



# Soft White Winter Wheat

(Western Oregon)

J.M. Hart, M.D. Flowers, N.P. Anderson, R.J. Roseberg, N.W. Christensen, and M.E. Mellbye

**S**oft white winter wheat is the most important non-irrigated grain crop grown in western Oregon. It is grown in a variety of rotations and landscape positions. The most yield-limiting nutrient for this crop usually is nitrogen. Liming to increase soil pH is sometimes necessary, as well as addition of sulfur, phosphorus, potassium, and magnesium.

This guide provides nutrient and lime recommendations for soft white winter wheat established after conventional tillage or with no-till on the Willamette Valley floor, on low hills bordering the valley, and in other Oregon valleys west of the Cascade mountain range in Benton, Clackamas, Douglas, Jackson, Josephine, Lane, Linn, Marion, Polk, Washington, and Yamhill counties.



Soft white winter wheat harvest in western Oregon (Linn County).  
Photo: Mark Mellbye

## Summary

*Note:* These recommendations do not apply to consecutive wheat crops.

### *Fall, before planting*

- Lime** If soil pH is below 5.5, apply lime according to Table 1. See page 7.
- Calcium (Ca)** When pH is above 5.5, calcium is usually sufficient.
- Magnesium (Mg)** If soil test Mg is below 60 ppm, use 1 t dolomite/a for 1 t lime/a of the lime requirement. See page 7.
- Sulfur (S)** If no S was applied the previous year, apply 10–15 lb S/a at planting time. If wheat or oat straw was incorporated, apply and incorporate 10–15 lb S/a preplant and band 10–15 lb S/a at planting. See page 8.
- Phosphorus (P)** If soil test P is below 30 ppm, apply P according to Table 3. See page 9.
- Potassium (K)** If soil test K is below 100 ppm, apply K according to Table 4. See page 9.
- Nitrogen (N)** Nitrogen usually is not needed in the fall. See page 6 for situations where N and other nutrients are recommended at planting.

### *Spring*

*Note:* These spring nutrient applications apply to all fall-planted fields, including those established by no-till.

- Nitrogen (N)** Use the N mineralization test during the second half of January to determine application rate. Apply spring N between Feekes growth stages 5 and 6 (early jointing). See pages 10–12.

### *Postharvest management*

- Grain protein** Target for grain protein is 8.5–10.5 percent. See page 14 for explanation.

Information in this guide should be used only for fall-planted soft white winter wheat. This guide does not apply to winter wheat planted after December.

Healthy plants with adequate root systems are required to obtain the greatest return from your fertilizer investment. The nutrient recommendations in this guide assume that adequate control of weeds, insects, and diseases is achieved. Lack of pest control cannot be overcome by the addition of nutrients.

Common pest problems for wheat production in western Oregon are take-all root rot, Septoria leaf and glume blotch, stripe rust, slugs, cereal leaf beetle, aphids, grassy weeds (such as annual ryegrass and wild oats), and broad-leaf weeds (such as bedstraw, speedwell, and thistles). The box at right, “Reduction in wheat yield when disease is not controlled,” provides an example of wheat yield loss from disease.

The average grain yield of soft white winter wheat in western Oregon is approximately 100 bu/a. The recommendations in this guide, especially those for nitrogen, are adequate to produce higher yields. Yields of 140 bu/a or greater can be produced with these recommendations on sites where soil pH and drainage do not limit yield.

The recommendations in this guide are based on research conducted during the past 50 years on both large and small plots throughout western Oregon (see Appendix, pages 16–18).

## Management decisions before planting

### Rotation

Wheat may be grown in rotation with vegetables for processing, peppermint, grass seed, legumes, or specialty seed crops. The previous crop or rotation can limit wheat yield where the risk of soil-borne disease (such as take-all root rot) is high, or where the surface soil pH is low after production of a grass seed crop. If you are considering planting consecutive wheat crops, see the box on page 3, “Growing wheat with the risk of take-all root rot,” as this disease can reduce grain yield by 50 percent or more. For more information about managing wheat with take-all root rot, see OSU Extension Service publication EC 1423-E, *Combating Take-all of Winter Wheat in Western Oregon*.

### Field selection

Select a field that will provide drainage even after heavy rain events during wet winters. Wheat does **not** tolerate “wet feet.” Complete stand loss has occurred when the entire wheat plant was underwater for 7 or more consecutive days. Losses from shorter periods of flooding are primarily determined by crop condition. Stressed plants—late-planted, cold-injured, those consistently in waterlogged soils, etc.—are typically less tolerant of water coverage. For more information, see the box “Planting in poorly drained soil” (page 4).

## Reduction in wheat yield when disease is not controlled

Figure 1 shows that wheat yield increases with increasing N rate until approximately 120 lb N/a is applied; however, yield is significantly reduced by stripe rust. When disease is present, wheat yield is consistently higher when fungicides are used than when they are not. Apply the amount of N needed to obtain the yield potential, and control diseases so that yield potential can be reached.

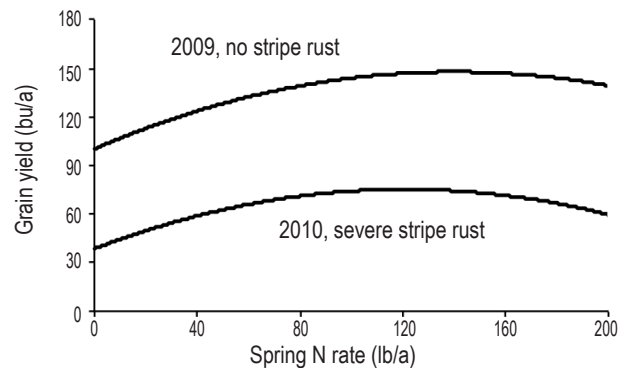


Figure 1.—Effect of N application rate and disease on wheat yield. These unsprayed trials were located at Hyslop Research Farm near Corvallis, Oregon.

Increasingly, winter wheat is planted without tillage (no-till) as a rotation crop with perennial and annual grass seed crops. Where fields are vulnerable to soil erosion because of slope, no-till seeding is common. See “Important no-till considerations” on page 4.

When fields are not tilled for as few as 3 years, soil pH in the surface declines, sometimes to levels that inhibit germination and result in stand loss. If wheat will be planted without tillage in a field that has not received tillage in 2 or 3 years, take a stratified soil sample to determine soil pH (see page 7).

Improved drainage and liming allow good wheat yields to be produced on sites once considered marginal for wheat production because of poor drainage or low soil pH. See “Soils and settings for wheat production” (page 5) for more information about soil suitable for wheat production.

### Variety selection

Nutrient recommendations in this guide assume that an appropriate variety is selected for the site. Select wheat varieties with agronomic and quality characteristics that match the growing environment. In western Oregon, consider varieties with good disease resistance and high yield potential. Diseases such as stripe rust and Septoria leaf blotch are common and may limit yield in susceptible or less resistant varieties.

Information on the agronomic and quality characteristics of common winter wheat varieties, as well as variety

performance, can be found on the Oregon Elite Yield Trials website ([http://cropandsoil.oregonstate.edu/wheat/state\\_performance\\_data.htm](http://cropandsoil.oregonstate.edu/wheat/state_performance_data.htm)).

## Planting date

Plant in mid- to late October after a period of cool temperatures, which reduce aphid populations and the risk of barley yellow dwarf virus (spread by aphids). If planting earlier, an insecticidal seed treatment is recommended to reduce the risk of aphid-spread diseases. Planting wheat in late September or early October also increases risk of stand loss from freezing temperatures occasionally experienced in early December.

Winter wheat must be exposed to cold temperatures, or vernalized, to trigger head formation. Vernalization requirements vary among cultivars. ‘Goetze’ has little to no vernalization requirement; ‘Madsen’, ‘Stephens’, and ‘Tubbs 06’ have intermediate vernalization requirements; and ‘Yamhill’ has a high vernalization requirement.

For varieties with low to intermediate vernalization requirements, planting as late as mid-February may be successful, although yields will be reduced. Avoid late planting for varieties with a high vernalization requirement. If winter wheat is not planted before January, consider planting a spring variety instead.

*continues on page 6*

## Growing wheat with the risk of take-all root rot

Take-all disease of wheat is caused by the soil-borne fungus *Gaeumannomyces graminis* var. *tritici*, which infects the roots, crown, and basal stem of plants (Figure 2). Take-all root rot is common in western Oregon when consecutive wheat crops are grown. Grain yield can be reduced by as much as 50 percent in the second or third crop of continuous winter wheat.

Few, if any, corrective measures are available after identifying a severe take-all root rot infestation. The following recommendations will minimize yield loss to take-all root rot when successive wheat crops are planted for fewer than 5 years. See OSU Extension Service publication EC 1423, *Combating Take-all of Winter Wheat in Western Oregon*, for more information.

Field selection is extremely important if take-all root rot may be a problem. If wheat will be grown for 2 or more consecutive years, choose a field with soil pH between 5.4 and 5.8. Yield loss from take-all increases when soil pH is above 5.8. Fields used to produce vegetable crops, clover, or sugar beets for seed usually have a soil pH above 5.8.

### Preplant management

#### Liming

A soil pH of 5.5 is desirable for combating take-all. Apply lime only if the soil pH is 5.2 or less.

#### Stubble

Chop stubble and plow deeply to bury the inoculum.

### Planting

#### Planting date

On well-drained valley floor soils, delay planting until late October if possible. On hill soils or valley floor soils with reduced drainage, plant by mid-October. For more information on wheat production on poorly drained soils, see OSU Extension Service publication FS 269, *Growing Winter Wheat on Poorly Drained Soil*.

### Fertilization

Band 20–30 lb N/a in ammonium form, plus 30–50 lb P<sub>2</sub>O<sub>5</sub>/a and 10–15 lb S/a. Apply 25–30 lb K<sub>2</sub>O/a if a soil test indicates the need for K.

### Growing season

#### Fertilization

Use the “N-min” soil test to determine spring N rate (see pages 11–12). For more information about the N-min soil test, see *Using the Nitrogen Mineralization Soil Test to Predict Spring Fertilizer N Rate*, EM 9020. Apply N as ammonium sulfate plus 100 lb Cl/a as KCl before Feekes growth stage 5 (see page 10). Alternatively, apply 40 lb N/a and 100 lb Cl/a at late tillering (Feekes 4; mid-February) and the remaining N within 3 to 4 weeks, but before jointing (Feekes 6).

#### Weed control

Control weeds to minimize competition with wheat for nutrients and moisture.

#### Disease control

Control leaf diseases such as Septoria and other root diseases by using resistant cultivars or fungicides. Maintaining plant health is important to ensure maximum benefit from other aspects of this management plan to reduce yield loss from take-all. Read and follow fungicide label directions.



Figure 2.—Wheat field with take-all. Photo: Neil Christensen



## Planting in poorly drained soil

Poorly drained soils have low oxygen levels because the air spaces in the soil are filled with water throughout the rainy season. Oxygen is required for normal root growth, so root development is restricted when the soil remains flooded (Figure 3).

Sufficient drainage can be created with ridges or “beds” made before planting (Figure 4). In poorly drained soils, seedlings growing on low ridges usually develop normal crown root systems because oxygen supplies are sufficient during the winter (Figure 5).

In theory, a bed of any height will work as long as the water can run into the furrow. In practice, a minimum of 3 inches from the bottom of the furrow to the top of the bed is needed. No matter how high the bed, complete stand loss is possible if the bed is underwater for 7 or more consecutive days. Losses from shorter periods of flooding are primarily determined by crop condition.

Variety selection is important as well. ‘Yamhill’ is the best cultivar for wetter fields. In drill strip trials, ‘Yamhill’ wheat had a yield potential of 85–90 percent of the top-producing varieties.



Figure 4.—Fall growth of wheat planted in poorly drained field with ridges. Photo: Neil Christensen



Figure 3.—Even when tile drains are installed, wheat may die or be injured by standing water in wet years. Tile drain is below green wheat. Yellow wheat is between drain lines. Photo: Mark Mellbye



Figure 5.—Wheat planted in poorly drained field with ridges in midwinter. Water is confined to furrows, allowing adequate oxygen to wheat roots in most of the field. Photo: John Hart

## Important no-till considerations

To ensure a suitable no-till situation, observe the follow guidelines:

- Take a stratified soil sample for pH analysis before planting (see page 7).
- Ensure that soil test levels are adequate for P (30 ppm), K (100 ppm), Mg (60 ppm), and pH (5.4).
- Consider using a starter fertilizer containing N and P, depending on soil test results.
- Apply 10–15 lb S/a at planting.
- Use the N-min test to determine spring N rate (see pages 11–12). The N-min test is applicable in both conventional and no-till situations.

## Soils and settings for wheat production

Soft white winter wheat requires better drainage than grass seed crops, but it is grown successfully on a broad range of soil and landscape positions in western Oregon. The majority of wheat in the Willamette Valley is planted on Amity, Woodburn, Willamette, Chehalis, Malabon, McBee, and other soil series characterized as either moderately well-drained or well-drained. Most of these fields have some relief or “roll” that provides drainage. In many fields, tile is installed to improve surface and internal drainage. Tiling is common on the river-bottom areas along the Willamette and Santiam rivers as well as on some steeper hill soils along the east and west sections of the valley.

Foothill soils include mostly the Nekia series along the valley foothills. Fields may be located on Hazelair, Helmick, and Steiwer soil series on the west side of the Willamette River. Soils are relatively shallow on many of these fields, and rock outcroppings can pose tillage problems. Proper tillage and planting are critical to protecting steep slopes from soil erosion, especially during fall seeding and the seedling stage. On the east side of the valley, fields can be located at elevations approaching 1,000 ft, and rainfall can be 50 percent greater than on the valley floor.

In the southern part of the Willamette Valley, wheat is grown with increasing success on somewhat poorly drained soil types such as Dayton. A combination of management practices has made this change possible. Increased use of lime and fertilizer, along with returning the full straw load, has removed soil pH and nutrient limitations on many grass seed fields. Good surface ditching and tiling are essential.

In addition, the use of no-till following grass seed crops, especially where the full straw load is chopped, has allowed successful winter wheat production on fields once considered too wet for grain production. No-till eliminates disturbance of soil structure and tilth that develop in a grass seed field, thus maintaining aeration and drainage on soils that are marginal for wheat production (Figure 6). However, some poorly drained grass seed fields are on landscape positions that pond or remain saturated for long periods of time, severely limiting wheat production regardless of drainage efforts or planting method.

In Douglas County, suitable soils for wheat production are Darby and Nonpareil. In Jackson County, wheat is planted in soil derived from two very different parent materials. In some areas, granitic parent material results in sandy loam soils such as Central Point sandy loam. These soils are easily tilled, but tend to have low native P and low water-holding capacity, requiring frequent irrigation for good yields of most crops. These soils are excellent for annual crops receiving frequent tillage, such as vegetables and specialty seeds.



Figure 6.—Planting wheat without tillage in the southern Willamette Valley. Photo: Mark Mellbye

The other primary soil type in Jackson County is derived from basaltic parent material, resulting in soils with moderate to high clay content and shrink–swell capacity, such as Carney clay and Coker clay. These soils are more difficult to till except under narrow moisture ranges, but tend to be high in native P. In the past, many productive acres of small grains and other agronomic crops were grown in Medford loam soil, which is derived from a mixture of both parent materials and exhibits a very good compromise of the physical and chemical characteristics of each.

In Josephine County, many soils are derived from ultramafic parent materials, resulting in loamy and stony soils that are moderately to strongly serpentine. Serpentine soils tend to be high in magnesium (Mg) and metals such as nickel (Ni), cobalt (Co), and zinc (Zn). They tend to be very low in native Ca, P, and S, but typically have a suitable pH for most crops. Crops grown on serpentine soils usually benefit from addition of Ca, P, and S. Since soil pH is usually adequate, Ca is supplied with gypsum rather than lime. Typical Josephine County soils used for agriculture include Brockman clay loam, Kerby loam, and Holland sandy loam, all found along alluvial fans of the Illinois River and its tributaries and all traditionally used for wheat production.

The mineralogy of the clay soils in Jackson County and serpentine soils in Josephine County is different, but both tend to strongly hold available P. As a result, observations have suggested that these soils typically require about twice as much added P to achieve the same crop yield or growth compared to the sandy loam soil in Jackson County and soils in other parts of western Oregon. See “Using the P soil test in Jackson County and southwestern Oregon” (page 9) for more information.



## Fall nutrient management

Sample and analyze soil to estimate the need for lime, phosphorus (P), potassium (K), calcium (Ca), and magnesium (Mg). Annual soil tests are not necessary for these nutrients—sampling and testing soil every other year or every third year is sufficient. If possible, sample soil after tilling and at the same time of year as previous soil tests. A single sample should represent no more than 40 acres, a single soil type, or an area in the field with the same management practices.

If you have questions about sampling or testing soil, contact your local OSU Extension Service office or refer to OSU Extension Service publication PNW 570-E, *Monitoring Soil Nutrients Using a Management Unit Approach*.

## Starter nitrogen (N), phosphorus (P), potassium (K), and sulfur (S)

Wheat planted with conventional tillage from October to early November usually does not benefit from “starter” fertilizer when P and K soil test values are adequate and the previous crop likely contributed a small amount of N (grass seed, legumes, peppermint, or vegetable crops). When planting wheat following a grain crop (e.g., oats, barley, or wheat), a small amount of N (20–30 lb/a) is needed. When planting consecutive crops of wheat on the same field, 30–50 lb/a of starter P and 10–15 lb/a of starter S are recommended to reduce the risk of take-all root rot.

Wheat may also benefit from starter N and other nutrients when planted in wet, cold soils, such as no-till establishment later than early November, planting on “ridges” in poorly drained fields, or when following crops that leave little residual N. Insufficient N during early growth limits tiller development (Figure 7).

Figures 8 and 9 illustrate the relationship between N at planting, previous crop, and wheat grain yield. When N was not applied in the fall (Figure 8), the wheat crop following oats never recovered from N deficiency early in the growing season. When 20 lb N/a was applied in the fall (Figure 9), grain yield was similar following oats and clover. When starter N was applied, the wheat crop following oats had sufficient early N. Early growth was not limited, and wheat yield was equal to or greater than that following clover when adequate spring N was applied (90 lb N/a or more).

Banding fertilizer near or with the seed is an efficient method for delivering a small amount of nutrient. The N may be applied in conjunction with other nutrients such as P, K, and S in a starter fertilizer. See pages 8–9 for more information about need for P, K, and S.

Placing fertilizer with the seed may delay emergence, sometimes by almost a week, and in dry years can reduce the stand. Do not apply more than 25 lb  $K_2O/a$  or 25 lb N/a with the seed.

## Lime, calcium (Ca), and magnesium (Mg)

Soil pH indicates whether soils are too acidic and lime is needed, as it indicates the chemical condition roots will experience. A decrease in soil pH is accompanied by increased solubility of iron, zinc, manganese, copper, and aluminum. The concentration of aluminum can reach levels that inhibit root growth.

Winter wheat tolerates moderately acidic soil (pH 5.4). However, wheat yields decrease as soil pH decreases



Figure 7.—Wheat on left did not receive N at planting. Wheat on right received N in a band at planting. Photo: John Hart

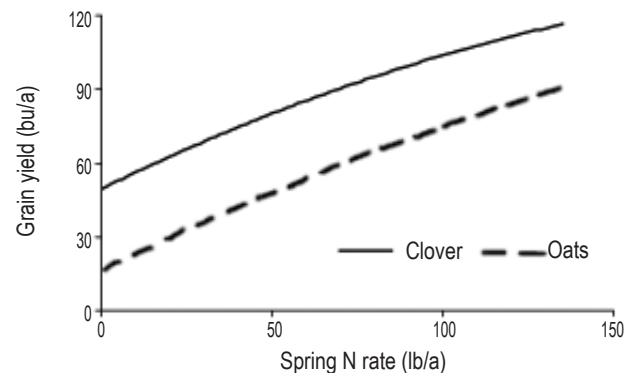


Figure 8.—Grain yield of wheat following oats or clover when no fall or starter N was applied.

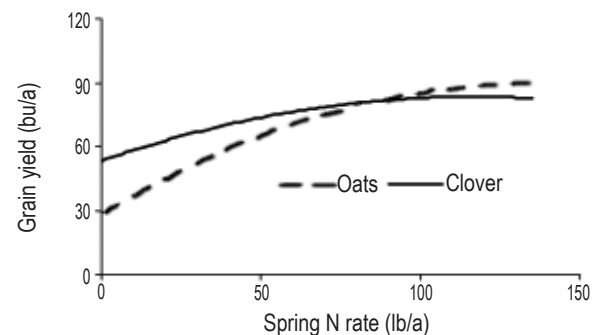


Figure 9.—Grain yield of wheat following oats or clover with fall or starter N application of 20 lb N/a.

below 5.4 (Figures 10 and 11). **Apply lime using the SMP buffer measurement when soil pH is below 5.5.** Yield probably will not increase if soils are limed above pH 5.7. Lime application is not recommended if the soil pH is above 5.8, especially if the risk of take-all is high, as yield loss from take-all increases when the soil pH is higher. A lime application is effective for several years.

The Shoemaker-McLean-Pratt (SMP) buffer or lime requirement (LR) test estimates the amount of lime needed to raise soil pH. Determine lime application rate by using the SMP buffer measurement and Table 1. Sometimes sandy or river-bottom soils such as Newberg have less than 5 meq Ca/100 g soil; in this case, a lime rate of 1 t/a is recommended even if soil pH is adequate.

Table 1.—Lime rate recommendations for western Oregon using the SMP buffer test. Note that SMP buffer is different than, and does not equal, soil pH.

SMP buffer test result <sup>a</sup>	Apply this amount of lime <sup>b</sup> (t/a)
Below 5.5	3–4
5.5–5.8	2–3
5.8–6.2	1–2
Over 6.2	None

<sup>a</sup>Lime recommendations are based on SMP buffer test only. If other buffer tests are used, recommendations may differ. Liming rates cannot be determined based solely on soil pH.

<sup>b</sup>Lime rate is based on 100-score lime.

Sample and test soil for pH, SMP buffer lime requirement, and Ca well before planting because lime should be mixed into the seedbed before seeding. Soil pH changes naturally between seasons by as much as 0.3–0.5 unit. It is lowest in late August and September, before the fall rains begin, and highest in February or March, when the soil is wettest. Sample soils for pH at the same time each year to avoid confusion caused by seasonal fluctuation.

In no-till situations, a stratified soil test is recommended to evaluate pH in the surface 2 inches of the soil. To collect a stratified sample, insert a soil probe 6 to 8 inches and then separate the top 2 inches of soil from the remaining depth. If soil pH in the top 2 inches is below 5.0, apply lime and mix with tillage to make a seedbed suitable for germination and early growth. This recommendation assumes that soil pH below the surface 2 inches is adequate for wheat production (above 5.5). In this situation, top-dressed lime without tillage immediately before planting will not adequately change the pH in the surface soil. For more information about pH stratification, see OSU Extension Service publication EM 9014, *Evaluating Soil Nutrients and pH by Depth in Situations of Limited or No Tillage in Western Oregon*.

See OSU Extension Service publication FS 52-E, *Fertilizer and Lime Materials*, for more information about liming materials.

Although wheat yield increase from application of Mg has not been documented in western Oregon, we advise adding Mg if soil test Mg is below 60 ppm or 0.5 meq/100 g soil. In this case, substitute 1 t dolomite/a for 1 t lime/a of the lime requirement. Magnesium can also be supplied by fertilizers such as Sul-Po-Mag and K-Mag. These materials also supply S. A band application of 10–15 lb Mg/a is sufficient.

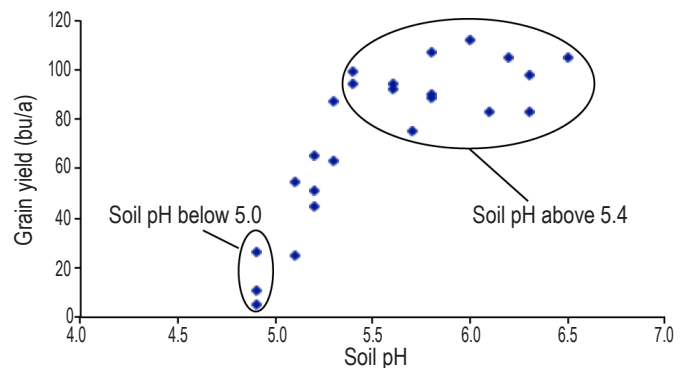


Figure 10.—Grain yield of winter wheat as related to soil pH on an acidic western Oregon field. Lime should be applied and incorporated when soil pH is less than 5.5.



Figure 11.—Low soil pH reduces wheat growth and vigor unevenly in a field. The areas of light green wheat and sparse growth have a soil pH of 4.3. The soil pH is higher in the areas with darker green wheat. Photo: Thomas Silberstein

## Sulfur (S), phosphorus (P), and potassium (K)

Banding P, K, S, and some N fertilizer with or near the seed at planting is an effective method of fertilizer application for small amounts of nutrients, especially immobile nutrients such as P and K. Placing fertilizer with the seed will delay emergence and in dry years can reduce the stand. Do not apply more than 25 lb K<sub>2</sub>O/a or 25 lb N/a with the seed.

These nutrients are discussed in order of importance (likelihood that deficiency will limit wheat grain yield).

### Sulfur

Grain yield increase from S application is site- and year-specific. No soil test adequately predicts soil S supply. Our approach is to place the likelihood of yield increase from S application in three categories—low or none, normal, and high.

- **Low**—Little or no S is needed when wheat follows vegetable or legume crops that received 30–40 lb S/a for several years. If growers wish to ensure that adequate S is present in this situation, 10–15 lb sulfate-S/a can be applied with spring N.
- **Normal**—Sulfur is likely to limit grain yield in fields that did not receive S the previous year (most rotations). In this situation, application of 10–15 lb sulfate-S/a at planting time will provide ample S.
- **High**—The need for S is highest if wheat or oat straw is incorporated. When straw is incorporated, S is “tied up” or immobilized, similar to N. Where wheat or oat straw is incorporated, broadcast and incorporate 10–15 lb S/a before planting and then band the same amount at planting. This practice may increase wheat grain yield by as little as 3–4 bu/a to as much as 15–20 bu/a in the second year compared to yields when only 10 lb S/a is banded and no additional S is applied. See the box below for more information.

## Early-season diagnosis of S deficiency

Sulfur is routinely applied to most crops in western Oregon. Therefore, S deficiency in a western Oregon soft white winter wheat crop is uncommon. Likewise, early-season N deficiency is uncommon.

If nutrient deficiency is suspected, look for the following signs:

- Early-season N deficiency is expressed by yellowing of older leaves as N is moved to new tissue.
- In S-deficient wheat, the new growth is light colored (Figure 12). Plants look very pale since this new growth often hides the darker green lower leaves. Examine plants closely, as the view from a vehicle or even walking through a field can deceive you into thinking the entire plant is pale.

Plant analysis can be used to determine whether the yellow color might be caused by lack of S. This analysis differs from the standard evaluation of tissue concentration of a single element or nutrient. For evaluation of plant S status, the ratio of N to S (N:S) concentration in plant tissue is used as the diagnostic criterion. The amounts of N and S in protein are the basis for using the N:S ratio. Using a ratio of two elements rather than the concentration of a single

element reduces the difficulty of interpreting decreasing tissue concentrations in the presence of rapid plant growth.

To evaluate early-season S deficiency in wheat, collect material from the entire above-ground portion of the plant. Have the sample

analyzed for total N and S. To calculate the N:S ratio, divide the N concentration by the S concentration ( $\% N \div \% S$ ). For example, tissue with 4.8 percent N and 0.4 percent S has an N:S ratio of 12:1 ( $4.8 \div 0.4 = 12$ ). To evaluate S sufficiency, compare your calculated N:S ratio with the values in Table 2.

Sulfur deficiencies can be corrected if diagnosed before Feekes growth stage 6. Treat deficiencies by applying 10–15 lb sulfate-S with spring N.



Figure 12.—Sulfur deficiency is characterized by pale, yellow new growth. Photo: Neil Christensen

Table 2.—Evaluation of N:S ratio in soft white winter wheat.

N:S ratio	Evaluation	Comments
Less than 10:1	S is adequate	N concentration should be greater than 3 percent; otherwise it might be limiting growth
Between 10:1 and 15:1	S may or may not be limiting	—
Greater than 15:1	S is deficient	Tissue S below 0.2 percent is likely



## Phosphorus

Phosphorus is especially important for early growth of most crops in the grass family, including small grains and corn. Deficiency during the seedling stage can severely limit yields. Applying P at planting when P availability is low due to cool, wet soil conditions is important.

Is P fertilizer always needed? The answer is no. Where P is routinely applied, P soil test values typically are quite high. When soil tests indicate high amounts of P (> 30 ppm), and soils have adequate temperature and aeration for growth, wheat yield does not increase from application of P fertilizer. For soils with a P soil test value above 30 ppm, reducing or eliminating P application will increase profit.

Phosphorus recommendations in Table 3 are for banding P near the seed at planting. An alternative P recommendation table for Jackson and Josephine counties is found in the box “Using the P soil test in Jackson County and southwestern Oregon.”

Table 3.—Fertilizer phosphorus rate recommendations for western Oregon using the Bray P1 soil test.

Soil test P <sup>a</sup> (ppm)	Apply this amount of P <sub>2</sub> O <sub>5</sub> (lb/a)
0–20	40–60
20–30	30–40
Over 30	None

<sup>a</sup>Bray P1 soil test method.

The one exception to using soil test results to determine the need for P application is when take-all root rot is expected. We then recommend banding 30–50 lb P<sub>2</sub>O<sub>5</sub>/a at planting. When take-all root rot was present, wheat grain yield increased 9 bu/a (from 56 to 65 bu/a) when P was banded with the seed on a Willamette soil with a Bray P1 soil test of 125 ppm—a statistically significant and profitable increase. See the box “Growing wheat with the risk of take-all root rot” (page 3) for more information.

## Potassium

Soil test K results and the need for K fertilizer are often related to crop rotation. Crops that remove several tons of dry matter per acre, such as peppermint or grass seed with baled straw, remove large amounts of K with harvested crops. The removal of several tons of stalks and leaves reduces K soil test values (see Tables 11 and 12, page 14). If straw is left in the field, K fertilizer requirements usually are reduced or eliminated.

If a soil test indicates K fertilization is required, 25 lb K<sub>2</sub>O /a can be placed with the seed. Placing fertilizer

with the seed will delay emergence and in dry years can reduce the stand. If normal rainfall and soil moisture aren't present, delay planting until adequate moisture is present or eliminate K in the fertilizer band. If higher rates of K fertilizer are needed, apply the fertilizer before seeding and work it into the seedbed.

Table 4.—Fertilizer potassium rate recommendations for western Oregon using the ammonium acetate soil test.

Soil test K <sup>a</sup> (ppm)	Apply this amount of K <sub>2</sub> O (lb/a)
0–75	60–100
75–100	30–60
Over 100	None

<sup>a</sup>Ammonium acetate soil test method.

## Using the P soil test in Jackson County and southwestern Oregon

Interpretation of soil tests varies geographically, primarily because soil parent material and the growing environment are different across the landscape. The same soil test, such as the Bray test for P, must be interpreted differently when the parent material of the soil is markedly different. The soil test itself does not provide a fertilizer recommendation—our interpretation of the soil test results leads us to propose a fertilizer recommendation.

This situation is true for western Oregon, where some serpentine soils in Josephine County and soils with high clay content in Jackson County have a greater ability to hold and compete with plants for available P. These soils require more P for optimum yield than do soils in other areas. In Jackson and Josephine counties, use Table 5 for P fertilizer recommendations based on soil test P.

Table 5.—Fertilizer phosphorus rate recommendations for Jackson and Josephine counties using the Bray P1 soil test.

Soil test P <sup>a</sup> (ppm)	Apply this amount of P <sub>2</sub> O <sub>5</sub> (lb/a)
0–10	60–80
10–40	30–60
Over 40	None

<sup>a</sup>Bray P1 soil test method.

## Spring nutrient management

Two questions are asked about spring N application: when to apply the N, and how much N to apply. We will consider N timing, or when to apply, first. For more information about the need for N during wheat growth, see the box below, “Wheat grain yield and N supply.”

### N timing, or when to apply

Use plant growth and development and not the calendar as a guide to determine when to apply N. Wheat growth and development is illustrated in the box below. A small amount of N (20–40 lb/a) is accumulated through the end of tillering (Feekes growth stage 5). As jointing and stem elongation begin (Feekes growth stage 6), N is rapidly accumulated by the plant.

Application of spring N prior to Feekes growth stage 6 (jointing) is critical because rapid N uptake begins at this stage. In a 5- to 8-week period, wheat takes up 100–150 lb N/a, with a peak N uptake rate of 2–3 lb N/a/day during jointing (Figure 14, page 11). Wheat grain yield decreases by 10–15 bu/a when spring N application is delayed until late March or early April, which typically is after jointing begins.

Date of jointing will vary by variety, planting date, and growing conditions. In western Oregon, jointing typically occurs between mid-February and mid-March, but can begin as early as the first of February or as late as the first of April. Calendar dates are not reliable predictors of jointing, as temperature (accumulating heat units) controls early wheat development. On average, jointing occurs between 1,000–1,200 growing degree days after planting. However, the best method to determine jointing is to examine plants by running your fingers along the stem. If you feel a bump or joint near the base of the plant, then that plant has jointed and is at Feekes growth stage 6.

By boot stage (Feekes growth stage 10), the plant has accumulated the majority of the N it will use, but only about half of its biomass (Figure 14). As grain begins to form, N is moved from the leaves and stems to the head.

An adequately fertilized wheat crop will not produce additional yield if fertilized with N after Feekes growth stage 8 (the appearance of the flag leaf). Late-season N fertilization has been shown to increase grain protein—an undesirable effect in soft white wheat. It also increases the risk of N loss to the environment.

Growers often wonder whether splitting the spring N application is better than applying it all at one time.

## Wheat grain yield and N supply

Wheat yield is a combination of number of heads per unit area, kernels per head, and kernel weight. Both head number and kernels per head are set early in wheat development (Feekes growth stages 2–5).

Twenty to 30 lb N/a is sufficient for growth and development through these stages. This amount of N is supplied by soil or from an application at planting. Nitrogen supply at jointing or stem elongation (Feekes growth stage 6) is critical for further plant development and optimum yield. Maximum N uptake occurs during this period of rapid growth and continues until head emergence (Feekes growth stage 10.1). Nitrogen stress during this period will reduce yield. Apply N fertilizer before jointing (Feekes growth stage 6) to optimize yield.

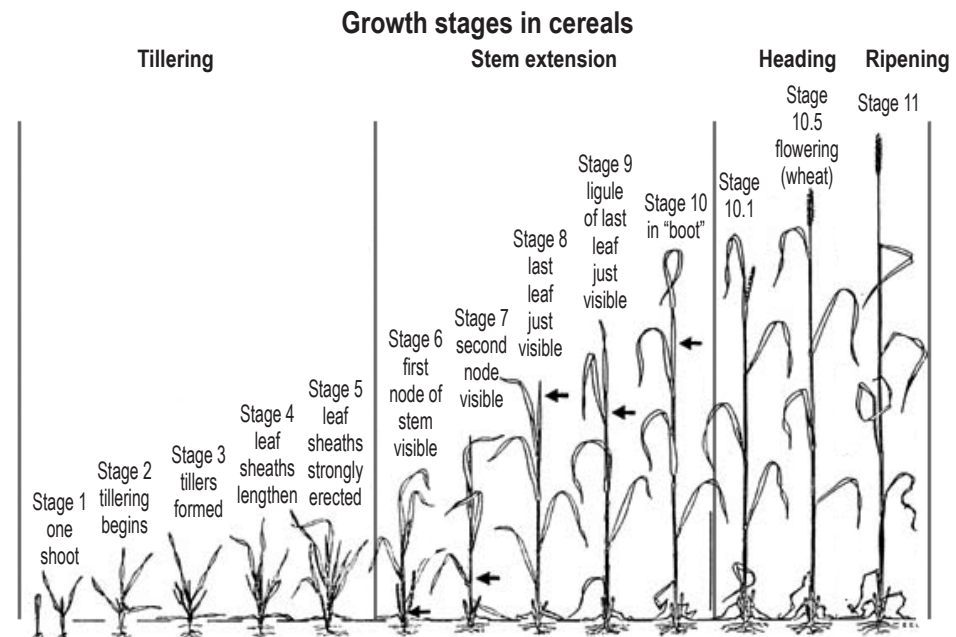


Figure 13.—Feekes growth stages.

Kernel weight is determined by the amount of N present in the plant and, to a lesser degree, the N present in the soil at head emergence (Feekes growth stages 10.1–10.5).

Although you can choose from several approaches, research has demonstrated that grain yield is similar regardless of whether a single application of N is made in February or March or N is split among multiple applications, as long as some N is applied in February or March (see Table 6).

If you do not want to risk leaching loss of N with a high rate (more than 140 lb N/a) in late February, split application is a good option; apply 40 lb N/a at Feekes growth stage 3 or 4 and 100 lb N/a within the next month. This N application schedule provides a small amount of N during tillering, and the remainder is made available before jointing. Split N applications can be beneficial where substantial early-season N losses are expected, such as on sandy soils with high rainfall.

Split N application is also appropriate if urea-ammonium nitrate liquid (Solution 32) is used to supply N. Liquid N is commonly applied with a midwinter herbicide application and should be counted in the total N applied. A single application of a high rate of Solution 32 is likely to injure or burn the wheat.

Table 6.—N timing influence on yield of ‘Stephens’ wheat (Central Point, Oregon).

N application date			Grain yield
February 10	March 10	April 11	
N rate (lb/a)			
120	0	0	88
0	120	0	91
0	0	120	75
60	60	0	91
60	0	60	92
0	60	60	88
40	40	40	90

### N rate, or how much to apply

Inadequate N results in reduced yield. However, excess N increases lodging, grain protein, production costs, and the potential for N loss to the environment. Determining the amount of N to apply is a challenge because wheat is produced in numerous rotations that provide varying amounts of N to the wheat crop. Wheat following some vegetable crops, tall fescue, or perennial ryegrass grown for seed may require a minimal amount of N (80 lb/a).

Wheat obtains N from two sources: soil and fertilizer. Soil N is provided in available mineral form (nitrate or ammonium-N) and as mineralizable N (nitrogen contained in organic matter; this N will become available during the growing season). The N mineralization (“N-min”) soil test measures both available and mineralizable N and can be used to accurately calculate the spring fertilizer N rate for winter wheat.

Numerous research projects from 1998 through 2011 evaluated the N-min test to predict spring N rate. No reduction in grain yield was measured when the N-min test was used to predict spring N rate. In these studies, soil

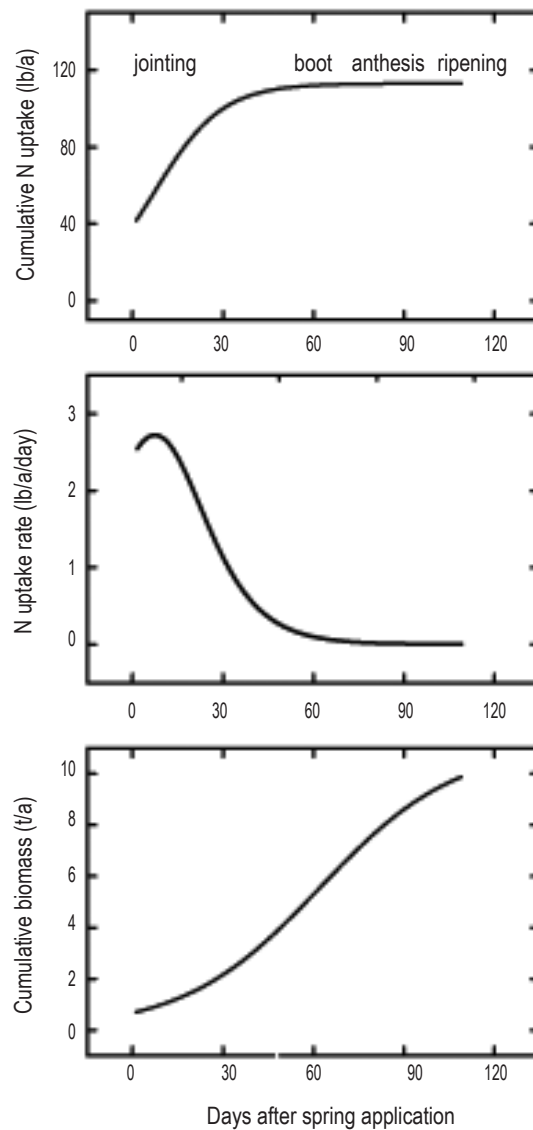


Figure 14.—Nitrogen uptake and biomass accumulation for winter wheat grown in western Oregon over one growing season. Day 0 is approximately March 1 (Feekes growth stage 3).

samples were taken in late January, and N was applied before stem elongation began. Timely soil sampling and N application are required to maintain yield.

Determining spring N rate using the N-min soil test has not been verified in Douglas, Jackson, and Josephine counties. Use it with caution in these counties!

### Using the N-min soil test

The first step in using the N-min soil test is to collect a composite soil sample. Take soil samples during the last 2 weeks of January. Sampling during this period allows enough time for analysis of the soil sample (about 2 weeks) and calculation of fertilizer needs before application of N fertilizer at Feekes growth stage 5. Sampling in late January also reduces variability in test results.

Sample to a depth of 12 inches and include a minimum of 20 soil cores representing the area to be fertilized.



Place the samples in a cooler with ice or an artificial cooling material immediately after collection. Rapidly air dry or keep the samples on ice and deliver to the laboratory within 24 hours. If neither of these procedures is possible, freeze the samples and ship them frozen to the laboratory. Request three analyses from the laboratory: (1) ammonium-N, (2) nitrate-N, and (3) mineralizable-N. Be sure the laboratory you choose can provide all analyses—not all laboratories offer a test for mineralizable N by anaerobic incubation. Request that analyses be expressed in parts per million (ppm) or milligrams per kilogram (mg/kg), not as pounds per acre (lb/a).

Using your three N analyses, see Table 7 to select a spring N fertilizer application rate. Table 7 recommends a range of spring N rates from 80 to 200 lb N/a. Even when the N-min test result is high, a minimum amount of fertilizer N is needed for optimum wheat production. OSU research has shown that 80 lb N/a is the minimum prudent amount to apply (shaded portion of Table 7).

To find a spring N rate using Table 7, be certain that the soil test results are in parts per million (ppm) or milligrams per kilogram (mg/kg). Begin with your mineralizable N soil test results. Values are found in the left-hand column of Table 7. Follow the N-min column down until you find the soil test value closest to yours. Next, add together your soil test  $\text{NH}_4\text{-N}$  and  $\text{NO}_3\text{-N}$  values. Then, locate the column heading that contains the sum of these values. Move down the  $\text{NH}_4 + \text{NO}_3$  column and to the right from your N-min value. The number where the row and column intersect is the recommended spring N rate given in pounds of N per acre.

In Table 7, N-min test values increase by increments of 4 ppm, and spring N rates increase by increments of 20 lb/a. If your N-min soil test value is between those listed in Table 7, adjust the recommended spring N application rate by 5 lb/a for each 1 ppm N-min.

For more information about the N-min test, see OSU Extension Service publication EM 9020, *Using the Nitrogen Mineralization Soil Test to Predict Spring N Fertilizer Rate: Soft White Winter Wheat Grown in Western Oregon*.

Table 7.—Recommended spring N fertilizer rates based on the N-min soil test and extractable soil  $\text{NH}_4\text{-N}$  plus  $\text{NO}_3\text{-N}$ .

N-min soil test (ppm or mg/kg)	Soil test $\text{NH}_4 + \text{NO}_3$ (ppm or mg/kg)			
	below 10	10–15	16–20	above 20
	Apply this amount of N (lb N/a)			
12	200	180	165	145
16	180	160	145	125
20	160	140	125	105
24	140	120	105	85
28	120	100	85	80
32	100	80	80	80
36+	80	80	80	80

continues on page 14

## Application equipment and yield loss

Spring N is most commonly applied as granular urea using three-wheel buggies with wide tires that provide high flotation. Some growers use four-wheel (narrow-tire) applicators. Both options trample or crush some of the crop. Before jointing, wheat can be trampled or grazed with little damage or yield loss. After jointing, nutrient applications using either type of equipment can cause yield loss since the plants will not recover from damage. Most of the damage to tillering wheat is caused when plants are ripped from the ground.

Table 8 compares yield loss from three-wheel buggies driven in a random pattern and four-wheel, narrow-tire applicators repeatedly driven in the same tire tracks (“tram lines”). Data were averaged over three locations in each field. Sampled areas did not include corners or turns.

Yield in three-wheel buggy tracks was 16–18 bu/a less than in areas with no tracks. Overall, average field yield was 4 bu/a lower than yield outside the tracks. Assuming buggy application is 60 feet wide, 20 percent of the field will have tracks that have been driven on. If your field has more tracks, especially corners, turns, or areas driven over twice, a greater yield loss will occur.

Yield loss in the track area from a four-wheel applicator was approximately the same as for buggy application. However, much less area was driven on, so field yield loss was only 2 bu/a with the four-wheel applicator.

In a continuously or solidly planted stand, the tram line of a four-wheel applicator will crush a row or two of wheat plants. If rows that match the wheel spacing of the applicator are not planted, the tires usually push aside the remaining rows. The undamaged plants will tiller and compensate in growth and yield for the unplanted area. Thus, yield is reduced little, if any, with this system.

Aerial application prevents yield reduction caused by wheel-track damage to plants.

Table 8.—Wheat yield loss from applicator tracks in spring.

	Buggy	Narrow-tire applicator
	Wheat yield (bu/a)	
Yield outside track, 1987	119	123
Average yield, 1987	115	121
Yield in track, 1987	101	110
Yield outside track, 1984	96	—
Yield in track, 1984	80	—

## Fertilizer additives

Standard N and P fertilizer materials are marketed with coatings to reduce volatile loss of ammonia (urease inhibitors), to stop or slow conversion of ammonium-N to nitrate-N (nitrification inhibitors), to increase availability of P, and to protect fertilizer from leaching loss (polymer coatings). Fertilizer additives have been marketed for more than 100 years, and nitrification inhibitors have been common for 50 years. All of these materials add to fertilizer cost.

When considering whether to purchase a fertilizer additive, first identify the problem the additive might solve, and then consider whether you can meet the same goal with a slight management change. For example, nitrification inhibitors slow the conversion of ammonium-N to nitrate-N and reduce the possibility of N loss by leaching. However, leaching can be avoided by applying spring fertilizer at early jointing when rapid N uptake begins.

Research to assess the benefit of nitrification inhibitors was conducted in soft white winter wheat fields in western Oregon in 2010. Urea was applied at varying rates in a single application with and without a nitrification inhibitor. Wheat yields ranged from 45 to 132 bu/a. No significant yield increases resulted from use of a nitrification inhibitor at either location (Table 9). As yield increased, the nitrification inhibitor did not increase yield. This experiment shows that when the timing of urea application matches the timing of wheat N use, a nitrification inhibitor is not beneficial or needed.

Additional experiments with wheat and other crops have given similar results. Use of nitrification inhibitors or other fertilizer additives without consideration of your specific situation can result in additional expense without benefits.

Table 9.—Soft white winter wheat yield, nitrogen (N) rate, and nitrification inhibitor (NI), Forest Grove and Corvallis, Oregon, 2010.<sup>a,b</sup>

N rate (lb/a)	Forest Grove		Corvallis	
	Urea	Urea + NI	Urea	Urea + NI
	Wheat yield (bu/a)		Wheat yield (bu/a)	
0	45.1 b	41.0 b	74 a	78 a
40	69.2 a	52.7 b	101 a	106 a
80	79.8 a	72.5 a	118 a	114 a
120	80.9 a	76.5 a	130 a	124 a
160	80.8 a	79.6 a	132 a	128 a

<sup>a</sup>At each location, yields followed by the same letter in each row are not statistically different.

<sup>b</sup>N was applied at Feekes 5.

## Alternative N sources

Increasing fertilizer prices and alternative production practices cause growers to consider alternative nutrient sources. Available materials are usually low analysis (1–10 percent nutrient content), compared to 15–45 percent for many “commercial” fertilizer nutrient sources. The low analysis creates a challenge of supply. For example, heat-treated biosolids contain 0.5 percent N, requiring 3,000 lb material/a to supply 150 lb N/a.

Another challenge encountered with use of alternative nutrient sources is availability of nutrients or “release” rate. The nutrients in most alternative materials are part of compounds. These compounds usually require microbial degradation to become available for plant uptake. Microbial change requires time. Matching nutrient availability to wheat nutrient need, especially N in the spring, can be difficult using alternative sources.

Current work at OSU (2011) is evaluating heat-dried biosolids and feather meal as fall and spring N sources. After 2 years of evaluation, a fall application of 40 lb N/a as biosolids or urea did not provide a yield advantage compared to no fall N. Grain yield from a spring biosolid application was comparable to grain yield from urea when sufficient N was supplied. Feather meal treatments produced grain yields similar to heat-dried biosolid treatments.

This research confirms that soft white winter wheat can be produced in western Oregon with either conventional commercial fertilizer or alternative N sources. For both nutrient sources, providing an adequate rate of N early in the season (before Feekes 6) is critical.

## Micronutrients and foliar applications

Wheat yield in western Oregon has not been observed to increase from applications of micronutrients such as boron (B), manganese (Mn), or zinc (Zn). Application of chloride (Cl) may play a positive role when plants are stressed, especially by take-all root rot. Chloride deficiency has also been linked to physiologic leaf spot in wheat, which reduces grain yield in eastern Oregon.

Foliar nutrients are recommended only when nutrient deficiencies are visible in a growing crop and the nutrient can be absorbed through the leaf tissue. This combination is extremely rare in western Oregon. Some growers advocate foliar nutrient applications for some crops when roots are damaged or yield is high. Research in western Oregon does not support the use of foliar nutrient applications in either of these situations for soft white winter wheat production. Foliar application does not increase wheat yield.

Table 10 contains data from three sites where N and Zn were applied to wheat foliage in April. No yield increase was found. Even when wheat yield was 125 bu/a, foliar nutrient application did not increase yield. In addition, wheat yield was not increased when yield was low due to an infection of take-all root rot (Lane County site).

Table 10.—Wheat grain yield with foliar application of N and Zn compared to grain yield without application, 1981.

N rate (oz/a)	Zn rate (oz/a)	Date	Grain yield (bu/a)		
			Lane	Marion	Linn
0	0	—	65	102	122
4	1	April	61	78	117
8	3	April	66	87	110
15	5	April	57	—	—

## Postharvest evaluation of N

Growers routinely receive grain protein data when wheat is sold. Use this data as a “report card” to check adequacy of N fertilizer rate. Maximum economic yield is associated with grain protein concentrations between 8.5 and 10.5 percent. Grain protein less than 8 percent suggests that N may have been inadequate. Grain protein greater than 10.5 percent suggests that N may have been excessive or that yield was limited by a factor other than N.

## N, P, K, S content in wheat grain and straw

As wheat producers consider baling straw, they want to know the amount of nutrients in wheat straw. Table 11 provides data for nutrient concentrations in wheat grain and straw, and Table 12 shows the typical nutrient content of a soft white winter wheat crop.

Table 11.—Grain protein and nutrient concentrations in soft white winter wheat grain and straw.<sup>a</sup>

	Protein	N	P	K	S
	(%)				
<b>Grain</b>					
Range	7–12	1.4–2.3	0.25–0.4	0.38–0.53	0.12
Average	9	1.5	0.33	0.46	0.12
<b>Straw</b>					
Range	—	0.20–0.50	0.02–0.14	0.75–2.0	—
Average	—	0.25	0.05	1.3	—

<sup>a</sup>Data from research in western Oregon.

The data in Table 11 are from field experiments performed in grower fields and at Hyslop Research Farm from 1981 through 2003. They represent more than 200 measurements for P, 100 for K, and as few as 15 for S. Grain P, K, and S and straw P values are more consistent than grain and straw N and straw K.

The variability in data from field to field and year to year suggests that you should use these values only for information or for comparison to values measured in your fields, rather than as a basis for fertilizer application rates.

The amount of N, P, K, and S expected in a 100 bu/a wheat crop is given in Table 12. Most of the crop N is in the grain. In contrast, three-fourths of the K is in the straw. Baling straw removes a substantial amount of K.

The amounts of P and K in Table 12 are given in elemental form. To make comparisons with P<sub>2</sub>O<sub>5</sub>, multiply the P values in Table 12 by 2.27. To compare elemental K data to K<sub>2</sub>O, multiply the K values in Table 12 by 1.2.

Table 12.—Nutrient content for a typical soft white winter wheat crop yielding 100 bu/a.<sup>a</sup>

	N	P	K	S
	(lb)			
Grain (100 bu)	90	20	28	7
Straw (3 ton)	16	3	81	—
Crop total	106	23	109	7

<sup>a</sup>Calculated using average concentrations from Table 11 and a Harvest Index of 0.49.

## Economics: Should N rate change when N costs or wheat prices change?

When the cost of N fertilizer or the price for a bushel of wheat changes abruptly and considerably, growers wonder whether they should adjust spring N rate. Should the N rate be reduced when N cost climbs or increased when wheat price increases? The answer is the same for either circumstance—do not change N rate. Table 13 (page 15) illustrates how the cost of N or price for wheat affects the maximum economic rate of N.



Table 13.—Change in maximum economic spring N rate as influenced by cost of N fertilizer and price for wheat.

Wheat price (\$/bu)	N cost (\$/lb)				
	0.40	0.50	0.60	0.70	0.80
	<b>Maximum economic N rate (lb/a)</b>				
4	108	105	101	98	95
6	113	110	108	106	104
8	115	113	111	110	108
10	116	115	114	112	111

In Table 13, most of the changes in maximum economic N rate are less than 10 lb N/a. For example, if the wheat price doubles from \$4/bu to \$8/bu and N cost is constant, the maximum economic N rate increases only 7 lb/a when the N cost is \$0.40, and only 13 lb/a when the cost of N is \$0.80/lb. This level of change is negligible and is less than the accuracy of most commercial fertilizer applicators.

The base N rate used in Table 13 was 105 lb N/a, using an N mineralization soil test of 24 ppm and ammonium-N plus nitrate-N of 18 ppm. The equation used to calculate the maximum economic N rate was derived from an on-farm N rate trial conducted in 1986 in a second-year wheat field where the average yield was more than 110 bu/a.

## Plant growth regulators

The use of plant growth regulators on winter wheat is not recommended. Modern winter wheat varieties are semidwarf and selected for good straw strength and lodging resistance. Only under extreme circumstances, such as the application or availability of N greater than 1.5 times the recommended N rate, would the application of a plant growth regulator be advisable.

## For more information

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## Acknowledgments

We thank the following reviewers for their thoughtful advice and assistance during preparation of the original publication.

Susan Aldrich-Markham, former OSU Extension agent

Gale Gingrich, Marion Ag Service

T.J. Hafner, Wilbur Ellis Company

Russ Karow, Oregon State University, Department of Crop and Soil Science

John Leffel, former OSU Extension agent

Steven Petrie, Oregon State University, Columbia Basin Agricultural Research Station

Steve Salisbury, Wilbur-Ellis Company

Robert Schroeder, Crop Production Services

Robert Spinney, Crop Production Services

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## Appendix. Nutrient-related winter wheat research in western Oregon

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Over the past 50 years, significant plant nutrition research has been performed in soft white winter wheat in western Oregon. An overview of this work is presented below.

- **1962:** Plots were located in Benton (Hyslop Research Farm) and Polk counties. Site-specific N rate was measured. Maximum yield was produced at a range of N rates, with a low of 40 lb N/a at one site and a high of 120 lb N/a at another site. A single N application was superior to multiple N applications. Maximum yield at two locations was produced with 7–8 percent grain protein and at a third location with 9.5–10 percent grain protein. These values are similar to current protein concentrations used to evaluate adequacy of a spring N management program.
- **1969–1976:** Wheat varieties with varying levels of aluminum tolerance were used in a series of nutrient solution experiments examining the inhibitory effect of aluminum on wheat growth and nutrient uptake. Root elongation was inhibited more than was nutrient uptake. The severity of toxicity increased sharply when the concentrations of nutrients in aluminum-containing solutions were increased. When seedlings were treated with a minimum critical concentration of aluminum for as few as 48 hours, the root primary meristem was irreversibly damaged and did not reinitiate growth when transferred into an aluminum-free solution. Lateral roots were more sensitive to aluminum concentration than were primary roots.
- **1970:** Temperature and moisture were managed in a greenhouse to measure P assimilation by seedling wheat under varying conditions. Phosphorus concentration in the shoots increased as a linear function of root temperature between 50 and 95°F. The fraction of P translocated from roots did not vary over this temperature range. No relationship was measured between P uptake and transpiration. The low rate of P uptake at lower temperatures was likely caused by limited energy availability.
- **1972–1975:** Field (Nekia soil series in Marion County) and growth chamber experiments examined lime rates, amount of mixing, and longevity of lime application. Results confirmed that soil pH should be above 5.4 for wheat production. Aluminum toxicity inhibited root growth when soil pH was below 5.0.
- **1975–1991:** In consecutive wheat crops, take-all root rot substantially reduced yield in many cases. No fungicide controlled the disease. Certain crop management practices reduced yield loss: delaying planting until late October, planting on well-drained valley floor soil with

a soil pH between 5.5 and 5.8, banding P regardless of soil test P, using only ammonium-N, and adding 100 lb Cl/a at late tillering or early jointing.

- **1976–1979:** Small ridges (3–5 inches high) kept wheat crowns above water and were critical for plant survival. Planting on ridges increased grain yield by 20–50 percent compared to planting without ridges.
- **1977–1980:** Effects of P addition were studied in Linn and Douglas counties. Soil test P was 12 or 25 ppm (Bray soil test), and soil pH was between 5.0 and 5.5. The greatest differences in tissue P concentration between treatments with and without P occurred at the one-shoot development stage. ‘Yamhill’ and a ‘Yamhill’/‘Hyslop’ cross produced the highest grain yield without P addition. ‘Stephens’ yield was low.
- **1981 and 1982:** Efficiency of N fertilizer uptake was measured across a range of soil and crop histories in the Willamette Valley using  $^{15}\text{N}$ . Plant uptake of applied N ranged from 42 to 67 percent. Recovery of fertilizer N in the grain was between 54 and 73 percent of the fertilizer taken into the crop. Fertilizer N remaining in the soil was primarily an organically combined form, principally in the top 6 inches of soil. Only half of the residual N was measured following the second crop, with 10 to 30 percent of the N loss occurring during the fall, after crop harvest.
- **1981:** In 16 western Oregon locations from Oakland to Perrydale, foliar application of Cl, S, Mg, N, Zn, or K increased wheat yield only where the nutrient application decreased foliar diseases.
- **1982:** Measurements from fields producing wheat for 5 or more consecutive years demonstrated that “take-all decline” is predictable in western Oregon. Grain yields in the fifth and succeeding years approached yields from the first year and were higher than those from the second or third year. Chloride application mitigated some yield loss from take-all root rot, possibly by alleviating moisture stress.
- **1983:** Nitrogen, S, Cl, P, and lime were applied on 14 farms from Douglas County to Yamhill County. Not all combinations were used at each site. Significant residual N was measured following a snap bean crop and after biosolid application. In these situations, addition of 40 to 50 lb N/a produced maximum yield.
- **1984:** Sulfur and N rates, sources, and timing were used to assess need in several rotations. An application of 10–12 lb S/a at planting was recommended for consecutive wheat crops. No application of S was recommended when wheat was planted after summer fallow, a legume seed or processing vegetable crop receiving 30–40 lb S/a, or a wheat crop where ammonium sulfate or other fertilizer supplied more than 40 lb S/a to the previous crop. When 4–6 t/a straw was incorporated, an application of 25 lb S/a, with half in the fall, was recommended. When 5–6 t straw/a was incorporated, a



Figure 15.—Harvesting OSU wheat trials with a small-plot research combine. Photo: Mike Flowers

total N rate (fall + spring) of 175–200 lb/a was required to produce 100–115 bu grain/a. Four trips across the field before Feekes growth stage 6 with a wide-tire applicator resulted in about 4–5 percent yield loss for the field.

- **1985–1988:** When all spring N was withheld until after Feekes growth stage 6, grain yield was reduced by 10–12 bu/a, compared to treatments receiving at least some N (40 lb/a) slightly before Feekes growth stage 6. Wheat grain yield was measured in fields using narrow-tire vehicles traveling in the same tracks and wide-tire vehicles without a set driving pattern. Yield reduction of 2–3 percent was measured in fields with narrow-tire application equipment. Yield reduction was 4–7 percent in fields with wide-tire application equipment.
- **1987–1989:** Dry matter accumulation and N distribution patterns for soft white and hard red winter wheat were compared. Soft white winter wheat cultivars were more efficient at partitioning dry matter to grain than were hard red wheat cultivars. Higher grain protein for hard red wheat occurred at the expense of yield rather than through efficient partitioning of N to grain. Early determination of crop N status allows for options in N fertilizer management. Total N concentration at Feekes growth stage 7 provided the highest correlation with grain yield, protein yield, and grain protein.
- **1993–1996:** The relationship between N supply and crop rotation was explored. In treatments receiving no N, mineralizable N significantly influenced both total N uptake of the above-ground biomass and grain yield. A greater than four-fold increase in soil-supplied N values (ranging from 20 to 100 lb N/a) was measured when mineralizable N test values increased from 14 to 29 ppm. Mineralizable N values satisfactorily predict approximate soil N availability and can be used to predict spring fertilizer N requirements.



- **2002–2005:** Use of N mineralization plus ammonium and nitrate-N soil tests predicted spring fertilizer need in both conventionally established and no-till wheat. The work reaffirmed the utility of the N mineralization test to establish a spring fertilizer N rate and confirmed that the same calibration can be used regardless of establishment method. A protein concentration between 8.5 and 10.5 percent was consistently measured in wheat that was adequately supplied with N and produced a yield of more than 80 bu/a.
- **2005–2011:** Continued evaluation of the N mineralization soil test in both small-plot and large on-farm trials showed that the test accurately predicts spring N requirements. A microbial seed treatment designed to increase nutrient uptake was evaluated at Hyslop Research Farm and found to be no different than the control. A new nitrification inhibitor added to granular urea was evaluated at two locations in the Willamette Valley and found to be no different than the control. Multiyear trials evaluating the timing and rate of a foliar N product are being conducted.

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Revised June 2009. Revised July 2011.