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Effect of N Fertilizer on Protein Content of Grain, Straw, and Chaff Tissues in Soft White Winter Wheat[1]

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ABSTRACT

Nitrogen management programs of soft white winter wheat (*Triticum aestivum* L.) in semiarid regions are generally based upon soil tests of available water and residual N levels. The purpose of this work was to develop postharvest criteria for N-sufficiency and N-insufficiency based on tissue protein levels as it relates to maximum grain yield in a fallow-wheat rotation. Yield-protein relationships in grain, straw, and chaff tissues were examined in field trials from 4 harvest years on a Walla Walla silt loam (coarse-silty, mixed, mesic, Typic Haploxeroll). Grain protein content was a better postharvest indicator of N sufficiency for maximum grain yield than straw or chaff protein levels. Excessive weed growth confounded this relationship in 1 year. Using a chi-square interaction procedure, a critical level of 8.8% grain protein was determined necessary for N sufficiency in 'Stephens' soft white winter wheat when weed growth was not a management problem. The transition zone between N sufficient and N insufficient responses was between 8.3 and 9.1% grain protein. The amount of relative yield lost to N insufficiency was related to grain protein content. There was a 9.8% yield reduction for each grain protein percentage below 9.1. Critical protein values indicative of N insufficiency could not be determined for straw and chaff tissues. Straw and chaff protein levels greater than 2.6 and 3.5%, respectively, were exclusively associated with N sufficiency.

***Additional index words:* Critical N percentage, N sufficiency, Grain protein, Straw protein, Chaff protein, N response.**

DRYLAND production of soft white winter wheat (*Triticum aestivum* L.) in the Pacific Northwest is limited primarily by water and N availability. In this region, a N fertilizer management model developed by Leggett (6) is utilized in winter wheat production with modifications for regional and cultivar differences (10). The potential yield level is estimated by the amount of available soil water in the spring of the crop year. The amount of N fertilizer required to produce this potential yield is determined from a linear N response function after deducting the amount of residual soil N. Researchers have demonstrated that grain protein levels may serve as a biological index of the available N to moisture status in plants (7,12,13). However, attempts to correlate wheat yield and protein levels have had variable success in the Great Plains (2,4,18). Soil nitrate content and moisture conditions have been identified as major factors affecting this relationship (16). Goos et al. (2) demonstrated that grain crude protein levels in the Great Plains are an effective postharvest indicator of N sufficiency for grain production. However, the level of yield loss due to N deficiency was not related to grain crude protein content. Their N sufficiency critical level was 11.5% grain protein with a transition zone between 11.1 and 12%.

Non-statistical appraisals of N-yield-protein relationships for soft white winter wheat in the Pacific Northwest have suggested that the critical grain protein percentage level indicative of N sufficiency falls within the range of 8.5 to 11.5% (14,15). A protein content of 10% or less is preferred in soft white winter wheat used for pastries (11).

The purpose of this research was twofold: 1) to determine if relationships exist between grain, straw, or chaff protein content and soft white winter wheat grain yield, and 2) to determine if critical values can be constructed for postharvest protein content in grain, straw, and chaff tissues that distinguish between N sufficiency and N insufficiency.

MATERIALS AND METHODS

This study was located in Sherman County in north central Oregon near Moro. The soil was a deep Walla Walla silt loam (coarse-silty, mixed, mesic, Typic Haploxeroll) that will hold approximately 5.6 cm of water in each 30 cm increment. Research plots for crop years 1979 and 1980 were located 7 miles from the Sherman Branch Exp. Stn. (Moro, OR) and at the experiment station in crop years 1982 and 1983.

Crop years 1979/1980. Actual precipitation amounts were altered by the addition and exclusion of precipitation during both the fallow and crop seasons (1977 to 1980). Natural precipitation was augmented in high precipitation treatments during the winter months (November - March) by irrigating with a solid set sprinkler grid on a 3-m square spacing. Water was applied at a rate of approximately 10 mm/h for 2 h. Plastic tarps were used to exclude a portion of the winter precipitation (November - March) from low precipitation treatments in both the fallow and crop seasons. A polyvinylchloride (PVC) support grid was used to hold the tarp above the soil surface in the crop period. Tarps were installed immediately prior to a precipitation event and removed immediately at the conclusion. Two fallow (14-month)-wheat (10-month) rotations were treated in this manner (Table 1). The study area was uniformly cropped in winter wheat prior to imposing the fallow and crop season precipitation levels. A split-plot design was established with four blocks; the main plots were precipitation levels. Prior to seeding, six levels (0, 15, 45, 60, 75, 105 kg N/ha) of liquid N (32-0-0) were injected into the subplots at a 15 cm depth on a 45 cm spacing. 'Stephens' wheat was planted in late September at a seeding rate of 60 seeds/m of row on a 30 cm spacing. A mixture of 2,4-D and bromoxynil was applied in early March to the crop to control the broadleaf weeds. Grassy weeds were not evident. At harvest, the aboveground portion of 4.8 m of row was clipped in each subplot. The plant material was separated into grain, chaff, and stems. Overall grain yield in each plot was determined with a mechanical combine harvesting an area of 4.2 m^2. The straw and chaff samples were ground through a 5 mm screen and analyzed for crude protein percentage using a Kjeldahl N analysis (1). After milling the grain crude protein percentage was determined with a Technicon Infra-Analyzer 400. The Technicon was calibrated for protein content using the micro-Kjeldahl procedure described by Nelson and Summers (9). A correlation coefficient of 0.97 was obtained for the calibrated relationship. The grain yield of wheat was expressed as a percentage of the maximum fertilized grain yield, termed relative grain yield. The average of all yields not significantly different than the highest measured yield within a main block treatment was determined to be the maximum fertilized yield.

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Table 1. Measured levels of received water in fallow and crop periods developed by rainfall exclusion and irrigation for 1977–1979 and 1978–1980.

Treatment	Changes in received water†		Level of water received		
	Fallow (14 month)	Crop (10 month)	Fallow	Crop	Total (24 month)
			mm		
		1977–1979			
1	–	--	306	180	486
2	–	–	371	133	504
3	–	--	371	180	551
4	–	+	371	290	661
5	+	+	488	201	689
Control	--	--	422	180	602
		1978–1980			
6	–	--	237	389	626
7	+	–	301	351	652
8	+	–	301	389	690
9	+	+	301	426	727
10	+	--	418	389	807
Control	--	–	263	389	652
70 year avg			298	247	545

† – water excluded in winter months using portable tarps. + water added in winter months through sprinkler irrigation. -- no change from natural precipitation.

Table 2. Grain yield and protein response to precipitation, N level, and date of planting treatments.

Treat-ment	Parameter measured	Nitrogen fertilizer level 0	15	45	60	75	105	Maximum fertilized yield§
		kg/ha						
1979								
1	RY†	0.84	0.94	0.98a	0.99a	1.00a	1.03a	3120d
	GP‡	9.08	9.20	10.16	10.40	10.92	11.34	
2	RY	0.76	0.80	0.91	1.00a	1.00a	0.99a	3410d
	GP	7.48	8.23	8.99	9.66	9.59	10.86	
3	RY	0.81	0.90	1.02a	0.98a	1.03a	0.97a	3305d
	GP	7.93	8.24	9.69	9.98	9.92	10.93	
4	RY	0.75	0.83	0.91	0.95a	1.04a	0.96a	3885c
	GP	7.06	7.57	8.65	9.28	9.35	10.50	
5	RY	0.76	0.86	0.96a	1.02a	1.01a	1.00a	3550cd
	GP	7.00	7.49	8.47	8.86	9.54	11.24	
Control	RY	0.76	0.79	0.91	1.02a	1.01a	3430d	
	GP	7.68	8.09	9.06	8.97	9.99	10.40	
1980								
6	RY	0.65	0.71	0.90	0.97a	0.98a	1.05a	5300a
	GP	6.90	7.90	8.22	8.30	9.18	9.11	
7	RY	0.59	0.70	0.91	0.91	0.98a	1.02a	5350a
	GP	7.67	7.64	8.28	7.98	8.51	9.05	
8	RY	0.68	0.78	0.88	0.97a	0.99a	1.03a	5290a
	GP	7.09	7.80	8.34	9.30	9.14	9.54	
9	RY	0.70	0.75	0.96a	1.00a	1.00a	1.01a	5340a
	GP	7.07	7.89	9.09	9.23	9.56	9.46	
10	RY	0.67	0.76	0.98a	0.99a	0.99a	1.04a	4790b
	GP	7.43	6.85	8.88	8.38	8.30	9.62	
Control	RY	0.74	0.76	0.88	0.96a	1.00a	1.04a	5200ab
	GP	7.05	7.05	8.68	8.68	8.80	9.45	
1982								
N	RY	0.66	0.80	0.90	0.98a	1.00a	1.03a	4220c
	GP	5.71	5.80	5.98	6.14	6.39	6.99	
N × Date								
D1	RY	0.88				1.00a		3930c
	GP	6.31				7.91		
D2	RY	0.78				1.00a	3250d	
	GP	8.28				8.89		
1983								
N	GY¶	2250	2720	3440	3710	3990	4340	
	GP	4.44	4.60	4.64	5.51	5.71	6.59	
N × Date								
D1	GY	3590			5250	6430		
	GP	5.33			5.70	6.70		
D2	GY	2170			2340	3570		
	GP	6.39			6.79	6.14		

† Relative yield expressed as a decimal fraction of the maximum fertilized yield. Values followed by "a" are not significantly different than the maximum fertilized yield (P = 0.05).
‡ Grain protein percentage.
§ Mean separation by Duncan's Multiple Range Test (P = 0.05); coefficient of variation = 0.07.
¶ Grain yield (kg/ha).

Crop Years 1982/1983. A date-of-planting N level study was established in a split-plot design with four blocks. Main plots were the normal date of planting (D1, mid-September) and late planting (D2, mid-November). Subplots were N levels (1982: 0 and 80 kg N/ha and 1983: 0, 60, 80 kg N/ha). Ammonium nitrate (33.5-0-0) was broadcast immediately prior to planting. 'Stephens' wheat was seeded at a rate of 60 seeds/m of row on a 30 cm spacing, and the fertilizer was incorporated at planting. A mixture of Metribuzin, 2,4-D, and bromoxynil was applied as a broadleaf and grassy weed control measure in late March. Broadleaf weeds were controlled; however, grassy weeds presented a problem in D1 in 1982. The dry weight of weeds was collected randomly from 1 m of row in a non-harvested portion of each plot every 2 weeks beginning in May and ending at harvest for D1. Incomplete weed control in D2 was controlled by hand weeding. Weed growth was too great for hand weeding to be feasible in D1. In 1983 a mixture of 2,4-D and bromoxynil was applied in late March. Weed control was effective.

An additional N level study (0, 20, 40, 60, 80, and 100 kg N/ha) was established in a randomized block design with four blocks. Ammonium nitrate was applied immediately prior to seedings. 'Stephens' wheat was seeded in mid-September at a rate of 60 seeds/m of row on a 30 cm spacing, and the fertilizer was incorporated at planting. Herbicide application was the same as for D1 and D2. Weed growth was not measured but was assumed to be similar to that of the normal date of planting, D1, in the 1982 date of planting trial.

Straw and chaff production and crude protein levels were not measured in the 1982 and 1983 studies. Overall grain yield in each plot was determined with a mechanical combine harvesting an area of 4.2 m^2.

For each year individual field studies were statistically analyzed for grain yield response based upon the statistical design of the field plots. Maximum grain yield levels across all years were analyzed in a randomized complete block design. The relative grain yield-grain/straw/chaff protein relationship was analyzed by the adjusted chi-square method of Steel and Torrie (17) to establish critical levels and transition zones.

RESULTS AND DISCUSSION

The relative and maximum grain yield levels and grain protein content are presented in Table 2. The approach of water addition and exclusion to create diversity in grain yield levels was effective in 1979 and 1980 (Table 1). A wide range of significantly different maximum grain yield levels were observed during the study due to the overall yield differences between years (Table 2). Treatment × N level interactions on grain yield were not significant within years.

The correlation between relative grain yield and grain protein content when N was insufficient was significant for the complete data set (r = 0.481, n = 37) (Fig. 1). However, the data from 1979, 1980, and 1982 late date of planting (D2), and 1983 demonstrate a stronger, significant correlation between relative yield and protein content among the N-deficient observations (r = 0.735, n = 33). The low level of protein in the 1982 early date of planting (D1) and N level trial can be attributed in large part to significant weed growth of *Bromus tectorum* (cheatgrass). The precipitation

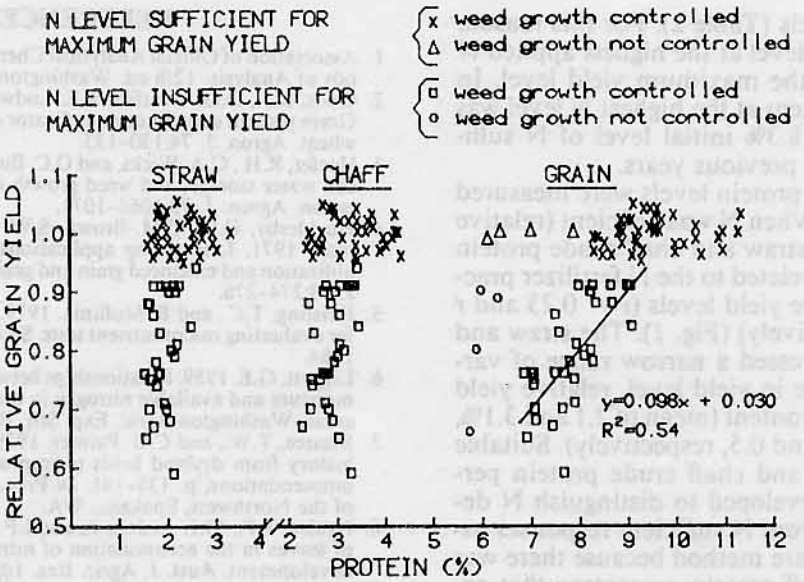

Fig. 1. Relationship between relative yield level and the protein content of straw, chaff, and grain tissues in 'Stephens' soft white winter wheat.

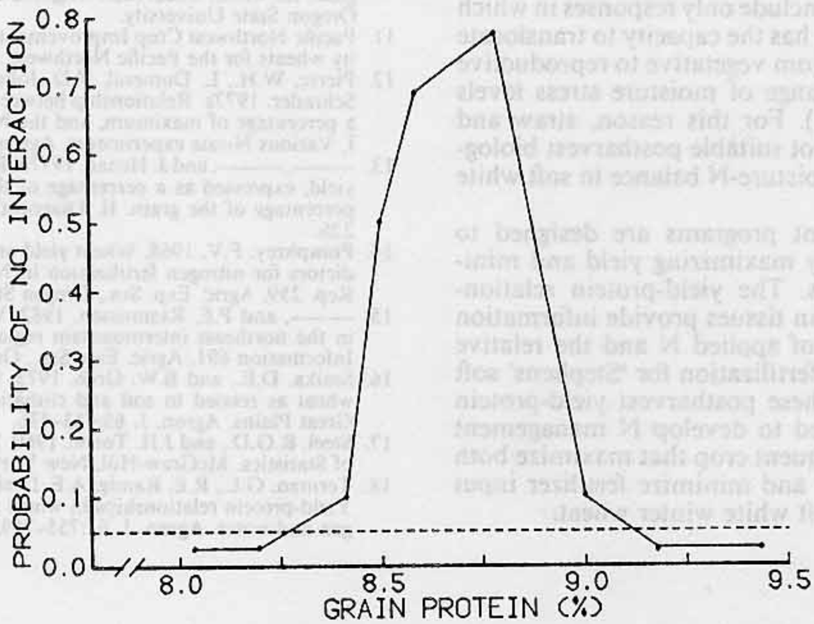

Fig. 2. Relationship between the probability value of the interaction Chi-square and grain protein content.

level in the 1980 to 1982 fallow-crop period (667 mm) was above normal (Table 1). From May through July the 0 and 80 kg N/ha treatments in D1 averaged 9.3 and 46.0 g of weed dry weight/0.3 m^2, respectively. Weed growth was not a problem in the late date of planting in 1982, and in the 1979/1980/1983 trials. Weed growth creates competition for the limiting factors of water and N (3) and reduces the availability of N to the plant. When the data confounded by poor weed control in 1982 are removed from consideration, the regression of grain protein content (X) on relative yield of N deficient observations (Y) indicates that there is a 9.8% yield reduction for each grain protein percentage below 9.1.

The critical percentage of grain protein was determined using the adjusted chi-square method of Steel and Torrie (7). This quantitative methodology can be used to define a critical level and estimate the transitional zone around the critical level (2, 5). When data confounded by weed growth are excluded, the critical protein percentage indicating N sufficiency is 8.8% and the transition zone lies between 8.3 and 9.1% (Fig. 2). The interpretation of this relationship for 'Stephens' in a fallow-crop rotation is that grain protein levels less than 8.3% indicate yield levels were probably reduced by N deficiency; grain protein levels between 8.3 and 9.1% indicate yield levels may or may not have been reduced by N deficiency; grain protein percentages greater than 9.1 indicate yields were probably limited by factors other than N deficiency and more N was applied than needed.

Extremely wet and cool fallow and crop season conditions (790 mm of precipitation) resulted in higher than normal yield levels in the 1983 crop year. In both the N level and date of planting study no significant yield plateau or curvilinear response was indicated at the highest fertilizer levels (Table 2). For this reason, it was felt that the yield level at the highest applied N level did not represent the maximum yield level. In all cases the protein content at the highest N level was substantially below the 8.3% initial level of N sufficiency determined from previous years.

Straw and chaff crude protein levels were measured only in 1979 and 1980. When N was deficient (relative yield less than 1.0), the straw and chaff crude protein levels were not strongly related to the N fertilizer practices affecting the relative yield levels ($r = 0.23$ and $r = 0.34$, $n = 32$, respectively) (Fig. 1). The straw and chaff protein levels expressed a narrow range of variation for the wide range in yield level, relative yield levels and grain protein content (mean of 2.1 and 3.1%, standard deviation 0.4 and 0.5, respectively). Suitable critical values of straw and chaff crude protein percentage could not be developed to distinguish N deficient plant responses from N sufficient responses using the adjusted chi-square method because there was no zone of straw or chaff protein percentage that exclusively represented N insufficiency. However, protein contents greater than 2.6 and 3.5% (straw and chaff, respectively) did include only responses in which N was sufficient. Wheat has the capacity to translocate nitrogenous materials from vegetative to reproductive tissues under a wide range of moisture stress levels and yield potentials (8). For this reason, straw and chaff plant tissues are not suitable postharvest biological indicators of the moisture-N balance in soft white winter wheat.

Nitrogen management programs are designed to maximize net return by maximizing yield and minimizing fertilizer inputs. The yield-protein relationships developed for grain tissues provide information on both the adequacy of applied N and the relative yield loss due to underfertilization for 'Stephens' soft white winter wheat. These postharvest yield-protein interactions can be used to develop N management programs for the subsequent crop that maximize both grain yield and quality and minimize fertilizer input in low grain protein soft white winter wheat.

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