Intensively Managed Irrigated Hard Red Winter Wheat Production

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SUMMARY

Hard red winter wheat will produce grain yields comparable to soft white winter wheat in intensively managed irrigated fields. Planting should be early enough in the fall for the plants to initiate tillers and crown roots before winter dormancy. Seeding about 80 pounds of seed per acre will provide an optimum stand and yield. Narrower row spacing, such as 4 to 7 inches, will produce higher grain yields than wider row spacings such as 12 to 18 inches. The bulk of the nitrogen and sulfur fertilizer, 100 to 150 pounds N and 20 pounds S per acre, should be applied during late tillering. From 30 to 50 pounds N per acre should be applied during heading or flowering to insure a marketable protein content in the grain. Applying more S than needed for normal plant nutrition has no effect in increasing grain protein.

Soil sampling for nitrate and sulfate sulfur just before spring growth starts is recommended. Soil testing after the wheat has resumed growth in the spring is of questionable value for predicting the need for N and S fertilization. Tissue tests are not reliable in predicting the need for N and S fertilization except where major deficiencies exist.

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INTRODUCTION

A surplus of soft white winter wheat and exports of hard red wheats from West Coast ports have renewed interest in producing hard red winter wheat in the Columbia Basin. Historically, Columbia Basin hard red wheat has not had acceptable bread-baking qualities because of low grain protein. When hard red grain yield equalled soft white yield, protein content of the hard red grain was less than the 11.5 percent minimum desired by bakers.

Hard red winter wheat production systems have been investigated to identify practices which result in both high yields and protein content. Time of seeding, seed distribution, fertilizer application, irrigation, and growth regulator studies were conducted in intensively managed irrigated fields. Soil and plant tissue were analyzed to (1) determine nitrate and sulfate change in the rooting zone during plant growth; (2) determine total nitrogen, nitrate nitrogen, and total sulfur in the growing plant; (3) relate these analyses to grain yields; and (4) improve fertilizer recommendations.

UNDERSTANDING GROWTH AND DEVELOPMENT

The winter wheat plant seems to be optimistic and realistic about reproduction. It is optimistic because more tillers are initiated than develop into heads; more flowers are started than are fertilized and filled into kernels. This over-design in early growth stages allows adjustment to growing conditions as the plant develops. If less than favorable conditions exist, some of the excess parts die; remaining tillers, head, or flowers have a better chance of having enough light, moisture, and nutrients to survive and mature. Such a system provides options for the plant to cope with various growth conditions.

Growth is directly related to temperature, providing no other conditions for growth are limiting (Rickman and Klepper, 1983; Russelle and Bolton, 1979). Approximately 150 growing-degree days (GDD) are needed for germination and emergence of the wheat seedling. From 90 to 100 GDD are needed for the appearance of each successive leaf. The first tiller and crown roots appear at the time the fourth leaf develops. Plants which initiate tillering before winter dormancy produce more grain than plants which do not initiate tillers before winter dormancy.

A long period of mild temperatures (40 to 65^{o} F) in late winter and early spring, soil moist to the surface, and adequate fertility aid the development of tillers. As the mid-tillering growth stage is approached, head size (number of spikelets per head) is established. Few, if any, new tillers are initiated after the plant starts jointing, and many weak tillers die. By early jointing, the number of heads per plant is set. These processes are not reversible. Still to be established are the flowers that will be fertilized and kernel size. Favorable growing conditions are needed during boot through flowering growth stages to develop and fertilize the maximum number of flowers. Mild summer temperatures, bright days, and a healthy plant aid photosynthesis, minimize respiration, and promote kernel development.

The primary components of yield are number of heads per unit area, kernels per head, and weight per kernel. Interactions between these three yield components permit compensation when a modest deficiency in either number of heads or kernels per head exists.

The genetic yield potential of varieties and advanced selections greatly exceeds present yield. Management practices are designed and applied to develop the genetic yield potential within the constraints of light, temperature, and other environmental limitations. Inherited traits and growing conditions contribute to milling qualities. Some varieties are milled more easily than others. Shriveled or sprouted kernels are more difficult to mill and have a lower flour yield than plump, sound kernels. Baking qualities of hard red winter wheat are enhanced by high protein in the grain.

Associating management practices with plant growth stages rather than specified calendar dates provides a method for adjusting the time of applying management practices to earliness or lateness of seasons between years and between localities. The scale of growth stages developed by Feeke (Large, 1954) has proved useful when referring to plant development (Figure 1). Wheat is physiologically mature when water and nutrients cease flowing to the kernels. This occurs when the kernel has approximately 35 percent moisture.

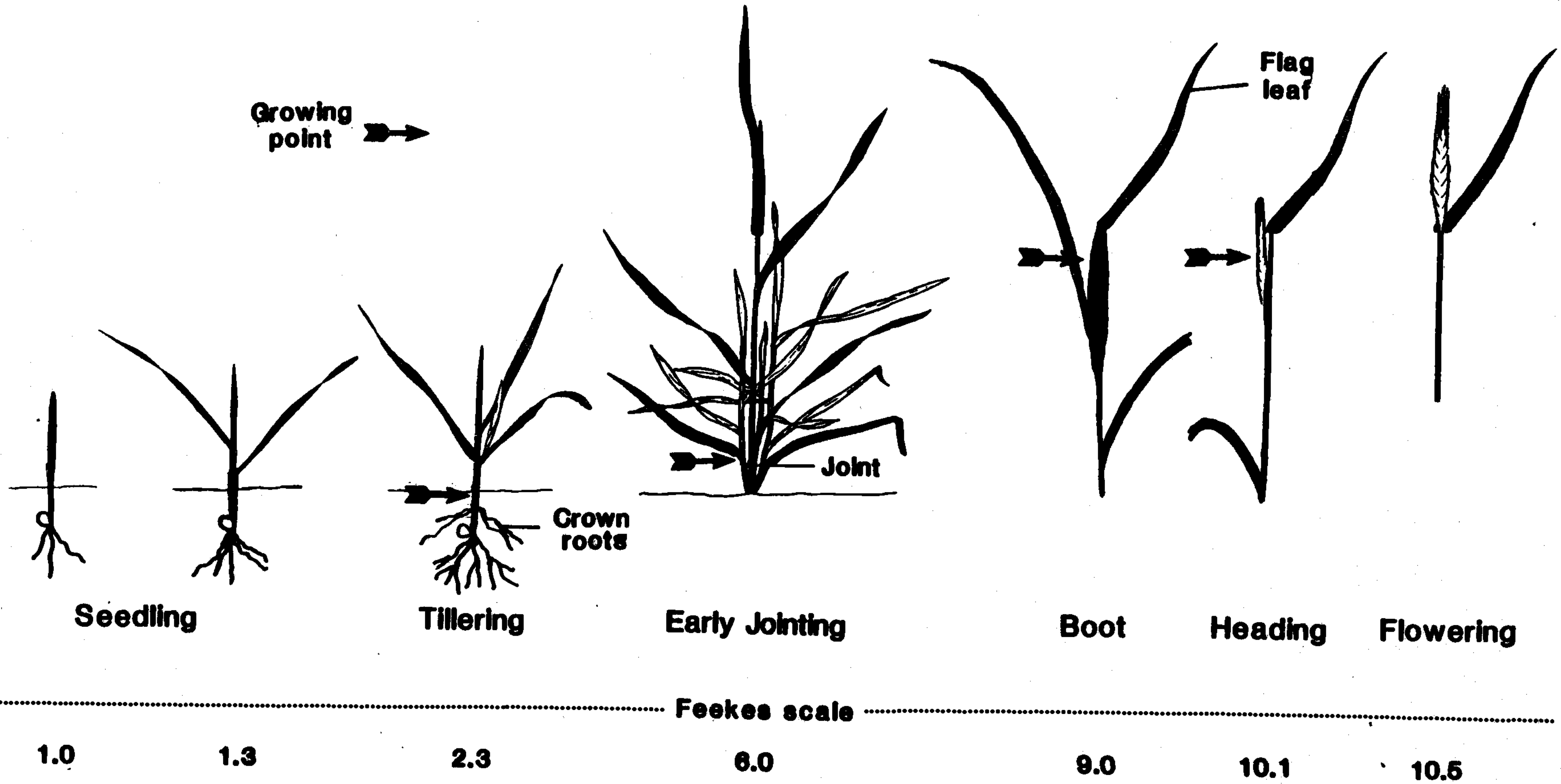

Figure 1. Growth stages of wheat. Feekes scale.

METHODS AND MATERIALS

Fields used to study hard red winter wheat production practices were in well-managed rotations; wheat followed a crop such as potatoes, peas, or alfalfa where residue was expected to decompose rapidly. Sprinkler irrigation provided a means of readily moving soluble fertilizers, such as nitrogen, into the rooting zone. If well-fertilized, intensively managed, irrigated fields do not produce high yields of hard red winter wheat with acceptable protein content, fields with less fertility and poorer management almost certainly will not. Experiments were located on coarse-textured soils in Morrow County, on coarse- and medium-textured soils in Umatilla County, and on medium-textured soils in Union County.

Wheat was planted in late September or early October except in date-of-seeding experiments. The rate of seeding was 80 pounds per acre except in rate-of-seeding experiments. Seeding depth, weed control, and irrigation practices were the same as those recommended for irrigated soft white winter wheat.

Researchers used advanced selections of hard red winter wheat from the cereal breeding project, Oregon State University Crop Science Department. These selections had growth habit and disease resistance similar to Stephens, Daws, and Hill 81 soft white varieties and excellent tillering, yield potential, and kernel size. The selections responded similarly to the cultural practices investigated, which allowed combining of results from experiments having the same objectives.

Nitrogen (N) was applied at the following growth stages: preplant, early and late tillering in the spring, jointing, boot, heading, and flowering. Ammonium sulfate was used as a fall-applied source of N; ammonium nitrate was used as a spring-applied source of N, except Solution 32 was used in foliar spray. Gypsum was used as a source of sulfur (S) and was applied at planting, late tillering, heading, or a combination of these growth stages. Phosphorus and potassium, if applied, were preplant-incorporated over the experimental area.

Soil and plant samples were taken periodically from early tillering through flowering. Soil samples were analyzed for nitrate and sulfate; plant samples were analyzed for nitrate, total nitrogen, and total sulfur. Soil and plant analyses, grain yields, and grain protein were examined to define relationships influencing plant growth and to improve fertilizer efficiency. Figures and tables present summarized results. Detailed data are presented in Appendix Tables.

RESULTS AND DISCUSSION

Date of Seeding

Wheat planted near October 1 grew several leaves, a few tillers, and crown roots (Feekes 3.0) before winter dormancy. Successively later plantings had less development and growth to the extent that wheat seeded after November 1 just emerged before winter (December 3 to 10). Fall growth of earlier plantings (September 1 in the Hermiston area) had more disease problems than later plantings.

Delaying seeding after October 1 had a negative effect on grain yield, bushel weight, heads per square foot, and plant height (Figures 2 and 3, Appendix Table 1). Grain yield was reduced more than one bushel per acre for each day seeding was delayed from October 1 to November 1; after November 1, yield decreased 0.3 bushel per acre per day of delay in seeding. Grain test weight from October 1 plantings averaged 0.8 pound per bushel higher than the test weight of grain planted October 15. Heads per square foot decreased as date of seeding was delayed; this is important because of the positive relationship between number of heads and grain yield. Maturity was delayed one day for each one week of delay in planting from October 1 to November 1. Planting date had no effect on protein content of the grain.

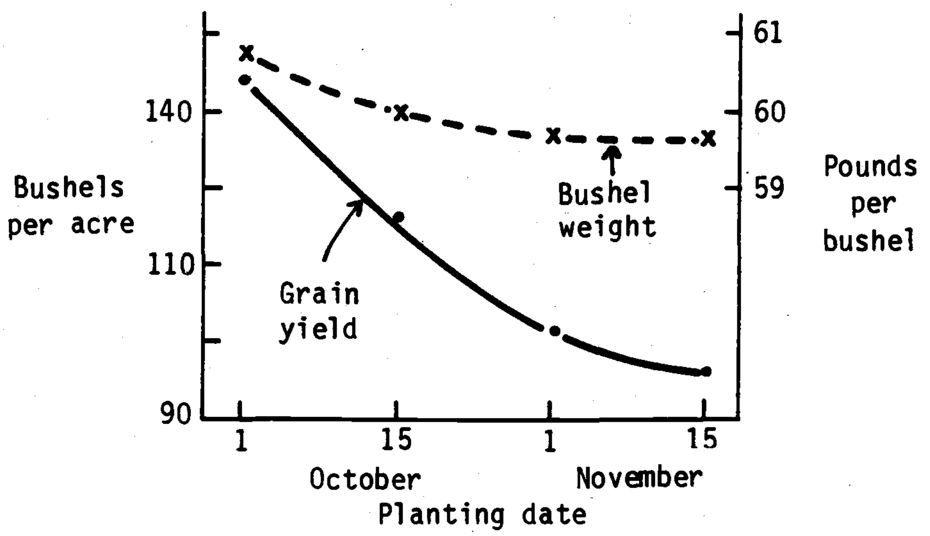

Figure 2. Grain yield and test weight of hard red winter wheat from four planting dates.

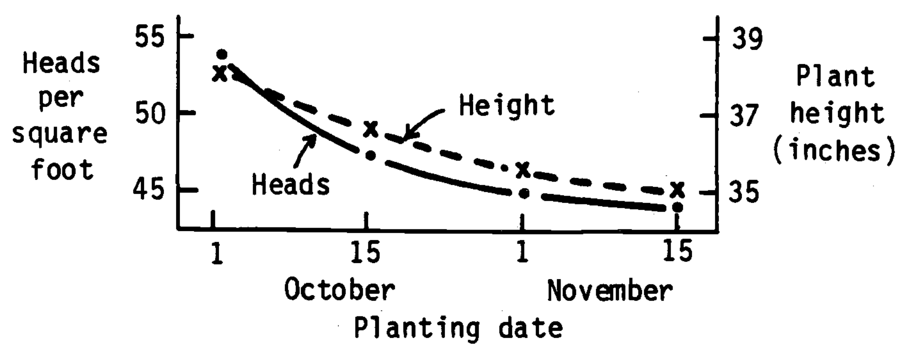

Figure 3. Heads per square foot and plant height of hard red winter wheat from four planting dates.

Rate of Seeding

Wheat seeded at 80 pounds per acre yielded eight bushels per acre more than wheat seeded at 40 pounds per acre (Figure 4, Appendix Table 2). Seeding more than 80 pounds per acre did not increase grain yield significantly. Lower yield from wheat seeded at 240 pounds per acre was attributed to lodging, because plant competition produced taller plants with weak stems. Plants increased three inches in height as the seeding rate increased from 40 to 240 pounds per acre.

Wheat seeded at 40 pounds per acre had only five fewer heads per square foot than wheat seeded at 80 pounds per acre (Figure 4, Appendix Table 2). Heads per plant were inversely related to seeding rate (Figure 5).

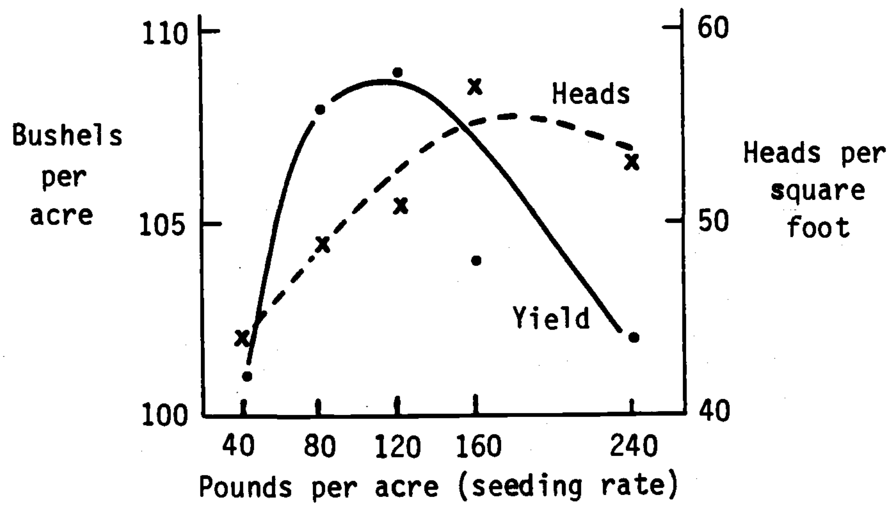

Figure 4. Grain yield and heads per square foot from five seeding rates of hard red winter wheat.

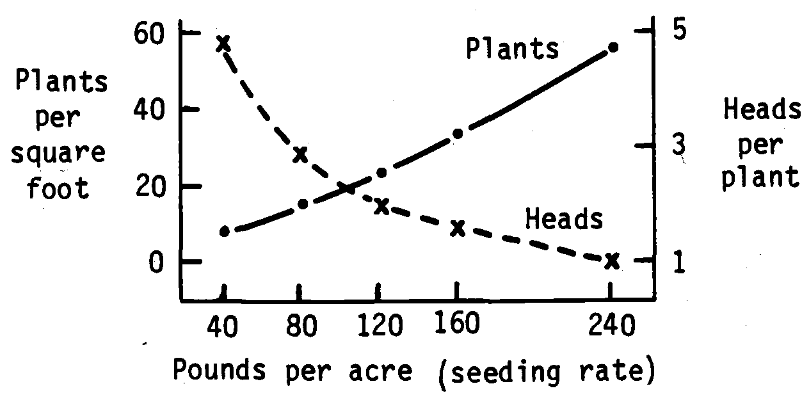

Figure 5. Plants per square foot and heads per plant from five seeding rates of hard red winter wheat.

The potential for increasing yield by increasing seeding rate over 80 pounds per acre at the optimum seeding date is minimal. Low plant populations of present-day varieties and advanced selections have exceptional ability to utilize favorable growth conditions through increasing heads per plant, kernels per head, and kernel size. High plant populations exhibit no capacity to utilize more efficiently favorable growth conditions than average plant populations.

Some adjustment in seeding rate is necessary for differences in seed size between lots and varieties. Removal of small seeds aids the establishment of uniform, vigorous seedlings. Increasing the seeding rate is beneficial when seeding after the optimum seeding date.

Row Spacing

Grain yield and heads per square foot declined as row spacing increased (Figure 6, Appendix Table 3), but row spacing had no effect on test weight and grain protein content. Plants were 1 inch taller in 12- and 18-inch rows than in 6-inch rows.

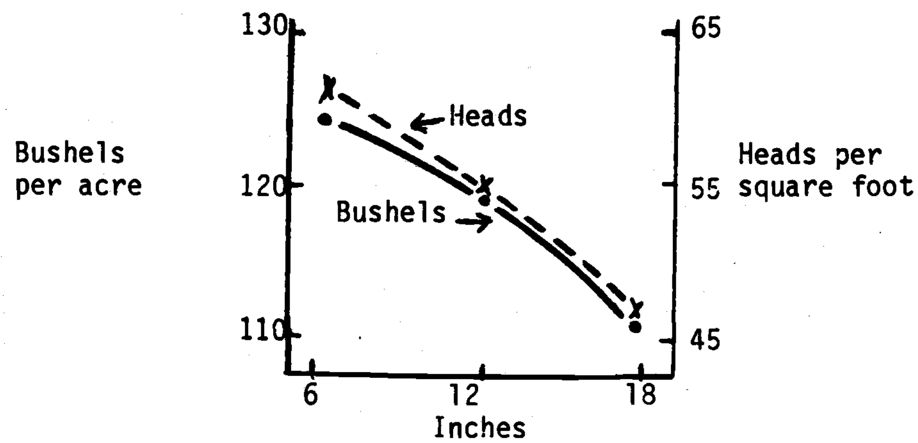

Figure 6. Grain yield and heads from three row spacings. Constant seeding rate of 80 pounds per acre.

Seeds per linear foot of row are reduced with narrower compared to wider row spacings, provided the seeding rate is constant. This greater distance between seedlings reduces within-row competition and shading from nearby plants. Light and shading become more important as yield potential increases.

Rate of Nitrogen Application

Fall or early spring application (before Feekes 3.0 growth stage) of 100 or more pounds N per acre usually produced luxuriant early growth and increased lodging during heading and flowering. This visually appealing early growth did not produce higher yield or improved grain quality. Yield of the lodged grain was often 20 to 30 bushels per acre less than where plants did not lodge. Test weight of grain from lodged plants was lower than grain from upright plants. Over-stimulation of early growth was avoided by not applying nitrogen before late tillering or, preferably, by applying the nitrogen in several increments between tillering (Feekes 2.5) and flowering (Feekes 10.2).

Wheat receiving no fertilizer, or no more than 40 pounds N plus sulfur (S) preplant, produced an average yield of 92 bushels of grain per acre (Table 1, Appendix Table 4). This indicates a high level of residual fertility and nutrient availability from a large quantity of readily decomposable organic matter.

Table 1. Hard red winter wheat grain yield and protein response to time and rate of N application.

N fertilizer applied		Grain	Grain	Pounds N per bushel
Late tillering	Heading	yield	protein	yield increase
pounds per acre		bu/acre	percent	
0	0	92	11.4	----
100	0	120	12.2	3.6
100	50	125	13.3	10.0
150	0	129	12.8	5.6
150	50	130	13.4	50.0
200	0	z	z	z
5% LSD		9	0.5	----

z = yield and protein results meaningless because of excessive fall and early spring growth and lodging during heading which reduced grain yield and test weight.

Application of 100 or 150 pounds N per acre during late tillering increased the average yield 28 and 37 bushels per acre, respectively (Table 1, Appendix Table 4). An additional 50 pounds of N applied during heading increased yields 5 and 1 bushel where 100 or 150 pounds, respectively, had been applied during late tillering. Lodging consistently occurred where 200 pounds N per acre was applied during late tillering; grain yield and test weight were reduced where lodging occurred during heading. Efficiency of the N fertilizer applied in terms of pounds N per bushel grain increase was, at best, moderately acceptable only where 100 pounds of N was applied during late tillering.

Hard red winter wheat required 3.0 or more pounds N per bushel of grain produced. Yields of 70 to over 100 bushels per acre from where no fertilizer was applied (Appendix Table 4) indicate that plants obtained 200 to 300 pounds N per acre from residual nitrogen and decomposition of organic matter. Nitrogen fertilization during late tillering increased grain yield from 15 to 35 bushels per acre. These increases would utilize from 40 to 100 pounds of fertilizer N with optimum efficiency from the N applied.

Protein content of unfertilized grain in five of six fields was below the desirable level of 11.5 percent (Appendix Table 4). Fertilizing with N during late tillering consistently increased the protein content of the grain. Protein content was 0.6 percent higher where 150 pounds N was spring-applied than where 100 pounds N was applied (Table 1). Applying additional N during heading increased average grain yields only a few bushels per acre, but increased the average protein content to over 13 percent. Protein increase from fertilizing with N during heading was largest where the least N was applied during tillering.

These data support the principles that (1) development and growth processes in N-deficient wheat plants give priority to grain production over grain protein with additional N and (2) grain protein increases curvilinearly as the demand for N for grain production decreases (Figure 7).

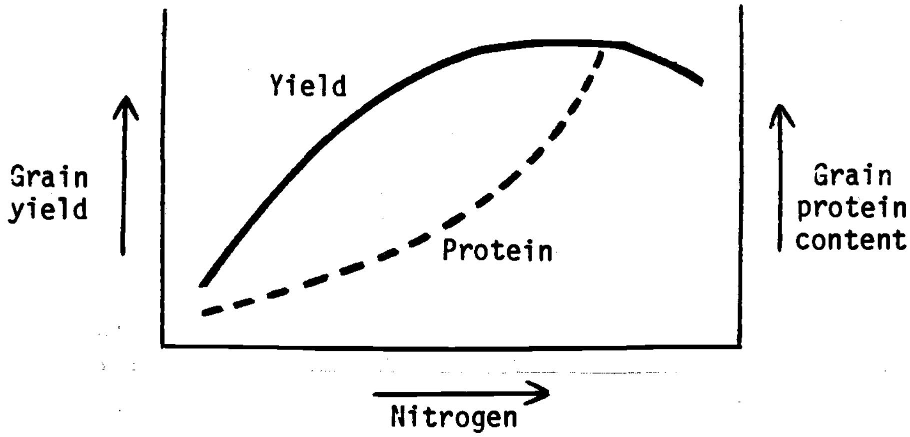

Figure 7. Influence of nitrogen on wheat grain yield and grain protein content.

Nitrogen Application during Heading and Flowering

Grain increase from nitrogen applied during heading or flowering averaged three bushels per acre (Figure 8, Appendix Tables 5, 6, 7, 8, and 9). This increase in grain yield indicates either the wheat had been adequately fertilized for yield earlier or fertilizing with N during heading or flowering is ineffective in increasing grain production. Nitrogen applied at heading or flowering had no effect on test weight.

Nitrogen applied during heading or flowering consistently increased grain protein (Figure 8, Appendix Tables 5, 6, 7, 8, and 9). Twenty-five or fifty pounds of N per acre applied during heading increased grain protein content by 0.5 and 1.0 percent, respectively. Fifty pounds of N applied during flowering increased protein 1.1 percent. The highest protein content was obtained where N was applied during heading and flowering. Foliar application of N was less effective than broadcast N moved into the rooting zone with irrigation water. Economic justification for N application during heading or flowering requires primarily a favorable increase in the price of hard red winter wheat grain as grain protein content increases.

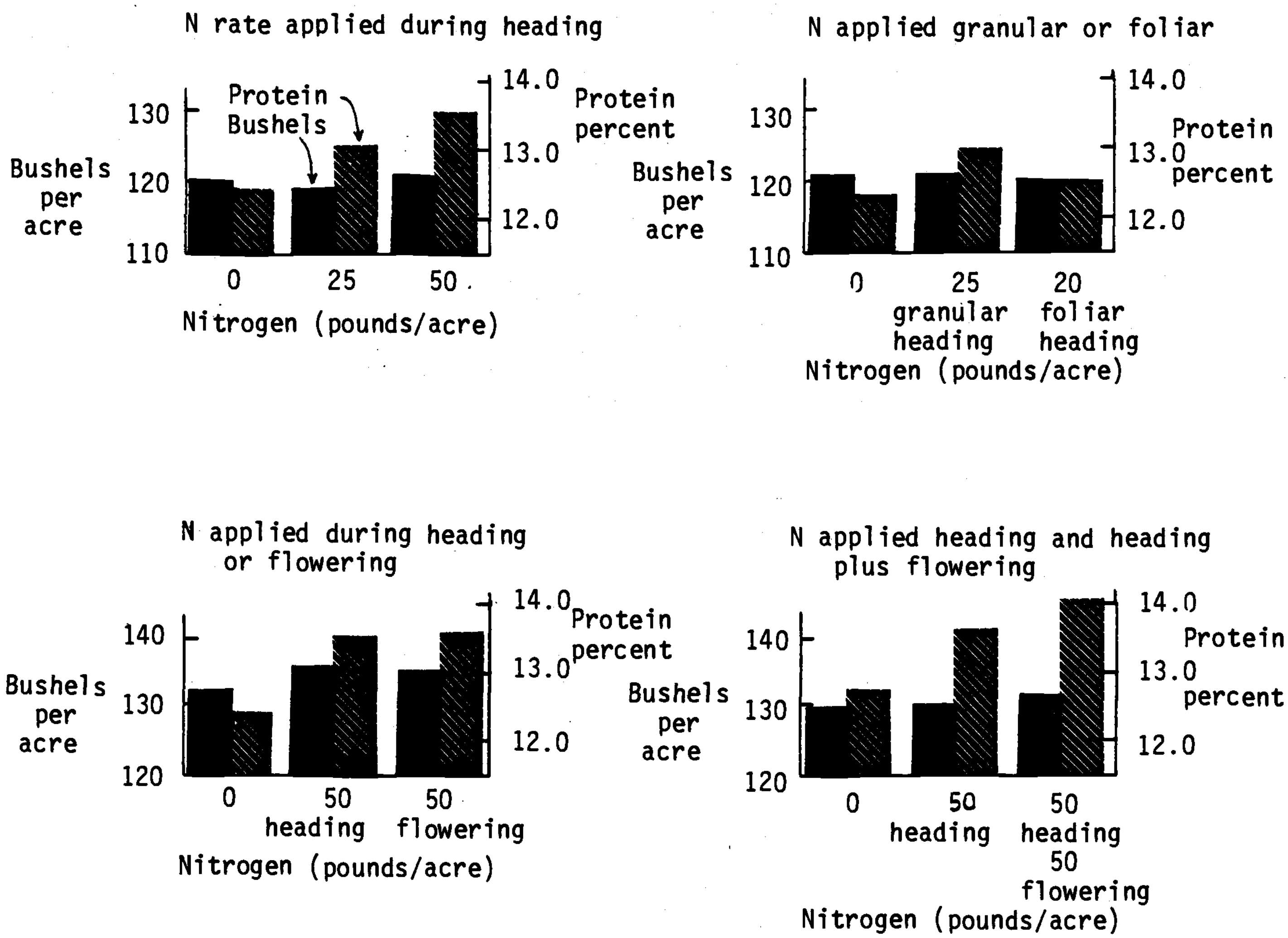

Figure 8. Grain yield and protein response to nitrogen (N) application at heading and flowering.

Sulfur (S)

Applying S fertilizer had no significant effects on wheat grain yield or protein content (Table 2, Appendix Table 10). This indicates that grain protein is not increased by applying more S than is needed for plant growth and grain production. Sulfur fertilizers also have more residual value than nitrogen fertilizers (Rasmussen, et al., 1975).

Sulfur deficiency in north central and northeast Oregon in intensive crop production is of such magnitude that fertilizing with S is essential for optimum production. Knowledge of previous S applications, soil test results, and irrigation water quality is useful when deciding how much S to apply to wheat. Some sources of irrigation water, such as the Columbia River and a few wells, contain amounts of S which will supply most of the S required for crop production.

Table 2. Sulfur fertilization effects on grain yield and protein content of hard red winter wheat.

Fertilizer applied				Grain[z]	
Late tillering		Heading			
N	S	N	S	Yield	Protein
pounds per acre				bu/acre	percent
100	0	50	0	126	13.3
100	20	50	5	127	13.3
150	0	50	0	129	13.5
150	20	50	5	130	13.4

[z]Means of five experiments.

Soil Testing

Many well-fertilized fields have large amounts of nitrate and sulfate in the rooting zone when winter wheat is seeded and in late winter (Table 3; Pumphrey and Rasmussen, 1983). In these studies, all fields had more than 100 pounds soil nitrate per acre preplant and in late winter. This large quantity of nitrate in the rooting zone partially explains why grain yields were 70 to 110 bushels per acre when no N fertilizer was applied. Applying fertilizer preplant in these well-managed fields may increase fall growth; however, these visual effects do not result in additional bushels of grain.

The quantity of nitrate in the rooting zone decreased rapidly after wheat growth became vigorous (Figure 9). Grain yields above 125 bushels per acre were produced when adequate N (150 pounds N per acre) was applied during late tillering even though soil nitrate was nearly depleted by boot stage of growth. This rapid decline in soil nitrate requires that a soil test for nitrate be closely associated with stage of plant growth to be an effective diagnostic tool. Also, there is little indication that testing for soil nitrate is useful in determining if additional N fertilizer should be applied to insure adequate grain protein.

Sulfate sulfur in the upper four feet of soil (Table 3, Figure 10) greatly exceeded the critical level of 8 to 10 pounds in the surface foot of soil or 15 to 20 pounds in the upper four feet of soil. The amount of sulfate sulfur in each soil depth remained reasonably constant during the growing season which is in contrast to the near depletion of nitrate in the upper 30 inches of soil by late jointing.

Table 3. Average soil test values for fields planted to hard red winter wheat on the Pendleton and Hermiston Research Centers.

Soil depth	pH^z	P	K	Ca	Mg	NO_3-N^y	SO_4-S^y
inches		ppm	ppm	meq/100g	meq/100g	lbs/a	lbs/a
Pendleton							
0-12	6.2	31	659	9.2	3.8	130	15
12-30	7.2	12	402	10.4	4.7	36	16
30-48	---	--	---	----	---	12	9
Hermiston							
0-12	6.0	23	226	5.6	1.8	204	20
12-30	6.7	6	140	6.0	2.0	78	14
30-48	---	--	---	---	---	90	11

[z]Preplant sampling for pH, P, K, Ca, and Mg; Soil Testing Laboratory, Oregon State University, Corvallis.

[y]Late winter sampling; ARS, USDA Laboratory, Columbia Plateau Conservation Research Center, Pendleton, Oregon.

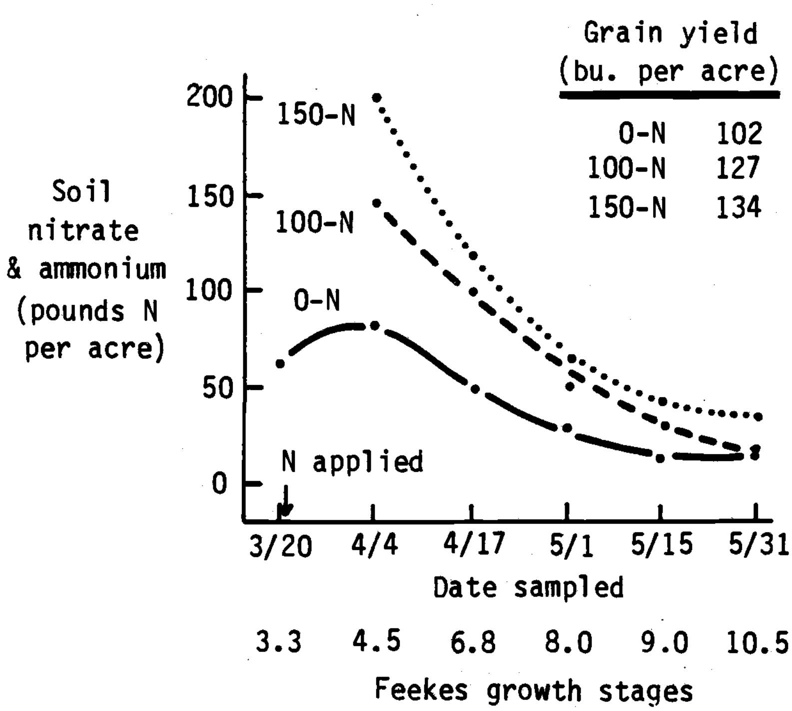

Figure 9. Soil nitrate plus ammonium in four feet of soil during growth of wheat as influenced by nitrogen application.

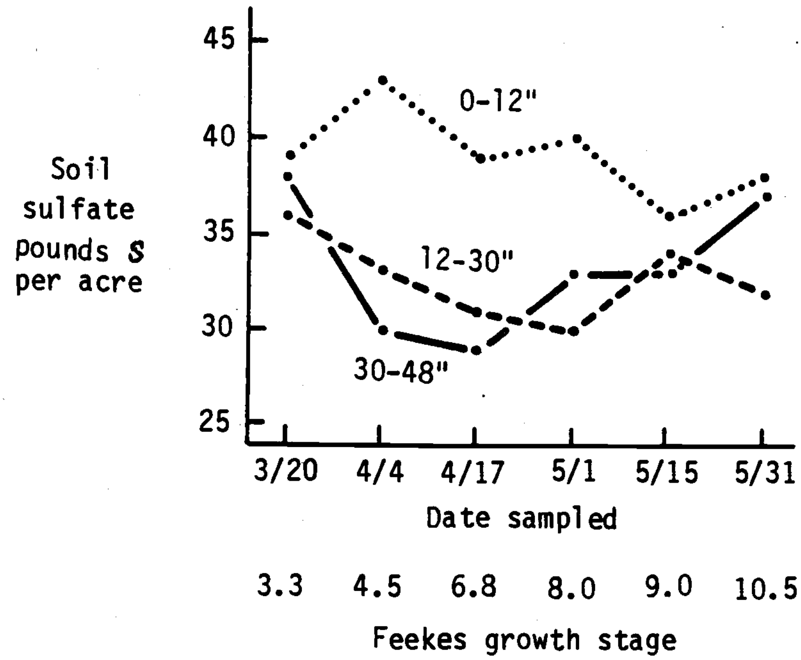

Figure 10. Soil sulfate in four feet of soil during growth of wheat. No sulfur was applied (mean of six fields).

Plant Tissue Testing

Nitrate in the youngest mature leaves of wheat not fertilized with N was less than 0.05 percent during spring tillering and declined to nearly unmeasurable levels by mid-jointing (Figure 11). Fertilizing with N increased leaf nitrate immediately after N application; but six weeks after N application, the youngest mature leaves of N-fertilized wheat had only a slightly higher percent nitrate than leaves of N-deficient wheat. Analyzing the youngest mature leaves of tillering wheat for nitrate can be used as a guide for applying N. Nitrate in wheat plants which are jointing or older is rapidly converted to other forms of nitrogen; this eliminates the possibility of identifying N-deficient and non-deficient older plants using percent nitrate. Nitrate in stem tissue just above the crown has greater potential as a diagnostic tool (Pumphrey and Rasmussen, 1981) than analyzing for nitrate in youngest mature leaves.

The youngest mature leaves from N-fertilized wheat plants contained 0.5 percent more total N than N-deficient wheat from late tillering to heading (Figure 11); however, percent total N declined nearly 1 percent during this growth period. These data indicate that wheat adequately fertilized with N should contain approximately 4.5 percent total N during late tillering. The difference in total N percent in N-sufficient and N-deficient plants provides an opportunity to identify young plants not adquately fertilized with N for optimum grain yield.

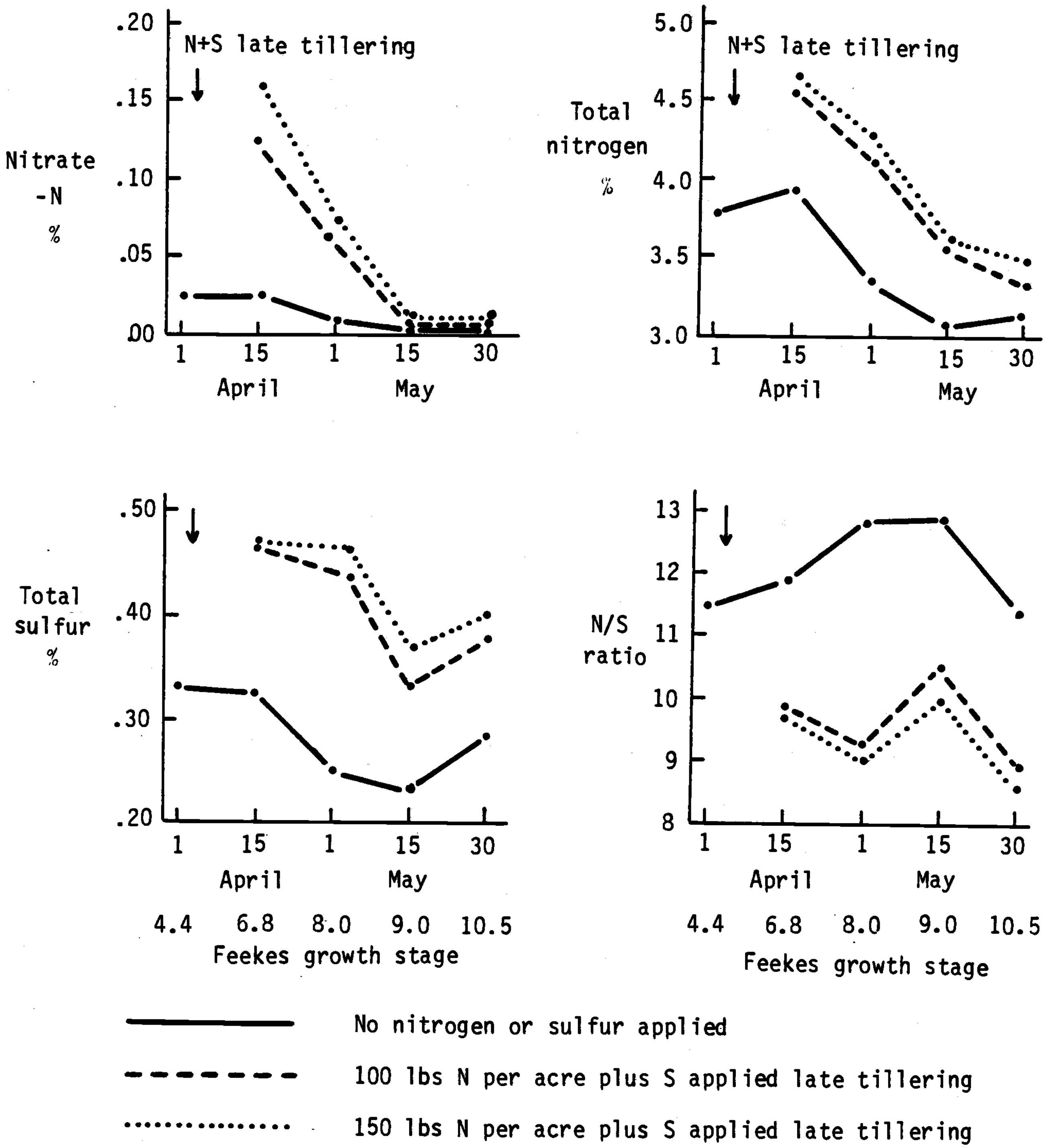

Figure 11. Nitrate-N, total nitrogen, total sulfur, and nitrogen-sulfur ratio in youngest mature leaves during spring growth of hard red winter wheat.

Wheat not fertilized with N had a lower percent total S in plant tissue than N-fertilized wheat (Figure 11). This higher percent S in N-fertilized plant tissue is to be expected if (1) N fertilization increased the N content of the plant and (2) no S deficiency was induced. The N/S ratio of N + S fertilized wheat was narrower than the N/S ratio of non-fertilized N-deficient wheat even though the nonfertilized wheat was not S deficient. The narrower ratio indicates proportionately more S than N absorption. The N/S ratio in plant tissue not S-deficient should be 15 to 1 or less (Rasmussen, et al., 1975). N/S ratio is a more reliable guide than total S for identifying S deficiency. Soil and tissue test data provide no guidelines for applying N or S fertilizers to increase grain protein.

Irrigation

Irrigation after fall planting needs to be applied cautiously. Filling the soil over field capacity not only leaches nutrients from the soil but increases the possibility of overwinter leaching from winter precipitation.

Irrigated wheat producing over 100 bushels per acre uses 17 to 23 inches of water as evaporation from the soil and transpiration from the plants (evapotranspiration). Water consumption in the Hermiston-Boardman area in inches per month is approximately: March - 1.0, April - 4.0, May - 5.5, June - 6.0, and July - 3.5.

Daily water consumption varies greatly with humidity and wind. Consumption on a rainy day with no wind is as little as 0.05 inch; consumption may exceed 0.40 inch on a windy day with low humidity. Irrigators can use daily pan evaporation (Hane and Pumphrey, 1984) or more sophisticated calculations from temperature, wind, relative humidity, and solar radiation (Jensen, et al., 1971; Penman, 1963) for irrigation scheduling.

Plant water stress from heading through grain filling is more damaging to grain yield than water stress during earlier growth stages. The worst possible moisture conditions for obtaining high yields of quality grain are optimum to excess water during tillering and jointing followed by a deficiency during flowering and early grain filling. Frequency of irrigation has little effect on growth, yield, and water use efficiency when the plant has a continuous supply of readily available water. Wheat irrigated at two-week intervals will yield approximately the same as wheat irrigated several times per week (Pumphrey et al., 1982). The time to stop irrigating depends on remaining days to maturity, expected weather, and the amount of water in the rooting zone.

Lodging and Growth Regulators

Dense stand and luxuriant early spring growth produce tall, weak plants that are easily lodged. Luxuriant growth results from a combination of too much nitrogen applied too early, favorable growing conditions, and in some instances planting too early.

Nitrogen fertilizer management can minimize luxuriant growth and lodging without sacrificing yield. Fall and early spring nitrogen application, if needed in intensively managed irrigated fields, should be only enough to avoid N stress in young plants. The bulk of the N should be applied during late tillering or in small applications from tillering through heading.

Growth regulators can reduce lodging by shortening the plant and strengthening the straw. Growth regulators will not increase, and may decrease, grain yield if no lodging occurs (Morrison, et al., 1987). Application of growth regulators should be considered when nitrogen fertilizer management does not control lodging.

REFERENCES

Hane, D. C. and F. V. Pumphrey. 1984. Crop water use curves for irrigation scheduling. Oregon Agric. Exp. Stn. Spec. Rep. 706. p. 1-7.

Jensen, M. E., J. L. Wright, and B. S. Pratt. 1971. Estimating soil moisture depletion from climate, crop, and soil data. Trans. Amer. Soc. Agr. Eng. 14:954-959.

Large, E. C. 1954. Growth stages in cereals. Phytopathology 3:128-129.

Morrison, L. A., F. V. Pumphrey, D. O. Chilcote, and M. F. Kolding. 1987. Plant growth regulator treatment of winter wheat and spring barley to prevent lodging and increase yield. Oregon Agric. Exp. Stn. Spec. Rep. 793. p. 20-23.

Penman, J. L. 1963. Vegetation and hydrology. Tech. Comm. No. 53, Commonwealth Bureau of Soils, Harpenden, England. p. 1-125.

Pumphrey, F. V., D. C. Hane, and Earl M. Bates. 1982. Water consumption of frequently irrigated wheat in North Central Oregon. Oregon Agric. Exp. Stn. Spec. Rep. 664. p. 29-33.

Pumphrey, F. V. and P. E. Rasmussen. 1981. Nitrogen fertilization, stem nitrate concentration, and grain yield of irrigated white winter wheat in eastern Oregon. Pacific Northwest Fertilizer Conf., Proc., Billings, Montana. 32:59-73.

Pumphrey, F. V. and P. E. Rasmussen. 1983. Overwinter soil nitrate and ammonium in irrigated wheat fields and grain yield-soil nitrate relationships. Pacific Northwest Fertilizer Conf., Proc., Portland, Oregon. 34:31-38.

Rasmussen, P. E., R. E. Ramig, R. R. Allmaras, and C. M. Smith. 1975. Nitrogen-sulfur relations in soft white winter wheat. II. Initial and residual effects of sulfur application on nutrient concentration, uptake, and N/S ratio. Agron. J. 67:224-228.

Rickman, R. W. and B. L. Klepper. 1983. Using air temperature to anticipate wheat crop development. Oregon Agric. Exp. Stn. Spec. Rep. 680. p. 28-36.

Russelle, M. P. and F. E. Bolton. 1979. Emergence of winter wheat and winter barley as influenced by field soil temperatures. Oregon Agric. Exp. Stn. Spec. Rep. 547. p. 43-49.

APPENDIX

Appendix Table 1. Seeding date influence on grain yield, bushel weight, head number, and plant height.

Oate seeded		Grain yield	Test weight	Head density	Height
		bu. acre	lbs. bu.	number sq. foot	inches
1984^z	Oct. 3	125	61.7	50	35
	Oct. 20	127	61.4	46	35
	Nov. 4	90	60.9	35	34
	Nov. 16	87	60.9	35	33
1985^z	Sept. 26	121	58.7	55	39
	Oct. 10	96	57.1	47	37
	Oct. 30	92	56.7	57	36
1985^z	Oct. 1	156	61.2	57	--
	Oct. 17	126	60.6	48	--
	Nov. 14	116	60.5	44	--

^{z}Mean of three selections.

Appendix Table 2. Seeding rate influence on grain yield, head numbers, and stand.

Seeding rate		Grain yield	Head density	Stand
lbs. acre		bu. acre	number sq. foot	sq. foot
Imbler,	40	91	50	--
Oregon^z	80	103	59	--
	120	102	59	--
	160	95	67	--
	240	93	63	--
Hermiston,	40	110	37	9
Oregon^z	80	113	38	17
	120	117	42	24
	160	113	47	35
	240	110	46	66
Average				
	40	100	43	--
	80	108	48	--
	120	109	50	--
	160	105	57	--
	240	101	54	--
	5% LSO	5	5	--

^{z}Mean of two selections.

Appendix Table 3. Row spacing influence on grain yield, test weight, grain protein, and head numbers.

Year	Row spacing	Grain yield	Test weight	Grain protein	Head density
	inches	bu. acre	lbs. bu.	percent	number sq. ft.
1983[z]	6	95	--	----	63
	12	102	--	----	52
	18	87	--	----	42
1984[z]	6	102	--	----	57
	12	98	--	----	53
	18	92	--	----	49
1984[z]	6	150	63	12.1	52
	12	137	63	12.1	46
	18	130	63	12.0	44
1985[z]	6	147	61	13.0	74
	12	137	61	13.1	64
	18	136	61	13.4	53
Averages					
	6	124	62	12.5	62
	12	119	62	12.6	54
	18	111	62	12.7	47
	5% LSD	5	--	----	7

[z]Mean of two selections.

Appendix Table 4. Grain yield and protein with and without nitrogen fertilizer in individual fields.

Rate of N applied, pounds per acre									
0		100[z]		100[z] + 50[y]		150[z]		150[z] + 50[y]	
Yield	Protein	Yield	Protein	Yield	Protein	Yield	Protein	Yield	Protein
bu. acre	percent	bu. acre	percent	bu. acre	percent	bu. acre	percent	bu. acre	percent
77	11.6	103	12.1	115	13.1	---	----	---	----
118	11.2	130	12.5	135	13.5	135	13.1	134	13.8
105	10.3	125	11.6	129	13.1	130	12.4	132	13.2
84	10.8	125	10.9	133	12.6	136	12.1	142	12.7
98	12.8	127	13.3	129	13.8	131	13.5	128	13.7
71	11.9	107	12.6	109	13.5	112	13.1	114	13.6
Average									
92	11.4	120	12.2	125	13.3	129	12.8	130	13.4
5% LSD	Yield: 9 bushels, protein: 0.5 percent								

[z]Pounds N per acre applied during late spring tillering (Feekes 3 to 4).

[y]Additional 50 pounds N per acre applied during heading (Feekes 10.0 to 10.5).

Appendix Table 5. Grain yield and protein as affected by nitrogen applied during heading.

Nitrogen late tillering	Nitrogen applied at heading, pounds per acre					
	0	25	50	0	25	50
	Grain yield			Grain protein		
lbs. acre	bushels per acre			percent		
100	110	112	110	12.9	13.7	13.9
100	118	114	119	12.9	13.3	13.3
100	125	122	129	11.6	11.3	13.1
100	84	88	82	12.3	13.1	13.8
150	130	126	132	12.4	12.2	13.2
150	147	149	148	12.1	13.5	13.8
Average	119	119	120	12.4	12.9	13.5
5% LSD	No significant difference				0.6	

Appendix Table 6. Effects of nitrogen applied at heading on grain yield and protein[z].

Nitrogen late tillering	Nitrogen applied at heading, pounds per acre			
	0	50	0	50
	Grain yield		Grain protein	
lbs. acre	bushels acre		percent	
100	97	100	12.3	13.5
100	109	109	13.2	13.5
100	112	115	12.5	12.9
100	107	106	11.3	12.5
100	96	91	11.4	11.8
100	103	115	12.1	13.1
100	130	135	12.5	13.5
100	125	133	10.9	12.6
100	123	126	11.9	13.0
100	124	123	12.4	14.9
100	127	129	13.3	13.8
100	107	109	12.6	13.5
100	116	117	12.5	13.7
100	105	103	13.5	14.6
150	142	149	12.0	12.4
150	153	151	11.8	11.8
150	135	134	13.1	13.8
150	136	142	12.1	12.7
150	144	152	12.8	14.4
150	116	125	13.7	13.8
150	131	128	13.5	13.7
150	112	114	13.1	13.6
150	117	123	13.2	13.6
Average	120	123	12.5	13.3
5% LSD	2.0		0.3	

[z]Data from fourteen experiments.

Appendix Table 7. Effects of nitrogen at heading or flowering on yield and protein content[z].

Nitrogen late tillering	No N[y]	50 N Heading	50 N Flowering	No N[y]	50 N Heading	50 N Flowering
	Grain yield			Grain protein		
lbs. acre	-------bushels acre------			---------percent---------		
100	110	110	110	12.9	13.9	13.9
100	118	119	118	12.9	13.3	13.8
100	97	100	96	12.3	13.5	12.6
100	125	133	131	10.9	12.6	13.6
100	125	129	127	11.2	13.1	11.9
150	136	142	140	12.1	12.7	13.7
150	130	132	133	12.4	13.2	12.3
150	156	157	156	13.2	13.6	14.4
150	147	148	162	12.1	13.8	14.3
150	147	149	151	12.1	13.5	13.7
150	156	156	148	12.8	14.4	14.7
Average	132	134	135	12.3	13.4	13.5
5% LSD	no significant difference				0.8	

[z]Data from six experiments.

[y]No nitrogen applied at heading or flowering.

Appendix Table 8. Effects of nitrogen applied granular or foliar at heading on grain yield and protein content[z].

Nitrogen late tillering	None[y]	Granular[y]	Foliar[y]	None[y]	Granular[y]	Foliar[y]
	Grain yield			Grain protein		
lbs. acre	------bushels acre-------			---------percent---------		
100	110	112	108	12.9	13.7	13.5
100	118	114	115	12.9	13.3	13.3
100	97	100	96	12.3	13.5	12.6
100	104	101	100	12.0	12.8	11.9
150	153	151	155	11.8	11.8	12.0
150	142	149	145	12.0	12.4	11.6
Average	121	121	120	12.3	12.9	12.5
5% LSD	no significant difference				0.4	

[z]Data from four experiments.

[y]None--no N applied at heading; 25 pounds N per acre applied as granular ammonium nitrate; 20 pounds N per acre of solution 32 applied as a foliar spray.

Appendix Table 9. Grain yield and protein content where no nitrogen, nitrogen at heading, and nitrogen at heading and flowering were applied[z].

Nitrogen late tillering	None[y]	Heading[y]	Heading + flowering[y]	None[y]	Heading[y]	Heading + flowering[y]
	Grain yield			Grain protein		
lbs. acre	------bushels acre-------			---------percent---------		
100	110	110	114	12.9	13.9	14.5
100	118	119	116	12.9	13.3	14.1
100	114	118	113	13.4	14.1	14.1
100	116	118	120	13.1	13.8	13.7
100	97	97	89	12.3	14.0	14.7
100	104	103	109	12.0	13.6	12.9
150	150	151	159	12.5	11.8	12.7
150	156	157	156	13.2	13.6	14.4
150	147	148	162	12.1	13.8	14.3
150	147	149	151	12.1	13.5	13.7
150	156	156	147	12.8	14.4	14.6
Average	129	130	131	12.7	13.6	14.0
5% LSD	no significant difference				0.4	

[z]Data from six experiments.

[y]None--no nitrogen applied during heading or flowering; heading--50 pound N per acre applied during heading; heading + flowering--50 pounds N per acre applied during heading plus 50 pounds N per acre applied during flowering.

Appendix Table 10. Grain yield and protein from wheat fertilized with nitrogen and sulfur or nitrogen only[z].

Nitrogen and sulfur applied, pounds per acre							
100N 20S LT[y] + 50N 5S H[y]		100N LT + 50N H		150N 20S LT + 50N 5S H		150N LT + 50N H	
Bu acre	Protein percent	Bu acre	Protein percent	Bu acre	Protein percent	Bu acre	Protein percent
135	13.5	136	13.5	134	13.8	134	13.8
129	13.1	132	12.9	132	13.2	125	13.3
133	12.6	124	13.0	142	12.7	146	12.9
129	13.8	128	13.8	130	13.7	124	13.9
109	13.6	115	13.4	114	13.6	111	13.5
				125	13.8	132	13.9
Average							
127	13.3	126	13.3	130	13.4	129	13.5
no significant differences at 5% between grain yields or proteins							

[z]Data from five experiments.

[y]LT = fertilizer applied during late tillering; H = fertilizer applied during heading.