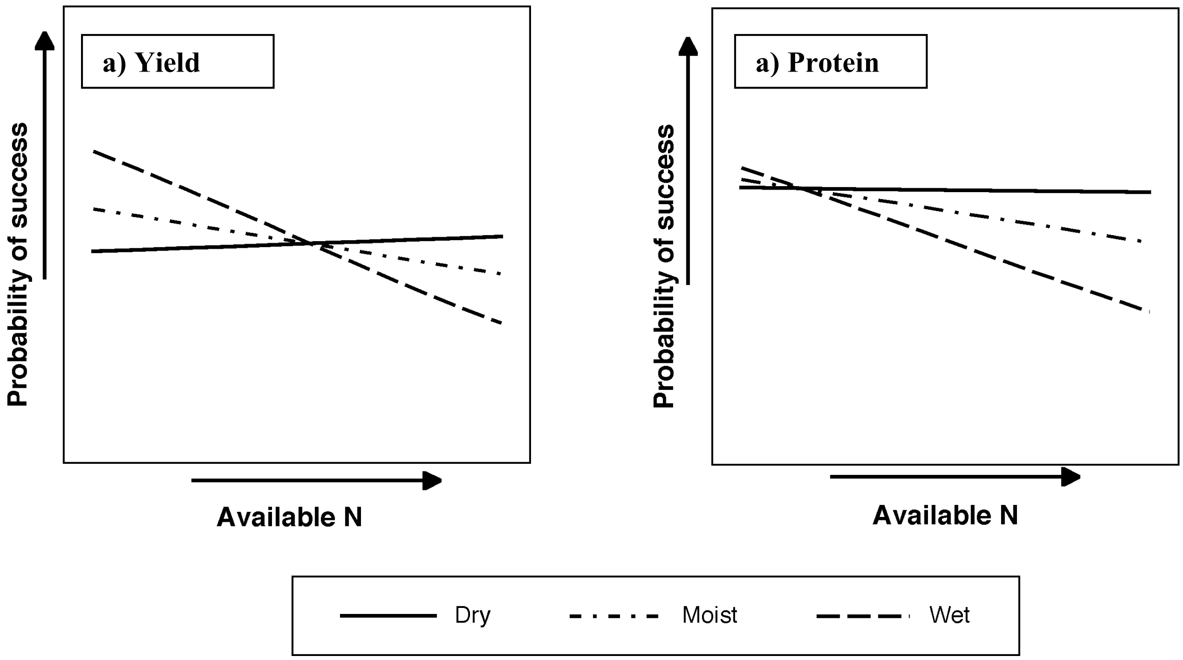


Figure 5. Idealized effects of available N on the probability of achieving a) yield increases and b) protein increases with topdressed N applications at various moisture levels

## CONCLUSIONS

Results from our study suggest that topdressing N fertilizer can be an effective tool to manage yield and protein of wheat grown under dryland conditions in southwestern Saskatchewan. However, producers must be aware that depending on growing season conditions there is not a 100% probability of success with this technology.

Topdressing under dryland conditions is best done between 5-leaf and flag-leaf stages of growth, as at later stages, topdressing tends to be less effective. After the crop has reached flag-leaf, the weather normally becomes hotter and drier, thus reducing the probability of success with topdressing.

Normally, fertilization according to soil test recommendations provides the best return from the investment in fertilizer. Current recommendations for N fertilization provide producers with a choice of N levels to apply, according to probable levels of water availability. One problem with this method is deciding whether to fertilizer for a dry, medium or moist growing season, based on growing season weather projections and soil water reserves. With topdressing, producers may consider applying the recommended rate for medium to dry conditions at seeding and, if moisture conditions improve or change as the growing season progresses, decide to apply extra N by topdressing. Approaching fertilization in this fashion will allow producers to reduce the risk of not maximizing the return on fertilizer expenditure if conditions during the growing season become drier than expected. Further, if moisture conditions improve, topdressing the crop would allow producers to apply extra N to capitalize on improved yield potential of the crop. In addition, topdressing will help to maintain GPC at higher levels than if all N requirements had been supplied with fertilization at seeding.

Finally, producers must be aware that in order to cash in on the protein price premiums, their grain must make the grades for which protein premiums are paid, be successful in increasing GPC with fertilization, and that the GPC increases occur within the protein band for which premiums are paid. Protein premiums should be considered a bonus rather than an overall target for fertilizer management.

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