Effect of Nitrogen Fertilization Practices on Spring Wheat Protein Content

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Abstract/Summary of Results and Conclusions:

Field trials were conducted in the San Joaquin Valley and Intermountain areas to determine the effect of nitrogen fertilization practices on the yield and protein content of different wheat cultivars. The wheat cultivar grown and the nitrogen fertilization program had a significant impact on both wheat yield and grain protein content. Topdress N applications increased protein contents markedly; over a 4 percentage point increase in protein content was observed at one site. The optimum fertilization rate varied by site depending on the initial preplant soil nitrate level as well as the yield potential of the site. A higher N rate was needed at Tulelake than at the Scott Valley or San Joaquin Valley sites. Maximum yield may have been limited due to planting conditions at one site and irrigation at another site. However, even with these possible yield limitations, results at all sites demonstrated that a preplant nitrogen application alone at the rate tested (120 pounds of N per acre) was insufficient to attain acceptable protein levels for the two wheat production areas and their respective markets (California and PNW). It has been a common fertilizer program for many growers, particularly in the intermountain area, to only apply a preplant nitrogen application. These data demonstrate that additional topdress N applications are needed to obtain the required protein level to avoid dockage. It did not appear that an anthesis application timing was critical. Earlier applications increased protein content to acceptable levels as well provided application rates were appropriate for the yield potential. Initial results were variable but suggest that foliar nitrogen applications at the flag leaf stage or anthesis show potential for increasing protein content but that the higher rates (at least 9 lbs N/acre) were needed. Additional studies are needed to more precisely quantify the nitrogen rate and timing required for different wheat cultivars and areas with different yield potential. Diagnostic tools that can be used during the production season are needed so that growers can better predict the need for late-season N to maximize yield and achieve protein goals.

Introduction and Objectives

Protein content is a significant issue for wheat producers throughout California—nearly as important as yield. The price that a producer receives for hard spring wheat is determined by the grain protein content with a discount for wheat with less than 13% grain protein in California and usually 14% for grain marketed in the Pacific Northwest. This has significant economic consequences for wheat producers. The primary production factors that affect protein content are cultivar selection and nitrogen fertility management. Unfortunately, yield and protein content are often inversely related and is difficult to achieve both.

Nitrogen fertilization practices have a profound effect on both yield and grain protein. A general guideline is to apply at least one-half to two-thirds of the total nitrogen fertilizer preplant to establish a vigorous crop with maximum yield potential. Late-season N applications, between boot and flowering, increase grain protein with little effect on yield. Sometimes growers over-apply N to achieve both yield and protein goals in fewer applications but this can lead to inefficient fertilizer use, reduced profitability and can have unwanted environmental consequences such as excessive nitrate leaching.

Late-season nitrogen applications to spring wheat have not been common in the Intermountain Region. However, the practice is gaining in popularity based partially on some initial research conducted last year. Many growers plant Yecora Rojo (generally a lower yielding variety) because it usually has a higher protein content than many of the newer varieties. Research is needed to determine the optimum fertilization rate and timing to maximize yield and protein for newer wheat varieties compared with the older standard Yecora Rojo.

With the high cost of fertilizers and their application, growers need to maximize N use-efficiency while at the same time minimize the number of fertilizer applications. There is interest in controlled- and slow-release N fertilizers that provide more gradual N release potentially reducing nitrogen losses and extending the availability of N to plants. Their potential use for small grain production deserves further attention.

The objectives of this research were to:

1. Compare the protein content of popular hard red or white spring wheats
2. Assess the effectiveness of late-season N applications to increase protein in different spring wheat varieties
3. Evaluate controlled- and slow-release N fertilizers for improving both grain yield and protein.

Materials and Methods:

There were two components to this research. The first was to evaluate the effect of different cultivars and nitrogen regime on yield, protein and bushel weight. Trials were conducted at three locations in California, representing distinct climatic conditions. One trial was conducted in the Central Valley at the West Side Research and Extension Center (WSREC) in Fresno County. Preplant soil nitrate nitrogen level at this site was 15 ppm. Two trials were conducted in the Intermountain region, one with a grower cooperator at a slightly warmer lower elevation area (Scott Valley) and a second in the Klamath Basin at the Intermountain Research and Extension Center (IREC) in Tulelake. Preplant soil nitrate nitrogen levels were 7 and 6 ppm for the Scott Valley and IREC sites, respectively. An additional study was conducted at IREC to evaluate late-season nitrogen application timing and fertilizer source. Preplant soil nitrate nitrogen in this field was 8 ppm.

Cultivar and Nitrogen Regime Studies. A factorial experimental design was used to evaluate the effect of wheat cultivar and nitrogen treatment on grain yield, protein and bushel weight. The wheat cultivars evaluated at WSREC were Redwing, Blanca Grande 515 and Summit 515. There were five nitrogen treatments. The nitrogen treatments are described in Table 1. In the Intermountain study four cultivars were evaluated—Yecora Rojo, Hank, Fusion and Malbec. In the Intermountain studies, seven nitrogen treatments/strategies were evaluated including the five in the WSREC study plus an untreated control and a treatment where nitrogen was applied preplant, at tillering and again at flowering. Urea was the nitrogen fertilizer source used for all applications. The fertilizer was broadcast using a hand spreader and irrigated in within one or two days after application.

Table 1. Nitrogen treatments evaluated in WSREC study (Fresno County).

1. 120 Pre-plant **(Total N 120 lbs)**
2. 120 Pre-plant + 30 lbs Flowering **(Total N 150 lbs)**
3. 120 Pre-plant + 50 lbs Tillering **(Total N 170 lbs)**
4. 120 Pre-plant + 50 lbs Tillering + 30 lbs Boot **(Total N 200 lbs)**
5. 120 Pre-plant + 50 lbs Tillering + 30 lbs Boot + 30 lbs Flowering **(Total N 230 lbs)**

Table 2. Nitrogen treatments evaluated in Scott Valley and IREC study (Siskiyou County).

1. Control – **(unfertilized)**
2. 120 Pre-plant **(Total N 120 lbs)**
3. 120 Pre-plant + 30 lbs Flowering **(Total N 150 lbs)**
4. 120 Pre-plant + 50 lbs Tillering **(Total N 170 lbs)**
5. 120 Pre-plant + 50 lbs Tillering + 30 lbs Boot **(Total N 200 lbs)**
6. 120 Pre-plant + 50 lbs Tillering + 30 lbs Flowering **(Total N 200 lbs)**
7. 120 Pre-plant + 50 lbs Tillering + 30 lbs Boot + 30 lbs Flowering **(Total N 230 lbs)**

Late-Season Nitrogen Application Timing and Fertilizer Source. A single trial was conducted at IREC. All plots received 92 pounds per acre of N preplant as urea. An additional 50 pounds per acre were applied as UN-32 through the sprinkler system at tillering. Then the fertilizers listed in Table 3 were applied. They were applied at the flag leaf stage and then to another set of plots at anthesis. NDemand and CoRoN are foliar nitrogen products marketed by Wilbur Ellis and Helena, respectively. Plots were harvested on September 19, 2011.

Table 3. Nitrogen source treatments applied at flag leaf and anthesis at IREC (Siskiyou County).

Fertilizer Source	**Lbs N/acre**
Urea	30
Urea + Agrotain	30
N-Demand	3
N-Demand	9
CoRoN	3
CoRoN	9
UN-32	3
UN-32	9
UN-32	30

All plots were harvested with a small-plot combine. Research plots at WSREC were 5 feet wide by 20 feet long and the entire plot was harvested. The plots in Scott Valley and at IREC were planted with a commercial drill and were 10 feet wide to allow for a buffer between plots. The center 5 feet of the plots was harvested. A randomized complete block with a split plot arrangement was used. The main plot was the wheat cultivar and the subplot was the nitrogen fertilization regime.

Results (present the results of the experiments conducted for each project objective; include figures and tables if needed for illustration purposes and clarity):

Cultivar and Nitrogen Regime Studies. The three varieties evaluated at WSREC yielded similarly but averaged across nitrogen treatments the hard red spring varieties Redwing and Summit tended to yield higher than the hard white variety Blanca Grande (Table 4). The plots at WSREC did not have an untreated check so it is not possible to determine the effect of nitrogen fertilization, only the effect from the different treatment timings and total amount of nitrogen applied. The assumption was that a zero nitrogen treatment was not something a grower would consider; however, an unfertilized check is included in the 2012 San Joaquin Valley study. Overall, there was not a significant consistent effect on yield with the different nitrogen treatments. This may due to the fact that the field had a moderate preplant soil nitrate level (15 ppm) giving the field approximately 45 lbs of N in the soil plus an additional 120 lbs at planting. In addition, the yield potential for this area could be a ton higher than the yield observed in this trial. Perhaps another irrigation was needed to reach full yield potential. Similarly, nitrogen regime did not significantly affect bushel weight.

While the hard white variety tended to have the lowest yield, it had a significantly higher protein content than the hard red spring varieties. Nitrogen fertilization practices significantly affected grain protein content. Applying additional nitrogen (after the initial preplant application) increased protein content for nearly all treatments and for all three varieties. The maximum increase in protein content was 0.6, 0.9 and 0.7 percentage points for Redwing, Blanca Grande 515 and Summit 515, respectively.

Table 4. Effect of nitrogen strategy on plant height, bushel weight, grain protein and yield of three wheat varieties grown at the West Side Research and Extension Center (WSREC).

Redwing (HRS)					
	Total N	Height	Test Wt.	Protein	Yield
Treatments	lbs/A	in.	lbs/bu	%	tons/A
Pre-plant	120	35.3	62	12.0	3.40
Pre-plant + Flowering	150	34.8	62	12.3	3.17
Pre-plant + Tillering	170	34.8	62	12.2	3.22
Pre-plant + Tillering + Boot	200	34.8	63	11.9	3.55
Pre-plant + Tillering + Boot + Flowering	230	34.8	63	12.6	3.24
LSD 0.05		1.08	NS	0.2	0.24
Blanca Grande 515 (HW)					
	Total N	Height	Test Wt.	Protein	Yield
Treatments	lbs/A	in	lbs/bu	%	tons/A
Pre-plant	120	38.5	65	13.1	3.04
Pre-plant + Flowering	150	39.0	64	13.7	3.14
Pre-plant + Tillering	170	38.3	64	13.8	2.87
Pre-plant + Tillering + Boot	200	38.8	64	13.3	3.23
Pre-plant + Tillering + Boot + Flowering	230	39.0	64	14.0	3.22
			NS	0.32	NS
Summit 515 (HRS)					
	Total N	Height	Test Wt.	Protein	Yield
Treatments	lbs/A	in	lbs/bu	%	tons/A
Pre-plant	120	37.5	64	12.5	3.41
Pre-plant + Flowering	150	37.8	64	12.9	3.42
Pre-plant + Tillering	170	37.8	64	13.1	3.33
Pre-plant + Tillering + Boot	200	38.3	63	12.8	3.34
Pre-plant Tillering Boot + Flowering	230	38.0	64	13.2	3.44
			NS	0.22	NS

Grain yields were higher at the IREC site (Tulelake) than at the Scott Valley site. This is commonly observed due to more favorable environmental conditions (cooler summer temperatures and better soil) in Tulelake compared with Scott Valley. In addition, 2011 was a fairly wet spring and it was difficult to find a planting window. The soil was prepared in spring and the wheat planted into moisture. Some of the seeds emerged with soil moisture and others did not emerge until there was subsequent rain. This resulted in staggered emergence which lowered the yield potential of the Scott Valley site.

Nitrogen fertilization had a significant impact on grain yield at both sites. Maximum yield increased from 0.6 to 1.1 tons per acre over the untreated check depending on the variety and fertilizer treatment (Table 5). The yield increase over the unfertilized plots was far greater at the IREC site where yields were nearly doubled (almost 2 tons higher) for many of the varieties (Table 6). Additional applications after the preplant application also increased yield in most cases. At the Scott Valley site the 230 pounds N per acre application did not increase yield over the other fertilization strategies that included a topdress application. However, at IREC maximum yield for all varieties occurred at the 230 pounds per acre application rate where N was applied preplant and top dressed at tillering, boot and flowering growth stages. This is probably due to the higher yield potential at this site and this site had a slightly lower preplant soil nitrate nitrogen level (6 ppm at IREC compared with 8 ppm in Scott Valley).

Averaged over all fertilizer treatments, Yecora Rojo was the lowest yielding variety in Scott Valley and Fuzion and Malbek with the highest (Table 7). In contrast, Hank was the highest yielding variety averaged across fertilizer treatments in Scott Valley.

All test weights were over 61 pounds per bushel or higher. In general, test weights at IREC were slightly higher than at Scott Valley. The variety Hank tended to have lower test weights than the other four varieties at both locations. The control plots tended to have slightly higher test weights than most the fertilized treatments. It is likely that the control plots were so nitrogen deficient that they had fewer tillers, heads and perhaps kernels per head, resulting in a higher test weight. Even though the difference is statistically significant, the numerical difference in test weight between treatments is quite small and all are well above 60 pounds per bushel.

Wheat cultivar and nitrogen fertilizer regime had a significant effect on wheat protein content. Hank had the lowest protein content of the four cultivars at both sites (Table 7). Protein content was much higher at the Scott Valley site than at IREC most likely due to the much higher yield at IREC and the slightly lower initial soil nitrate level. Many of the fertilizer treatments resulted in a protein content above 14 percent (the benchmark value in Pacific Northwest markets) in Scott Valley. In contrast, protein contents below 12 percent were common at IREC for the plots that received the lower N rates and none of the treatments ever reached 14 percent average for the four replications. A large increase in grain protein over the untreated check was observed at both sites. In Scott Valley, protein content increased up to 1.6 to 3.1 percentage points over the unfertilized control plot depending on the variety. It IREC protein content increased nearly 4 percentage points or more comparing the highest rate to the unfertilized control plot. A preplant application alone, common grower practice, was never sufficient to reach acceptable protein levels to avoid a discount at either site. At IREC the highest fertilizer rate (230 pounds N per acre over four applications) always resulted in the numerically highest protein content. In Scott Valley, the numerically highest protein content was also achieved with this highest rate. However, differences in protein content between this rate and lower rates were small and acceptable protein levels were achieved with some of the lower rates. In Scott Valley, any treatments that had 170 pounds of N or more over the season had a protein content over 14, except for the cultivar Hank (Table 5).

Table 5. Effect of nitrogen strategy on yield, protein and bushel weight of four hard red spring wheat varieties grown in the Scott Valley (Siskiyou County).

Treatments	Total N lbs/A	Yield tons/A	Protein (%)	Test Wt. (bu/A)
Yecora Rojo				
Untreated	0	1.80	12.5	63.2
Pre-plant	120	2.47	13.2	62.0
Pre-plant + Flowering	150	2.59	14.9	62.1
Pre-plant + Tillering	170	2.71	15.6	62.1
Pre-plant + Tillering + Boot	200	2.84	14.7	62.2
Pre-plant + Tillering + Flowering	200	2.93	15.3	62.2
Pre-plant + Tillering + Boot + Flowering	230	2.90	15.4	62.0
Hank				
Untreated	0	2.27	12.0	62.7
Pre-plant	120	2.82	12.7	61.2
Pre-plant + Flowering	150	2.96	13.2	61.5
Pre-plant + Tillering	170	2.91	13.2	62.2
Pre-plant + Tillering + Boot	200	2.71	13.5	60.7
Pre-plant + Tillering + Flowering	200	3.16	13.8	61.0
Pre-plant + Tillering + Boot + Flowering	230	2.88	13.9	61.2
Fuzion				
Untreated	0	2.58	12.3	63.7
Pre-plant	120	2.79	13.4	63.2
Pre-plant + Flowering	150	3.09	14.0	62.8
Pre-plant + Tillering	170	3.12	14.9	62.5
Pre-plant + Tillering + Boot	200	3.05	14.6	62.6
Pre-plant + Tillering + Flowering	200	3.09	15.0	62.5
Pre-plant + Tillering + Boot + Flowering	230	3.16	14.1	62.8
Malbek				
Untreated	0	2.66	12.7	63.3
Pre-plant	120	3.26	13.1	63.1
Pre-plant + Flowering	150	3.19	13.2	62.9
Pre-plant + Tillering	170	2.72	14.1	62.4
Pre-plant + Tillering + Boot	200	3.54	13.7	62.6
Pre-plant + Tillering + Flowering	200	3.06	14.0	62.5
Pre-plant + Tillering + Boot + Flowering	230	3.22	14.3	62.4
LSD 0.05		0.38	1.1	1.0

Table 6. Effect of nitrogen strategy on yield, protein and bushel weight of four hard red spring wheat varieties grown at the Intermountain Research and Extension Center (Siskiyou County).

Treatments	Total N (lbs/A)	Yield (tons/A)	Protein (%)	Test Wt. (lbs/bu)
Yecora Rojo				
Untreated	0	2.78	9.2	63.6
Pre-plant	120	3.99	10.0	63.2
Pre-plant + Flowering	150	4.35	10.9	63.1
Pre-plant + Tillering	170	4.19	11.4	62.8
Pre-plant + Tillering + Boot	200	4.32	12.8	62.0
Pre-plant + Tillering + Flowering	200	4.25	12.1	62.8
Pre-plant + Tillering + Boot + Flowering	230	4.47	13.1	62.8
Hank				
Untreated	0	2.50	8.5	62.5
Pre-plant	120	4.34	10.4	62.6
Pre-plant + Flowering	150	4.45	11.0	62.1
Pre-plant + Tillering	170	4.34	11.1	62.6
Pre-plant + Tillering + Boot	200	4.67	11.6	62.5
Pre-plant + Tillering + Flowering	200	4.62	12.0	62.3
Pre-plant + Tillering + Boot + Flowering	230	4.81	12.9	62.3
Fuzion				
Untreated	0	2.31	9.2	63.5
Pre-plant	120	3.96	10.6	63.1
Pre-plant + Flowering	150	4.20	11.3	63.0
Pre-plant + Tillering	170	4.25	12.4	63.3
Pre-plant + Tillering + Boot	200	4.36	12.7	62.9
Pre-plant + Tillering + Flowering	200	4.41	12.3	63.4
Pre-plant + Tillering + Boot + Flowering	230	4.47	13.5	63.1
Malbek				
Untreated	0	2.61	9.3	63.3
Pre-plant	120	4.03	10.7	63.3
Pre-plant + Flowering	150	4.31	11.7	63.3
Pre-plant + Tillering	170	4.23	12.4	63.3
Pre-plant + Tillering + Boot	200	4.33	12.6	62.8
Pre-plant + Tillering + Flowering	200	4.34	12.6	63.0
Pre-plant + Tillering + Boot + Flowering	230	4.43	13.3	63.1
LSD 0.05		0.27	0.5	0.5

Table 7. Effect of wheat cultivar on yield and protein content averaged across all seven nitrogen regimes. Scott Valley and IREC (Siskiyou County).

	Yield (tons/A)		Protein (%)	
Variety	**Scott V.**	**IREC**	**Scott V.**	**IREC**
Yecora Rojo	2.61	4.05	14.50	11.38
Hank	2.82	4.25	13.17	11.09
Fuzion	2.98	3.99	14.04	11.72
Malbek	3.09	4.04	13.59	11.79
LSD 0.05	0.15	0.06	0.70	0.19

Table 8. Effect of nitrogen regime on yield and protein content averaged across all four wheat cultivars. Scott Valley and IREC (Siskiyou County).

	Total N	Yield (tons/A)		Protein (%)	
Treatments	**lbs/A**	**Scott V.**	**IREC**	**Scott V.**	**IREC**
Untreated	0	2.33	2.55	12.4	9.1
Pre-plant	120	2.84	4.08	13.1	10.4
Pre-plant + Flowering	150	2.96	4.33	13.8	11.2
Pre-plant + Tillering	170	2.87	4.25	14.4	11.8
Pre-plant + Tillering + Boot	200	3.03	4.42	14.1	12.5
Pre-plant + Tillering + Flowering	200	3.06	4.40	14.5	12.2
Pre-plant + Tillering + Boot + Flowering	230	3.04	4.54	14.4	13.2
LSD 0.05		0.39	0.29	1.0	0.5

<u>Late-Season Nitrogen Application Timing and Fertilizer Source</u>. The late-season nitrogen applications applied at flag leaf or anthesis growth stages did not affect wheat yield (variety Yecora Rojo) in this trial (Table 9). The trial had already received 142 pounds of N preplant and at tillering before the late-season N treatments were applied. Wheat injury was rated after the nitrogen treatments were applied. Treatments with UN-32 resulted in significant injury, especially when applied at the 9 pound per acre N rate or higher. The injury was necrosis or burn back primarily on the flag leaf. Injury was still evident on the early-treated plots (flag leaf) at the second evaluation (after the second application timing--anthesis). However, the injury was less than that of the plots that were just treated. The other treatments only caused very slight injury; note numerical injury ratings were slightly higher for the higher rate of NDemand or CoRoN. However, while the injury from foliar UN-32 was visually striking, there was not a significant impact on yield.

The late-season N applications increased protein content. The maximum increase was about 0.6 percentage points. The higher rate of NDemand, CoRoN or UN-32 (9 lbs N/acre) seemed to be needed to have much of an impact on protein content. These results are somewhat inconsistent and it is difficult to determine which treatment might be the most cost effective. Additional research, perhaps at a more deficient site, is warranted.

Table 9. Effect of nitrogen source on yield, protein and bushel weight of Yecora Rojo produced at the Intermountain Research and Extension Center (Siskiyou County).

Fertilizer Source	N (lbs/A)	Injury 7/6	Injury 7/26		Yield (tons/A)		Protein (%)	
		Flag	Flag	Anthesis	Flag	Anthesis	Flag	Anthesis
Urea	30	0	7.0	5.0	4.30	4.16	14.0	--*
Urea + Agrotain	30	0	4.5	2.5	4.28	4.14	14.2	13.5
Ndemand	3	0	2.5	3.2	4.25	4.25	13.4	--
Ndemand	9	0	5.0	7.9	4.26	4.16	13.7	13.6
CoRoN	3	0	1.2	5.2	4.26	4.14	13.4	13.4
CoRoN	9	0	1.2	8.9	4.26	4.15	13.8	14.0
UN-32	3	10.8	8.0	21.2	4.20	4.33	13.7	13.7
UN-32	9	27.5	16.2	30.0	4.10	4.22	14.3	13.9
UN-32	30	32.5	19.8	31.2	4.28	4.32	14.2	13.8
Check	--	0	3.2	4.5	4.20	4.24	13.4	13.6
LSD 0.05		1.5	5.5		NS		0.6	

*Questionable data values

Discussion, Conclusions and Recommendations:

These results clearly demonstrate the need for nitrogen fertilizer to achieve acceptable yield and protein content. The nitrogen rate needed for maximum yield and to achieve market protein requirements depends on the yield potential of the field. At the WSREC site in the San Joaquin Valley, nitrogen applications after the initial preplant application had little effect on yield. This was due to the higher preplant N level (15 ppm NO_3-N) at this site and perhaps irrigation limited yield so that the full yield potential for the area was not realized. Nitrogen fertilization had a greater effect on yield in Scott Valley, but the rate of increase diminished at the higher rates. In contrast, yield potential was greatest at Tulelake and this site hads the largest response to applied nitrogen. In fact, we may not have reached maximum potential yield at the Tulelake site.

The wheat cultivar had a significant impact on protein level. These results confirmed prior field experience regarding these cultivars and their protein levels. Nitrogen fertilization also had a significant effect on protein at all sites. A preplant nitrogen application alone at the rate tested

(120 pounds of N per acre) was insufficient to attain acceptable protein levels for the respective markets (California and PNW) for the two wheat production areas. A preplant nitrogen application alone has been a common fertilizer program for many growers, particularly in the intermountain area. These data demonstrate that additional topdress N applications are needed to obtain the required protein level to avoid dockage.

Ideally, it would be desirable to be able to recommend a given variety and nitrogen fertilizer practice that would assure maximum yield at acceptable protein levels for all areas. However, it is difficult to precisely quantify the level of nitrogen fertilizer required and variety performance varies between years, and other agronomic characteristics are important in addition to protein content. Nitrogen fertilizer needs depend on initial residual soil nitrogen levels as well as yield potential. This research does provide some initial guidelines for different areas and yield levels but additional research is needed to confirm these results under different conditions.

This research clearly demonstrates the need for diagnostic tools to be used during the production season to ascertain if more mid-season N is needed to maximize yield and achieve protein goals. Foliar nitrogen applications show some promise and may be effective for a final late season N application for protein goals. However, the data was variable and additional research is needed, perhaps at a more N-deficient site. After we have completed the 2012 season trials, we should be able to complete an economic evaluation of the nitrogen strategies using the different yield levels and protein contents at different price levels and protein penalties (and premiums) to determine the profit potential with different nitrogen management strategies.