

Perennial Ryegrass Grown for Seed

(Western Oregon)

EM 9086 • November 2013

J.M. Hart, N.P. Anderson, T.G. Chastain, M.D. Flowers, C.M. Ocamb, M.E. Mellbye, and W.C. Young III

Perennial ryegrass is a short-lived, cool-season perennial bunchgrass with a shallow, fibrous root system. Cool, moist winters and warm, dry summers of the Pacific Northwest (PNW) are suitable for seed production of many crops, including perennial ryegrass and other cool-season grass species. The PNW currently produces about 85 percent of the perennial ryegrass seed used in the United States and about 40 percent of the world supply.

Most of the PNW perennial ryegrass is produced in western Oregon, where it is grown for turf or forage seed in numerous rotations. Stand longevity varies from 2 to 4 years, depending on the production contract and stand vigor. See “Soils and settings for perennial ryegrass seed production” (page 3) for more information.

This guide provides nutrient and lime recommendations for establishment and production of turf and forage perennial ryegrass grown for seed in western Oregon. Healthy plants with adequate root systems are required to obtain the greatest return from your fertilizer investment. The nutrient and pH recommendations in this guide assume that adequate control of weeds, insects, and diseases is achieved. Lack of pest control or low soil pH cannot be overcome by the addition of nutrients. Common pest problems for perennial ryegrass seed production in western Oregon are stem rust, barley yellow dwarf virus, slugs, grass weeds (such as annual and rough-stalk bluegrass), and broadleaf weeds (common groundsel, mayweed chamomile, speedwell, and chickweeds).

Straw is either baled and removed or finely chopped onto the stand. Straw management



William Young, © Oregon State University

considerations and implications for nutrient management are found in *Postharvest Residue Management for Grass Seed Production in Western Oregon*, Oregon State University (OSU) Extension Service publication EM 9051. Potassium (K) is the only nutrient for which management differs depending on whether straw is baled or chopped.

Between 10 and 20 percent of the perennial ryegrass seed produced are forage varieties. These fields are sometimes grazed with sheep. Even with this difference in management, perennial ryegrass forage and turf varieties are similar in nutrient requirement; therefore, no distinction is made between them in this guide.

The most yield-limiting nutrient for perennial ryegrass seed crops is nitrogen (N). Liming to increase soil pH is sometimes necessary, as well as

J.M. Hart, professor of crop and soil science emeritus; N.P. Anderson, field crops Extension agent; T.G. Chastain, associate professor of crop and soil science; M.D. Flowers, Extension cereals specialist; C.M. Ocamb, associate professor of botany and plant pathology; M.E. Mellbye, area Extension field crops agent emeritus; and W.C. Young III, Extension specialist (seed production) emeritus; all of Oregon State University. This publication replaces FG 46-E, *Perennial Ryegrass Grown for Seed: Western Oregon—West of Cascades Fertilizer Guide*.

Summary

Before planting

Lime	Apply preplant lime according to Table 2 when soil pH is below 5.5. See page 6.
Nitrogen (N)	Apply 20 to 40 lb N/a, preferably in a band. See page 7.
Phosphorus (P)	When soil test P is below 25 ppm, apply P in a band. See Table 5 (page 13).
Potassium (K)	When soil test K is below 150 ppm, apply K. See Table 6 and pages 15–16.
Sulfur (S)	Band 10–15 lb S/a at planting. See page 17.
Calcium (Ca)	When soil test Ca is below 5 meq/100 g of soil or 1,000 ppm, apply lime. See page 7.
Magnesium (Mg)	When soil test Mg is below 0.5 meq/100 g of soil or 60 ppm, use 1 t dolomite/a for 1 t lime/a of the lime requirement. See page 7.

Established stands

Lime	Top-dress 1 t lime/a if pH in the surface 2 inches of soil is below 5.5. See page 6.
Nitrogen (N)	Apply 120–160 lb N/a between mid-February and mid-April. See pages 7–12.
Phosphorus (P)	A maintenance application is common when soil test P is between 25 and 50 ppm. Application can be made in the fall or spring. See pages 13–14.
Potassium (K)	Apply K if soil test is below 150 ppm; the amount needed depends on residue management practices (see Table 6). Application can be made in the fall or spring if soil test K is above 100 ppm. If soil test K is below 100 ppm, fall application is recommended. See pages 15–17.
Sulfur (S)	Apply 10–15 lb S/a in the spring or 30 to 40 lb S/a every other year. See page 17.

addition of sulfur (S), phosphorus (P), potassium (K), and magnesium (Mg). The average seed yield for perennial ryegrass in western Oregon is 1,400 to 1,800 lb/a. The recommendations in this guide, especially for N, are adequate for seed yields of 2,500 lb/a or higher.

The nutrient recommendations in this guide are based on experiences of growers and agricultural supply industry representatives, as well as on research performed over the past 50 years on OSU experimental farms and in grower fields throughout western Oregon.

Crop growth and development

Nutrient rate and timing recommendations are based on plant demand. Perennial ryegrass growth and nutrient uptake patterns help determine application timing.

Research has shown that seasonal warming must occur before perennial ryegrass plants begin nutrient uptake and subsequently grow. Little to no growth or nutrient use occurs during cool-weather conditions from late November to mid-February. Oregon perennial ryegrass seed growers should use a heat unit (HU) or growing degree day (GDD) measurement to schedule the earliest nutrient application. See the sidebar “Calculating heat units or growing degree days” (page 4) for more information.

Cool-season grasses initiate growth in spring at or near the accumulation of 200 HU or GDD, with accumulation beginning January 1. The long-term average for accumulation of 200 GDD in western Oregon is mid-February. Reproductive development begins internally, generally in January or February,

continues on page 4

Growth versus development

- **Growth** is the quantitative increase in the weight or size (or both) of a plant.
- **Development** is the qualitative change in the tissues of a plant. Function or differentiation is the type of change seen.

Growth and development occur simultaneously.

Soils and settings for perennial ryegrass seed production

Perennial ryegrass is grown for seed in western Oregon's Willamette Valley region, including the gently sloping hills bordering the mountainous uplands of the Coast and Cascade mountain ranges in Benton, Clackamas, Lane, Linn, Marion, Polk, Washington, and Yamhill counties. "Western Oregon" is used to collectively describe the area for which recommendations in this publication are applicable.

The combination of productive soil and favorable climatic conditions (wet, mild winters and dry summers) provides a setting for high-quality perennial ryegrass seed production and gives the area a competitive advantage among the world's seed-producing regions.

In the southern, central, and northern areas of the Willamette Valley, perennial ryegrass grown for seed is planted primarily on soils formed in stratified glacio-lacustrine silts such as Amity, Willamette, and Woodburn, and on alluvial soil series such as Chehalis, Malabon, McBee, and Newberg. Most of these fields have some slope that allows water to drain. Tile has been installed on many fields to improve surface and internal drainage.

Soils on the floodplain tend to be well to excessively drained, and in many years supplemental irrigation is required to optimize seed yields. Soils found in these areas include Chehalis, Clackamas, and Newberg series, as well as small areas of other soils.

In the southern part of the Willamette Valley, a combination of management practices has increased the success of growing perennial ryegrass on somewhat poorly drained soil types such as Dayton ("white soil") and Bashaw ("gumbo" or "blue, sticky soil"). In these situations, surface ditching and tiling are essential to promote a soil environment conducive to perennial ryegrass seed production.

Perennial ryegrass is also produced in foothills on the east side of the Willamette valley, primarily on Nekia, Jory, and Stayton series. Here, fields can be located at elevations approaching 1,000 feet,

and rainfall can be 50 percent greater than on the valley floor. In the foothills on the west side of the Willamette River, fields are located on Hazelair, Helmick, and Steiwer soil series. Foothill soils can be relatively shallow, and rock outcroppings can pose tillage difficulties. Proper tillage and planting operations are critical to protecting steep slopes from soil erosion, especially during fall seeding and the seedling stage.

In addition to the soil series used for perennial ryegrass seed production in the central Willamette Valley, Aloha, Verboort, Laurelwood, Wapato, Helvetia, and Cove soils formed in loess and mixed alluvium are used for grass seed production in the Tualatin Valley.



John Hart, © Oregon State University



John Hart, © Oregon State University

Figure 1 (top and bottom).—Perennial ryegrass and other cool-season grasses are grown for seed in western Oregon's broad, flat Willamette and Tualatin valleys and on the gently sloping hills bordering the mountainous uplands of the Coast and Cascade mountain ranges.

with the formation of the spikelet ridge on the shoot apical meristem (double ridge stage).

Reproductive development can take place at temperatures lower than those required for plant growth, and the initial stages of development are on a microscopic scale. Thus, the start of reproductive development is not marked by any externally visible

or easily measurable change in the plant. Before the double ridge stage, only biochemical and physiological changes take place in the plant to mark the transition from vegetative development to reproductive development. The external indication of reproductive development begins with stem elongation much later in the season.

Calculating heat units or growing degree days

A heat unit (HU) or growing degree day (GDD) is the average of the high and low temperature for the day, in degrees centigrade (°C). An adjustment is made to take into account the minimum and maximum temperatures at which a species will grow. For perennial ryegrass, the minimum temperature for growth is 0°C or 32°F.

The formula for calculating a heat unit is:

$$\frac{\text{maximum}^{\circ}\text{C} + \text{minimum}^{\circ}\text{C}}{2}$$

For example, if the high for January 1 is 11.7°C and the low is 4.4°C, the number of heat units for that day is 8.1 (11.7 + 4.4 ÷ 2 = 8.1). Note: If the temperature is less than 0°C, use 0 as the minimum temperature.

To tally cumulative HU or GDD, add the sums daily starting on January 1 (see Table 1).

Table 1.—Example of GDD accumulation using 2003 western Oregon weather data.

Date	Temperature (°C)			Sum of GDD
	Max	Min	Avg	
1 Jan	11.7	4.4	8.1	8.1
2 Jan	15.0	7.2	11.1	19.2
16 Jan	9.3	2.0	5.7	121.9
17 Jan	6.0	-1.0	3.0	124.9
24 Jan	12.8	8.9	10.9	187.8
25 Jan	15.0	9.4	12.2	200.0

Temperature data for calculating HU or GDD are available from weather-collecting stations in your area (radio or TV stations, airports, etc.) or from weather/climate websites. Producers can also collect their own data by recording high and low temperatures.

If you collect temperature data in degrees Fahrenheit (°F), use the following formula to convert °F to °C:

$$(\text{°F} - 32) \times 0.556 = \text{°C}$$

For example: $(40^{\circ}\text{F} - 32) \times 0.556 = 4.45^{\circ}\text{C}$

When calculating season-long GDD, a maximum temperature needs to be considered, as plant growth does not increase linearly beyond the optimum temperature for growth. The optimum temperature for perennial ryegrass growth is 65 to 70°F, and the maximum temperature for growth is approximately 95 to 100°F. Maximum temperatures are not a concern in the spring, as spring temperatures are substantially below the maximum for perennial ryegrass growth.



Figure 2.—Early season perennial ryegrass growth.

John Hart, © Oregon State University

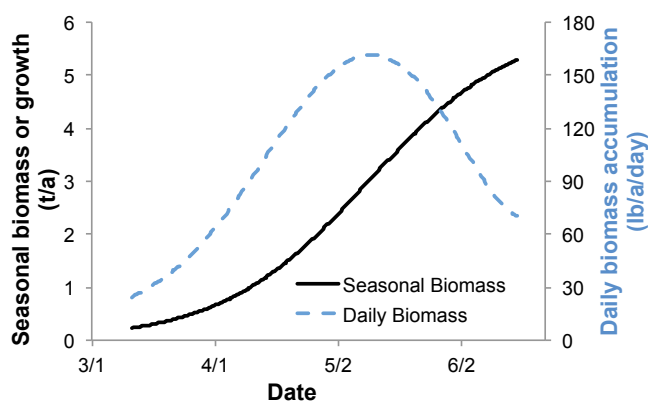


Figure 3.—Annual and daily total above-ground biomass accumulation (seed plus straw) for perennial ryegrass grown for seed in western Oregon. Seasonal biomass values are higher than the sum of grower seed and straw harvest, as all above-ground biomass, including crowns, was carefully clipped in small plots. Figure by John Hart.

Early-spring growth (after mid-February) is slow (Figure 3). Only 20 percent of above-ground biomass is accumulated by early to mid-April, when stem elongation starts (BBCH* scale 30).

After stem elongation begins, the rate of growth, or biomass accumulation, increases linearly through the end of May, as stems continue to elongate. Daily biomass accumulation reaches approximately 150 lb/a during this period. As the crop attains maximum leaf area and shifts to seed development (BBCH scale 69; early June until harvest), biomass accumulation slows considerably.

Nutrient application and seed yield

Seed yield is a measure of seed weight per area harvested. Yield depends on two factors: seed weight and seed number. Seed number is determined by the number of florets that are successfully pollinated, fertilized, and produce seed. Floret number is determined by the number of florets per spike and the number of spikes in the field. The number of seeds harvested can be affected by abortion of seed during development, as well as by losses during harvesting and cleaning processes.

The objective of fertilizer application in perennial ryegrass seed production is to increase seed yield by manipulating yield components and by ensuring

*The BBCH scale is used to identify the phenological development stages of a plant. BBCH officially stands for “Biologische Bundesanstalt, Bundessortenamt und Chemische Industrie.” The abbreviation of the scale is also said to unofficially represent the four companies that initially sponsored its development: Bayer, BASF, Ciba-Geigy, and Hoechst.

sufficient crop canopy to support the photosynthesis required for seed filling. Spring N application consistently increases perennial ryegrass seed weight and the number of fertile or reproductive tillers.

Perennial ryegrass produces tillers year-round, but even spring-emerged tillers can produce spikes and consequently seed in some cultivars.

Plant growth regulators (PGRs) are used in perennial ryegrass to reduce lodging, in turn possibly increasing seed yield. Using PGRs does not change perennial ryegrass nutrient needs or fertilizer application recommendations. See the sidebar “Plant growth regulators” for more information.



Figure 4.—Swathing a perennial ryegrass field.

Mark Mellbye, © Oregon State University

Plant growth regulators

Plant growth regulators (PGRs)—including proxexamide calcium and trinexapac-ethyl (TE)—have been widely adopted as a lodging control agent in grass seed production. Under growing conditions that include high N availability in spring, the stem cannot support the weight of the developing inflorescence and seed. As a result, the tiller and inflorescence lodge, or fall to the ground. Lodging affects pollination and seed development, so seed yield is reduced.

One PGR, paclobutrazol, increased seed yield of perennial ryegrass regardless of N application rate (Hampton et al., 1983). In other words, no additional N was needed or beneficial with the PGR application. In recent studies with TE, Borm and van den Berg (2008) similarly found no interaction between TE and N rate for seed yield in perennial ryegrass.

Lime, calcium, magnesium, and pH

Stand establishment can fail if soil pH is below 5.0 (Figure 5). *When soil pH is less than 5.5, lime is recommended.* Use Table 2 to determine lime rate based on SMP* buffer test results. Do not exceed 5 t lime/a in a single application, even if the SMP lime requirement is greater. For best results, mechanically incorporate lime during seedbed preparation (Figure 6).

To ensure adequate soil pH for the life of a stand and avoid the need for a top-dress lime application, raising soil pH to 5.7 or 5.8 before planting is an option. The amount of lime needed to reach this goal is estimated to be about ½ ton more than provided in Table 2 to reach a soil pH of 5.6.

Soil pH, especially in the surface 2 inches, decreases as a perennial ryegrass stand ages. Regular soil sampling and testing to monitor soil pH changes is recommended for established stands. If soil pH falls below 5.5 in the surface 2 inches, apply 1 t lime/a. Top-dressed lime applications should not exceed 2 t/a. Top-dressing lime without incorporation raises soil pH in only the surface inch of soil.

Seasonal fluctuation of soil pH makes year-to-year comparisons difficult unless soil samples are collected at the same time each year; for example, in the summer before planting. Soil pH increases as soil is wetted with fall and winter rain. Soil pH is highest in the wettest time of the year, February or March.

This seasonal fluctuation is caused by an accumulation of soluble salts as the soil dries (lowering soil pH) and flushing of the salts with winter rainfall (raising soil pH). A related situation occurs during a dry spring or prolonged dry summer. Since

*The SMP buffer test is named after Shoemaker, McLean, and Pratt, the soil scientists who published the method in 1961.



Mark Mellbye, © Oregon State University

Figure 5.—Low soil pH (4.6) disrupts perennial ryegrass establishment, creating an uneven stand.

Table 2.—SMP buffer lime requirement for perennial ryegrass.

SMP buffer	Amount of 100-score lime needed to raise pH of surface 6 inches of soil to the following pH ¹ (t/a)	
	5.6	6.0
4.8 to 5.0	6 to 5 ²	8 to 7 ²
5.1 to 5.3	5 to 4	7 to 6
5.4 to 5.6	4 to 3	6 to 4
5.7 to 5.9	3 to 2	4 to 3
6.0 to 6.2	2 to 1	3 to 2
6.3 to 6.5	0	2 to 1
6.6	0	1

¹Rates are based on 100-score lime. The combination of calcium carbonate equivalent, moisture, and fineness determines lime score. Lime score is legally required for all materials marketed as “liming materials” in Oregon. Lime application rates should be adjusted for score. For more information about lime score and liming materials, see *Applying Lime to Raise Soil pH for Crop Production (Western Oregon)*, EM 9057.

²The higher lime rate is required for the lower buffer test reading.

fertilizers are salts, fertilizer addition followed by a dry spring increases soluble salts and creates low soil pH (below 5.3) and relatively high SMP buffer value (above 6.2). This situation is temporary, and soil pH will increase as autumn rainfall leaches the salts. Use the SMP buffer as a guide to lime application.

Sandy soils to which fertilizers have not been recently applied sometimes have low pH and high SMP buffer values. In such cases, an application of 1 to 2 t lime/a should suffice to neutralize soil acidity.

For more information about problems caused by soil acidity and details about lime application, see *Soil Acidity in Oregon*, EM 9061, and *Applying Lime to Raise Soil pH for Crop Production (Western Oregon)*, EM 9057.



Gale Gingrich, © Oregon State University

Figure 6.—Preplant lime application.

Calcium (Ca) and Mg usually exist in the soil in adequate quantities when soil pH is above 5.5. *Where Ca is below 5 meq/100 g soil and soil pH is above 5.0, apply 1 t lime/a.*

If soil requires lime (Table 2) and soil test Mg is less than 0.5 meq/100 g soil (60 ppm), substitute 1 t dolomite/a for 1 t of the lime requirement.* Dolomite and lime have about the same capability to neutralize soil acidity and increase soil pH. An alternative to dolomite is to broadcast 30 lb Mg/a. Compare material cost before choosing a Mg source.

Nitrogen (N)

Nitrogen fertilizer application recommendations in this guide are in addition to the N supplied by the soil. Soil typically supplies 50 to 100 lb N/a annually, depending on soil type and stand age. Soil N supply usually is highest after tillage, about 100 lb N/a for the first 2 years of a stand, decreasing to about 50 lb N/a in subsequent years.

Poorly drained soils with more than 5 percent organic matter supply more N than well-drained soils with lower organic matter. Use lower rates of N for poorly drained soils, as these soils have not shown a consistent seed yield increase from higher rates.

New seeding

Apply 20 to 40 lb N/a at seeding. The application can be preplant broadcast or added to the banded charcoal slurry at planting. If N is subsurface banded at planting, at least 1 inch of soil should separate the seed from the fertilizer so the fertilizer does not delay crop emergence. See Appendix B, “Banding Fertilizer at Planting” (page 26).

Established stands

Postharvest residue management does not alter N need. Regardless of whether straw is removed or chopped back, perennial ryegrass fields have a similar N requirement during a typical 2- to 3-year stand life.

Fall application

Fall N is not required for second-year and older perennial ryegrass stands. Unlike tall fescue, spring-emerged perennial ryegrass tillers can produce seed heads. Therefore, fall N supply is less important for achieving yield in perennial ryegrass, as

spring-applied N is sufficient to meet crop needs for optimum seed production.

Nonetheless, OSU research in 2007 found that perennial ryegrass plants do use fall-applied N. A 40 lb/a fall N application was made to perennial ryegrass using a traceable isotope of N. Just before harvest the following year, N was measured in soil, roots, straw, and seed (Figure 7). Approximately 60 percent of the fall-applied N was in the plant and the seed, while 15 percent was in the soil. Only 5 percent of the fall-applied N was in the roots, showing that the N was moved to the straw and seed, rather than used for root growth.

Surrounding tissues such as the flag leaf, glumes, and other parts of the seed head are important sources of N for seeds in perennial ryegrass. Seed contained 25 percent of the fall-applied N, showing that even though fall-applied N is not physiologically essential for perennial ryegrass, it is efficiently used to produce seed.

Since fall-applied N is efficiently used by a perennial ryegrass seed crop, one might logically ask whether fall N increases seed yield. OSU research with varying fall and spring N rates answered this question. The answer is “yes” *only* if the spring N rate alone would have limited seed production (less than 150 lb N/a, Figure 8). Otherwise, fall N application is not necessary when the spring N rate is adequate.

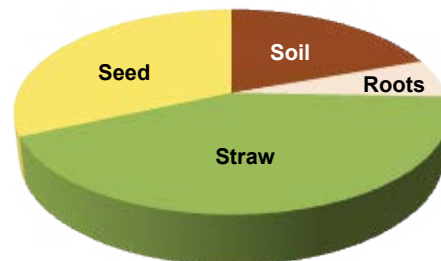


Figure 7.—Distribution of fall-applied N in perennial ryegrass seed, straw, roots, and soil. Figure by John Hart.

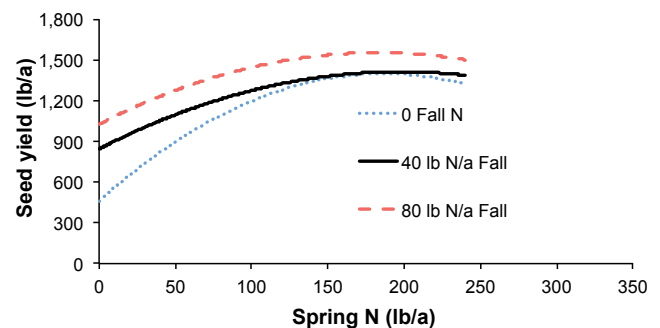


Figure 8.—Seed yield of ‘Top Gun’ perennial ryegrass as influenced by fall and spring N application, Hyslop Field Research Laboratory, 2007. Figure by John Hart.

*Milliequivalent = $1/1,000$ of an equivalent (equivalent = the amount of a substance that will react with 1 gram of hydrogen)

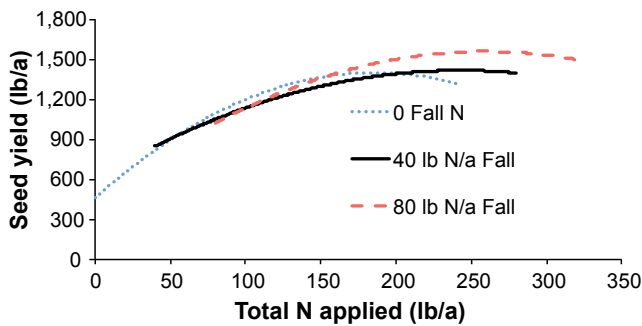


Figure 9.—Seed yield of ‘Top Gun’ perennial ryegrass as influenced by fall and total N application, Hyslop Field Research Laboratory, 2007. Figure by John Hart.

Low or insufficient N not only reduces seed yield, it also reduces fall growth. In this situation, a fall N application increases fall growth but will not increase seed yield if spring N is sufficient.

These data also show the ability of fall N to be part of the total N supply (Figure 9). For example, when 40 lb fall N/a was applied, and the spring N rate was 120 lb/a, seed yield was the same as when no fall N was applied and 160 lb N/a was applied in the spring. Thus, some fall N can be applied to meet total crop requirement, but the total N rate should not exceed the amount needed to achieve maximum yields, 140 to 160 lb N/a.

From a management perspective, application of fall N reduces the amount needed in the spring. Lower spring N rates allow faster N application compared to a higher rate. If you need to apply N to many fields in a limited dry weather period, a lower rate allows faster coverage of the field as you need to fill the fertilizer spreader less frequently.

If you choose to apply fall N, use 30 to 40 lb/a. Higher rates, such as 80 lb/a, are no more beneficial than 40 lb/a (Figure 8).

Spring application

N rate. The total amount of N required for production of a perennial ryegrass seed crop is 160 lb/a. This value was determined from the relationship between N in above-ground biomass and seed yield (Figures 10 and 11). Research was conducted in grower fields and small plots at OSU’s Hyslop Field Research Laboratory.

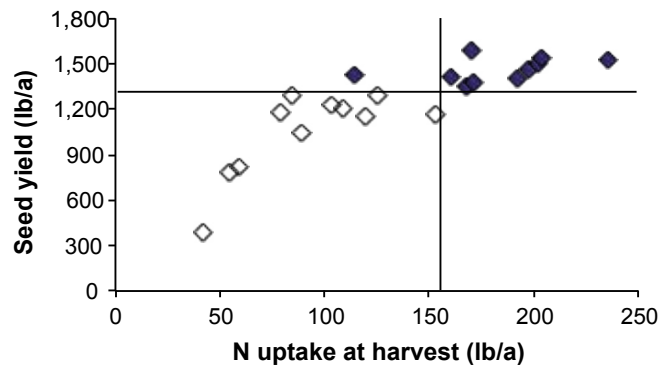


Figure 10.—The relationship between N in above-ground biomass of ‘Top Gun’ perennial ryegrass at harvest and seed yield. Data from Hyslop Field Research Laboratory, fall N experimental plots, 2007. Data points represented by the solid diamond shape are the highest seed yields and are not statistically different from each other. The seed yields from plots with less than 85 percent relative seed yield are represented by unfilled diamonds. Figure by John Hart.

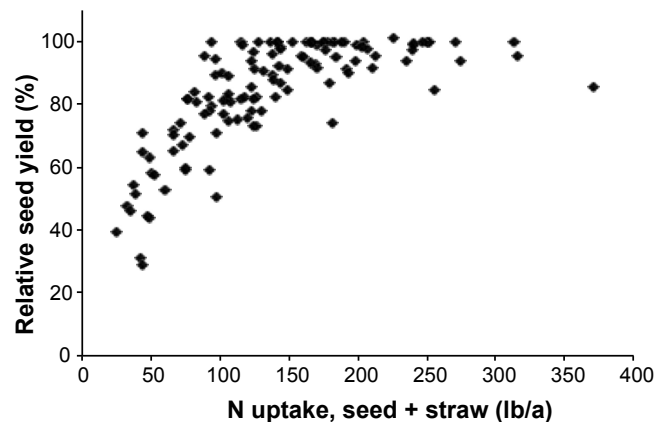


Figure 11.—The relationship between N uptake at harvest and relative seed yield. Data are from 24 perennial ryegrass spring N rate experimental plots in grower fields from 1997 through 2006. Figure by John Hart.

To adequately supply N for perennial ryegrass seed production, apply 120 to 160 lb N/a (see “Variation in spring N rate,” page 9). Lower rates of N are suggested for poorly drained, high organic matter soils. In addition, the spring N rate depends on use of fall N. Reduce spring N by the amount, if any, applied in the fall (see “Fall application,” above).

The most reliable predictor of N sufficiency is early season tissue N concentration. Apply 80 to

continues on page 10

Variation in spring N rate

Nitrogen supplied from the soil for perennial ryegrass seed production ranges from 20 to 100 lb N/a. Soil with low organic matter content, such as the “river bottom” Newberg series, typically provides less N to a perennial ryegrass seed crop than does the Bashaw series. Even the predominant glacio-lacustrine Amity/Woodburn soil series sometimes provides less than the average 55 lb N/a to a first-year perennial ryegrass crop. The amount of N from soil that becomes available for crops also varies annually for each field.

Growers of crops such as sweet corn and wheat deal with this variation by using the pre-sidedress nitrate soil test or N-mineralization soil test to determine N fertilizer rate. Unfortunately, neither test adequately predicts spring N need for perennial ryegrass seed production.

Fortunately, for perennial ryegrass seed production, the variation in optimum spring N rate is about 25 percent of the total N rate and isn't universal. This situation allows for the general recommendation of 120 to 160 lb N/a in the spring. Adjustment of this rate is usually based on grower perception and experience.

Many growers expect a first-year field to require a higher N rate than second- or third-year fields. This expectation is logical where the soil N supply is low, as the first-year crop requires N for both root and shoot biomass production (Table 3). Variation in soil N supply may contribute to the perception that higher N rates are needed for first-year crops.

Table 3.—Distribution of N in perennial ryegrass grown for seed.¹

Component	Amount (lb/a)
Seed	35
Straw	120
Roots	70
Total	225

¹The crop will have an average of 160 lb N in the above-ground portion.

The optimum spring N rate also varies in second- and third-year crops. Fortunately, the rate varies less than 45 lb/a annually, but choosing a spring N rate is difficult (Table 4).

New Zealand growers use a checkbook or balance sheet approach, beginning with the need for 160 lb N/a and subtracting available and mineralizable N provided by the top foot of soil. This approach provides western Oregon wheat growers a method for estimating spring N rate, but failed to adequately predict a spring N rate for perennial ryegrass in 3 years of research.

Table 4.—Optimum N rate for three western Oregon perennial ryegrass seed fields.¹

Site	1998	1999	2000
	Optimum N rate (lb/a)		
1	90	135	135
2	135	90	135
3	180	135	—

¹Data from large-plot experiments in grower fields. Spring N was applied in 45-lb increments from 0 to 270 lb N/a. Data from Seed Research Reports, 1999 through 2000.

Future research may provide growers the ability to adjust spring N rate not only for fields each year, but for areas of the field by using sensors mounted on fertilizer spreaders. See the sidebar “Can remote sensing be used to determine in-season N status and predict N application rates?” (page 11) for more information on this topic.



Figure 12.—Spring fertilizer application.

Bob Schroeder, CPS, Tangent, OR

100 lb N in early spring, measure tissue N to check N sufficiency, and, when necessary, apply additional N.

A critical time for tissue testing was reported from research in Oregon and other production areas. Rowarth et al. (1998) concluded that N concentration in above-ground biomass 2 weeks after N application at spikelet initiation is a useful predictor of yield where N is the only limiting factor.

Western Oregon research since 2007 has shown that 3 percent tissue N (100 lb N/a in above-ground biomass) 2 weeks after application of at least 90 lb N/a in early to mid-March is sufficient for perennial ryegrass. When N concentration is less than 3 percent, a March application of 50 lb N/a increases tissue N concentration approximately 0.5 percent.

Sample collection challenges exist, however. The combination of tissue N concentration and the amount of biomass more accurately predicts N sufficiency than does tissue N concentration alone. Biomass is most accurately measured by clipping a measured area, drying, and weighing the material collected.

An alternative to collecting tissue samples is a rapid and nondestructive measurement, near-infrared spectroscopy (NIRS). This approach holds potential for determining or adjusting spring N rate using sensors on fertilizer application equipment. Additional research is needed before this technology can be adopted. See the sidebar “Can remote sensing be used to determine in-season N status and predict N application rates in perennial ryegrass?” (page 11)

Negative effects can occur when excess N is applied. In OSU research, for example, stand life was decreased when N was applied above the recommended rates.

Use of most common N fertilizers increases soil acidity and lime need. Urea or other ammoniacal-N sources acidify soil at the rate of approximately 0.1 pH unit/100 lb N/a. For example, if N is applied at the rate of 140 lb N/a, soil pH will decrease by approximately 0.14 pH unit in 1 year. If 140 lb N/a is used for 3 years, soil pH will decline approximately 0.4 pH unit.

Thus, the use of N fertilizer beyond crop need has a double cost. The first cost—the excess N fertilizer itself—is not offset by increased seed yield or economic return. Second, the additional N acidifies soil, which then requires additional lime to raise the soil pH. Application of 50 lb N/a above crop need will require an additional 0.3 to 0.6 ton lime/a in 3 years.

Timing. Early season N utilization is low and is usually easily supplied from the soil. Thus, N should not be applied until after 200 GDD have accumulated in the spring. The timing for early N application can also be based on historical temperature data. For example, the 35-year average for accumulation of 200 GDD is mid-February in western Oregon.

As seen in Figure 13, only a small amount of N is used during the first month of growth after 200 GDD are accumulated. Nitrogen uptake is linear during April and essentially complete by mid-May, or about 6 weeks before harvest. Nitrogen applied after this time will not be effectively utilized by the plant to increase seed yield.

continues on page 12

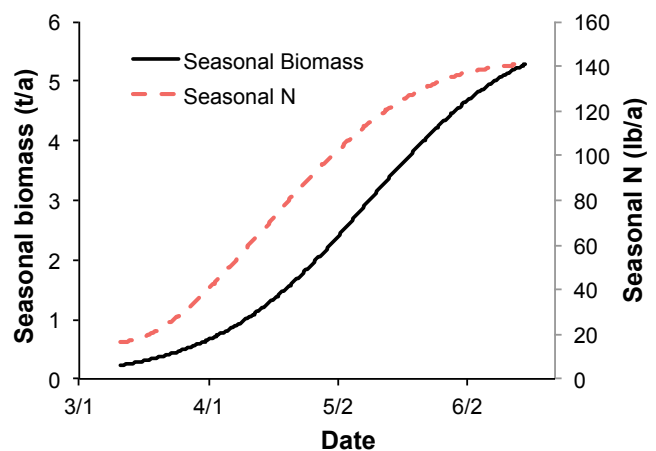


Figure 13.—Annual total above-ground biomass (seed plus straw) and N accumulation for perennial ryegrass grown for seed in western Oregon. Seasonal biomass values are higher than the sum of grower seed and straw harvest, as all above-ground biomass, including crowns, was carefully clipped in small plots. Figure by John Hart.

Can remote sensing be used to determine in-season N status and predict N application rates?

Remote sensing in the form of aerial photographs, or an on-the-go sensor, might replace costly tissues tests or less successful soil-based approaches to optimizing N applications in perennial ryegrass grown for seed. Additionally, remote sensing has the potential to capture the variability found in most fields in a cost-effective manner.

Remote sensing works by measuring the energy reflected from the crop canopy and/or soil background. Reflectance in the blue, green, and red regions of the visible spectrum is related to the chlorophyll and N concentration of plants. Reflectance in the near-infrared (NIR) region of the spectrum may be related to the amount and vigor of vegetation. Thus, remote sensing may be related to whole-plant N concentration or N uptake.

From 2007 to 2009, OSU conducted research to determine whether remote sensing could be used to determine the in-season N status of perennial ryegrass. This research found a significant and strong relationship between relative NIR and whole-plant N concentration across site-years (Figure 14). Additionally, a significant and strong relationship was found between the normalized difference vegetation index (NDVI) and N uptake across site-years (Figure 15). These results indicate that relative NIR or NDVI may be used as an indirect measurement of whole-plant N concentration or N uptake in perennial ryegrass grown for seed.

While the results of OSU's research are promising, technical problems need to be overcome before remote sensing can be used to predict N application rates in perennial ryegrass. One issue related specifically to perennial crops is the difficulty in developing a consistent relationship across stand years. The OSU study found that a single relationship was able to account for differences across older stands. However, first-year stands, where the canopy is relatively open, did not follow the same relationship.

Other problems include the ability to account for varietal differences; different responses to environmental stresses; and the presence of weeds, diseases, and other pests. Thus, more research is required to develop and validate a robust model for using remote sensing to predict N application rates in perennial ryegrass grown for seed.

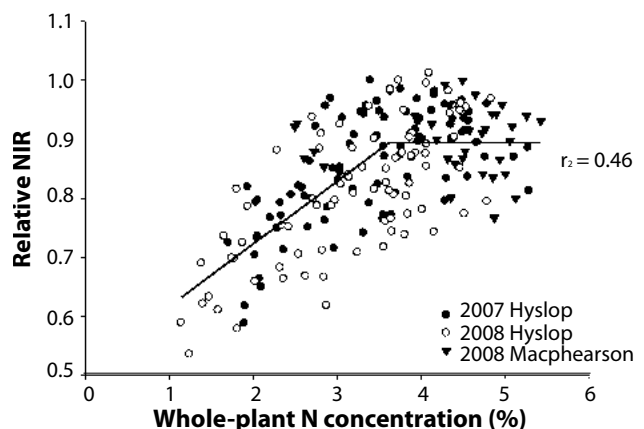


Figure 14.—Relationship between whole-plant N concentration and the relative near infrared (NIR) band at three sites in 2007 and 2008. Figure by Mike Flowers.

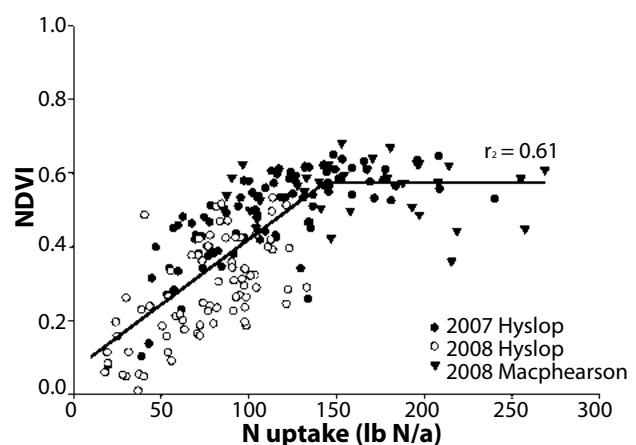


Figure 15.—Relationship between N uptake and the normalized difference vegetation index (NDVI) at three sites in 2007 and 2008. Figure by Mike Flowers.

Nutrient accumulation precedes growth or biomass accumulation (Figure 16). Peak N accumulation rates occur in mid-April, 3 weeks before peak biomass accumulation in early May.

The total amount of N in above-ground plant biomass ranges from 100 to 200 lb/a. The total amount of N used by perennial ryegrass depends on the cultivar and type. Forage types accumulate more N than turf types.

The goal of spring N application is to provide adequate N before crop demand or need. Flexibility exists for time of application, especially if fall N is applied or multiple (split) applications are made. Split N is recommended for uniformity and ease of management, to better match the timing of crop demand, and to provide flexibility in avoiding unfavorable weather conditions. However, a split application rarely increases seed yield.

Spring N application should occur between mid-February and mid-April. The earliest application, mid-February, is based on accumulation of 200 HU or GDD, after which perennial ryegrass will begin using or “taking up” N (see the sidebar “Calculating heat units or growing degree days,” page 4). Avoid early N applications on wet or saturated soils. Nitrogen applied to perennial ryegrass when soils are saturated and plants are chlorotic will not help “green up” yellow plants.

Soil temperature is used as a predictor of spring N timing in New Zealand. Both soil and air temperature methods provide the same application timing, but air temperature is more easily measured. See Appendix D, “Sheep, Kiwis, Perennial Ryegrass, and Spring Nitrogen Fertilizer Application” (page 28), for more information.

Peak uptake of 3 to 4 lb N/a/day occurs in early April, with a declining amount of N utilized through mid-May. Even though perennial ryegrass continues to use N through mid-May, and applications as late as early May can increase seed yield, applying N after mid-April is not recommended, as later applications have a potential for crop damage by application equipment and May rainfall is not sufficiently predictable to guarantee incorporation of top-dressed N.

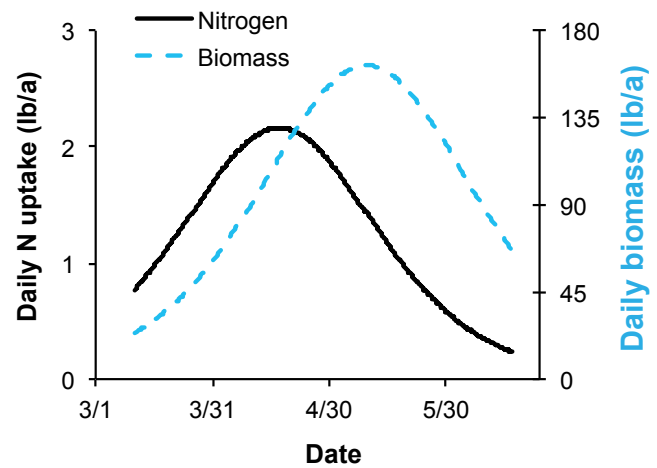


Figure 16.—Daily total above-ground biomass (seed plus straw) and N accumulation for perennial ryegrass grown for seed in western Oregon. Seasonal biomass values are higher than the sum of grower seed and straw harvest, as all above-ground biomass, including crowns, was carefully clipped in small plots. Figure by John Hart.

Source of N and method of application

Most N for perennial ryegrass seed production is top-dressed as urea alone (46-0-0) or mixed with another N form such as urea-ammonium nitrate solution (Solution 32). Another option is the physical mix of urea and ammonium sulfate (urea-sul 40-0-0-6). No difference in N availability exists among these sources for perennial ryegrass seed production.

Use of a nitrification inhibitor, polymer coating, or urease inhibitor is not recommended as a standard practice since no evidence exists of their benefit in western Oregon perennial ryegrass production systems. Polymer-coated urea does not produce a predictable or sufficient yield increase to justify the cost.

Urease inhibitors used to reduce volatile N loss in New Zealand produced a slight (6 percent) seed yield increase. These materials have not been evaluated in western Oregon grass seed production systems. When perennial ryegrass seed fields top-dressed with spring N fertilizer receive more than $\frac{1}{4}$ to $\frac{1}{2}$ inch of rain within 48 hours of application, urease inhibitors should not be necessary. See Appendix E, “Comparison of Urea, Polymer-coated Urea, and Urea with Urease Inhibitors for Perennial Ryegrass Seed Production” (page 29).

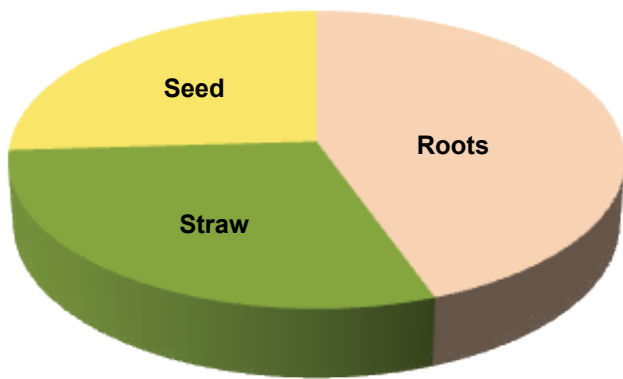


Figure 17.—Distribution of P in perennial ryegrass grown for seed. Figure by John Hart.

Phosphorus (P)

Perennial ryegrass, like other crops, moves P into the leaves, where it is incorporated into enzymes used for the transfer of energy produced by photosynthesis. Phosphorus is required by plants in a much smaller amount than N or K. Tissue P concentration of perennial ryegrass in vegetative development (jointing through flag leaf emergence) is usually 0.2 to 0.4 percent. About 25 lb P/a is found in physiologically mature perennial ryegrass plants, which is less than one-fifth the amount of K at the same stage of maturity.

Even though perennial ryegrass uses much less P than K, the amount removed with seed is similar for both nutrients, 5 lb P/a and 7 lb K/a. Most P remains in the straw or roots (Figure 17) and is slowly recycled when straw is chopped. Potassium, on the other hand, is easily leached from the straw by rain or irrigation water.

Phosphorus mobility in soil and in the plant is the same as K. Both have limited mobility in soil (they move less than 0.015 inch/day) but are mobile in the plant. Soil immobility creates high soil test concentration of these nutrients in the surface few inches of soil after top-dressing. Mobility in the plant allows movement from old (lower) leaves to new (upper) leaves. Therefore, lower leaves become discolored when these nutrients are deficient.

P fertilizer application

In western Oregon, use the Bray method to measure soil test P available to the plant. Use Table 5 to determine the need for P fertilizer application and the rate of P_2O_5 for new seedings and established stands. Fall application is recommended when Table 5 shows a need for P.

Table 5.—Phosphorus fertilizer application rates for perennial ryegrass.

Soil test or plant-available P (ppm) ¹	Apply this amount of P_2O_5	
	New seeding (lb/a)	Established stand (lb/a)
0 to 15	40 to 60	30 to 40
16 to 25	30 to 40	0 to 30
above 25	0	0

¹Application rates are based on a soil test using the Bray method for determination of plant-available P.

At planting, a band application of P is an efficient method of delivering this nutrient to a perennial ryegrass crop. However, when other nutrients such as K are applied in a band at planting, at least 1 inch of soil should separate the seed from fertilizer, as placing fertilizer with seed delays germination and emergence.

Using the application rates in Table 5 supplies adequate P for a perennial ryegrass seed crop. Predictable yield increase from P application is not measured unless soil test P is less than 15 ppm. Conversely, a yield increase is rare when soil test P is greater than 25 ppm. In this case, any yield increase that occurs usually is the result of correcting problems such as root disease or another factor limiting plant growth.

The need for P when soil test P is between 15 and 25 ppm varies with stand age, previous P application, and grower perspective. For example, if a 3-year-old perennial ryegrass seed field in its final year of production received top-dress P the previous 2 years, it likely will not benefit from P application. In contrast, seed yield of a first-year field might increase following a P application when soil test P is below 25 ppm.

For established fields with soil test P between 25 and 50 ppm, a maintenance or replacement application of P is sometimes used. It can be applied in spring or fall. This type of application replaces the amount removed with a crop. Since very little P is removed in seed, a replacement application should be considered only when straw is baled. Even when straw is baled, the economics of this approach are difficult to justify.

Phosphorus deficiency in western Oregon field and vegetable crop production is rare, as soil test P values are commonly above 50 ppm, especially in the central and northern Willamette Valley and Tualatin

Valley, where rotations with legume and vegetable seed and processing vegetable crops are common. Since P fertilizer is not needed when soil test P is above 25 ppm, production cost can often be reduced by eliminating P application.

On the other hand, soil test P can be below 25 ppm in several situations, such as fields primarily used for annual ryegrass seed production, “black” clay soils in the Tualatin and southern Willamette valleys, and “hill” soils adjacent to the Tualatin and Willamette valleys, such as the Silverton Hills and foothills of western Polk County.

For more information, see the sidebar “Increasing soil test P.”

Increasing soil test P

Soil test P is not easily increased, especially in several dark-colored alluvial soils high in clay such as Wapato and Bashaw. To increase soil test P in these soils, repeated applications of large quantities of P are needed.

Three categories of P are found in soil: (1) soluble (in soil solution) and immediately available for use by plants, (2) in soil and available for plant utilization (not in solution), and (3) unavailable for plant growth (mineral or precipitated material). Fertilizer P is relatively soluble when applied. As it reacts with soil, its solubility decreases, and eventually it becomes unavailable for plant growth, as shown in the diagram below.

Soluble ↔ **Available in soil** → **Not available for plant use**

Perennial ryegrass and other plants obtain P from the soil solution. The Bray soil test measures soluble P and P that will be available during the growing season.

Unfortunately, P concentration in soil solution is very low. In the top foot of two western Oregon grass seed fields, between 85 and 150 grams (3 to 5 ounces) of inorganic or plant-available P was in solution when soil test P was above 20 ppm. A rapidly growing grass seed crop requires more than 200 grams or almost 8 ounces of P/a each day. To adequately supply a perennial ryegrass

crop, the soil solution must be replenished multiple times daily.

Fortunately, solution P is continually replenished from P in the soil, as shown at left by the line with arrows at each end. Also, soil test P decreases slowly from plant use, less than 1 ppm/year for the silt loam, clay loam, and silty clay loam soils typically used for grass seed production in western Oregon. Thus, soil with more than 35 ppm soil test P can adequately supply P to grass seed crops for several years.

Increases in soil test P require considerably more P than needed to meet crop requirement. To increase soil test P 1 ppm in the surface inch of soil in western Oregon, between 25 and 50 lb P₂O₅/a is required. An increase in soil test P after top-dress P fertilizer application can be measured in the surface 2 to 3 inches of soil in 3 years, but if the same rate is mixed into the soil with tillage, you will not measure an increase in soil test P for more than 3 years, and possibly as long as a decade.

Increasing soil test P above 20 ppm does not increase the amount in soil solution or the P supply to a perennial ryegrass crop. Soil water content, which is controlled by soil textural class (sand, silt, and clay), and organic matter are key factors.

Potassium (K)

Potassium is required by plants in large amounts compared to other nutrients. Even so, physiologically mature perennial ryegrass plants usually contain less than 2 percent K (Figure 18). Although 2 percent is a small amount, it is much more than needed by the grass plant to produce top yields.

Figure 19 shows the distribution of K in perennial ryegrass. Compared to P, which is proportionally distributed, K is concentrated in the straw. Figures 18 and 19 lead to two critical management conclusions:

- Straw K concentration changes little when soil test K exceeds 100 ppm. Thus, K plant use is governed by the amount of biomass produced.
- Baling straw removes substantial amounts of K (Figure 20). Thus, more K must be added when straw is baled rather than chopped (Table 6, page 16). For more information, see EM 9051, *Postharvest Residue Management for Grass Seed Production (Western Oregon)*.

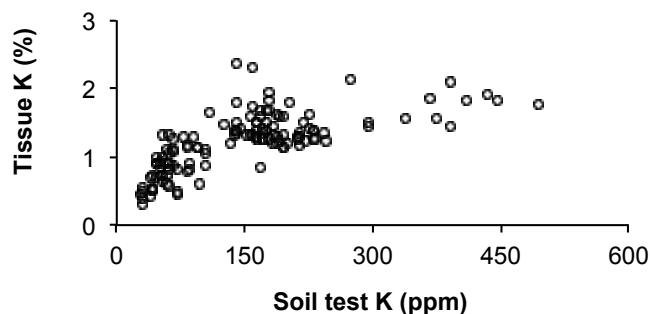


Figure 18.—Tissue K concentration increases as soil test K increases to 150 ppm. Data from a 1987 survey of 33 perennial ryegrass seed fields in western Oregon where 6-inch samples were collected. Figure by John Hart.



Tom Silberstein, © Oregon State University

Figure 20.—Nutrients, especially K, are removed with baled straw (left). In contrast, little K is removed with seed (right).

New seeding

Meeting a perennial ryegrass seed crop's K needs during an entire rotation begins with soil sampling and analysis before planting. When K soil test values are sufficient at planting, and little or no straw is

Potassium and plant water use

As part of a plant's regulation of water, perennial ryegrass obtains K through the roots and moves it to the leaves. When a plant uses K for water balance, it accumulates much more K than it needs for seed production. The term "luxury consumption" is sometimes used to describe plant uptake beyond the nutritional requirement.

To be used by plants as part of the water balance mechanism, K must be easily moved from one tissue to another. It also must be easily removed from desiccated plant tissue by irrigation water or rain. This aspect of K movement allows rapid recycling of K when straw residue is left on the field after harvest.

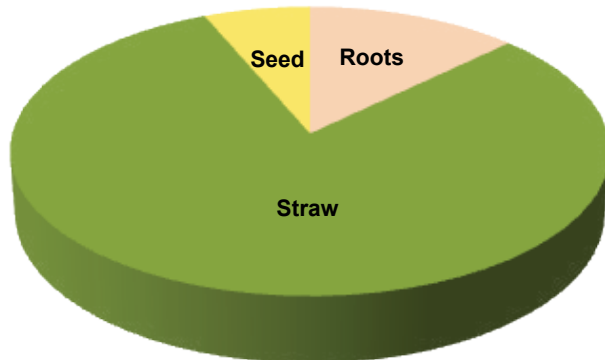


Figure 19.—Distribution of K in perennial ryegrass grown for seed. Figure by John Hart.



Richard Chynoweth, New Zealand Foundation for Arable Research

removed after harvest, K may be sufficient for the stand life.

When K is needed, applying K before or at planting is an efficient method of supplying K to a perennial ryegrass seed crop. Use Table 6 to determine K₂O (potash) application rate.

When banding K at planting, at least 1 inch of soil should separate the seed from fertilizer. Do not exceed 30 to 40 lb K₂O/a when banding K with seed. A banded application of N plus K as K₂O should not exceed 90 lb/a total to reduce salt injury. Additional information is in Appendix B, “Banding Fertilizer at Planting” (page 26).

Table 6.—Potassium fertilizer application rates for perennial ryegrass.

Soil test K (ppm) ²	Apply this amount of K ₂ O ¹		
	New seeding (lb/a)	Established stand (Straw management)	
		Bale (lb/a)	Chop (lb/a)
0 to 50	200 to 250	150 to 200	100 to 150
50 to 100	100 to 200	75 to 150	50 to 100
100 to 150	30 to 40	0 to 75	0 to 50
Above 150	0	0	0

¹Application rates based on analysis of a soil sample collected from a depth of 6 to 7 inches.

²Ammonium acetate extractable.

Established stands

Usually, K application rates exceed the amount that can safely be applied at planting. Therefore, the common method for supplying K to established perennial ryegrass seed fields is top-dressing with potassium chloride (KCl; 0-0-60 or muriate of potash). This practice adds K to the soil surface, similar to the result of chopping the full straw load.

Potassium application can occur in the fall or spring. Fall application is recommended if soil test K is below 100 ppm. The fall application allows roots to contact top-dressed K as the crop begins to grow in early February.

The rate of K assimilation by perennial ryegrass is greatest (3 to 4 lb/a/day) during early to mid-April, before rapid spring growth occurs (Figure 21). Adequate spring moisture during the period of peak K accumulation allows perennial ryegrass plants to readily use K in the top 1 to 2 inches of soil.

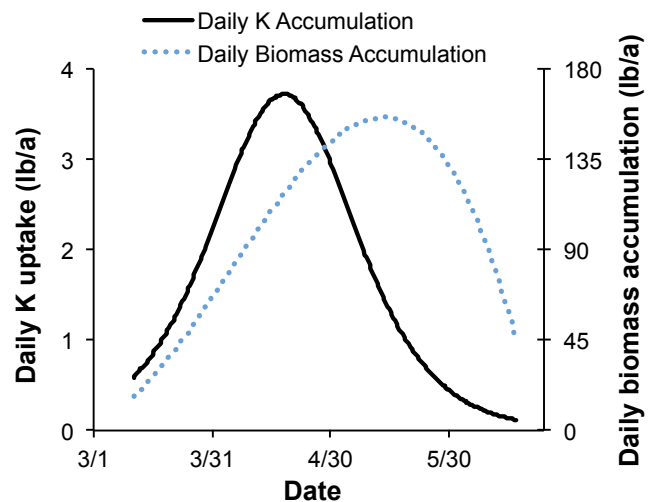


Figure 21.—Daily total above-ground biomass (seed plus straw) and K accumulation for perennial ryegrass grown for seed in western Oregon. Seasonal biomass values are higher than the sum of grower seed and straw harvest, as all above-ground biomass, including crowns, was carefully clipped in small plots. Figure by John Hart.

To determine the K application rate, use Table 6 and the soil test analysis of a sample collected from the surface 6 to 7 inches. *When soil test K is between 100 and 150 ppm, K application is not critical if straw is left on the field, as soil will adequately supply the crop. However, maintenance applications are necessary if straw is baled and soil test levels fall below 150 ppm.* Even where straw is baled, however, K application is not critical, especially as soil test K approaches 150 ppm and when the crop is in its final year.

When soil test K is above 150 ppm, the soil will adequately supply K to the crop, and no K application is needed. For more information about soil test K, see the sidebar “Kiwi K.”

Kiwi K

The soil test procedure for determining available K used in New Zealand is the same as that used in Oregon, and a soil test K range of 120 to 160 ppm is considered sufficient. This range is similar to the values for which no K fertilizer is recommended in Oregon (Table 6). The sufficient soil test K level in New Zealand has a “margin of safety,” as does the recommendation used in Oregon. New Zealand research showed that more than 2,000 lb seed/a can be produced when soil test K is 80 ppm.

The increase in perennial ryegrass seed yield from an application of spring K when soil test K is above 100 ppm is not predictable and occurs infrequently. Spring applications of KCl have sometimes produced a seed yield increase from the chloride (Cl) rather than from the K. The seed yield response to Cl application is typically less than 10 percent and results from an increase in test weight. For more information on this topic, see Appendix H, “Chloride in Perennial Ryegrass Seed Production” (page 37).

Additional information about soil test K and grass seed production is available in *Postharvest Residue Management for Grass Seed Production in Western Oregon*, EM 9051.

Sulfur (S)

In addition to N, K, and low soil pH, S is the element most likely to limit perennial ryegrass seed yield in western Oregon. Seed yield increase from S application is site- and year-specific. No soil test adequately predicts soil S supply; therefore, regular S application is recommended.

For stand establishment, band 10 to 15 lb S/a at planting. For established stands, a spring S application of 10 to 15 lb S/a is preferred, but S also can be applied in the fall. An alternative is to apply 30 to 40 lb S/a every other year.

The recommended application rate allows an ample amount for replacement of S removed with seed and straw. A typical yield (1,500 lb seed/a) contains about 1 lb S/a, and an average straw yield (4,500 lb/a) contains about 7 lb S/a. Additional S resides in crowns and straw not removed by baling, making the total amount of S in the above-ground portion of a perennial ryegrass seed crop 10 to 20 lb/a. An additional 5 to 7 lb S/a is contained in perennial ryegrass roots.

The accumulation of S begins gradually with about 1 lb/a present in the above-ground biomass by early March. Sulfur accumulation increases linearly as the plant grows, reaching about 0.2 lb/a daily until anthesis (flowering). As S use is small in late winter and early spring, applying S with spring N supplies S sufficiently early for use by the crop during rapid growth in April.

Since S accumulation is relatively constant and biomass increases during spring growth, S concentration decreases from early March (0.25 to

0.3 percent) to anthesis (0.1 to 0.15 percent), making use of tissue S concentration for determination of sufficiency difficult. An alternative approach is to use the N:S ratio for diagnostic purposes. See “Early season diagnosis of S deficiency” (page 18) for more information.

Micronutrients (B, Cl, Cu, Mn, Fe, Zn)

Seed yield increases from micronutrient application in perennial ryegrass seed production have not been documented in western Oregon, with the exception of Cl at a time before straw was routinely chopped. Soil test boron (B) levels normally are low (less than 0.2 ppm), and both tissue and soil test B increase when B is applied. A single application of 1 lb B/a will increase tissue B for more than a year. However, seed yield increases from B application have not been measured for perennial ryegrass seed production.

Zinc (Zn) is adequate for grass seed production when the DTPA* soil test value is above 0.6 ppm. If the soil test value is below 0.6 ppm, apply 1 to 5 lb Zn/a on a trial basis.

Additional information about micronutrient application for perennial ryegrass seed production is available in Appendix G, “Micronutrients for Western Oregon Grass Seed Production” (page 35).

*The DTPA (diethylenetriaminepentaacetic acid) micronutrient extraction method is a nonequilibrium extraction for estimating the potential soil bioavailability of Zn, Cu, Mn, and Fe for neutral and calcareous soils.



John Hart, © Oregon State University

Figure 22.—Combining a grass seed crop.

Early season diagnosis of S deficiency

Growers often assume that pale green or yellow leaves are a sign of a nutrient deficiency, specifically N or S. However, nutrient deficiencies are not the only cause of pale or yellow leaves. They can be the result of numerous problems or conditions.

Sulfur is routinely applied to most crops in western Oregon. Therefore, S deficiency in a western Oregon perennial ryegrass seed crop is uncommon.

Sulfur-deficient plants appear very pale, since the new growth is light colored and often hides the darker green lower leaves. When looking for S deficiency, 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.

Early season N deficiency is also uncommon. If present, it is expressed by yellowing of older leaves as N is moved to new tissue.

Plant analysis can be used to rapidly determine whether yellow leaves might be caused by lack of S or another problem. This approach differs from the standard evaluation of tissue concentration of a single element or nutrient. For evaluation of plant S status, the ratio of tissue N and S is used.

The amounts of N and S in protein are the basis for using the N:S ratio to determine S sufficiency. Using a ratio of two elements rather than the

concentration of S alone eliminates the difficulty in recognizing when a decrease in tissue concentration is caused by rapid growth.

To evaluate early season S deficiency in perennial ryegrass, collect leaves and stems from the entire above-ground portion of the plant. Have the sample analyzed for N and S. Before calculating an N:S ratio, examine the results to eliminate the possibility that both N and S might be deficient. The S concentration should be greater than 0.2 percent, and the N concentration higher than 3 percent.

To calculate the N:S ratio in tissue, divide the N concentration by the S concentration ($\%N \div \%S$). For example, tissue with 0.2 percent S and 3 percent N has an N:S ratio of 15 ($3 \div 0.2 = 15$). To evaluate S sufficiency, compare the N:S ratio you calculated with the values in Table 7.

Table 7.—Evaluation of N:S ratio for perennial ryegrass.

N:S ratio	Evaluation	Comments
Less than 10:1	S is adequate.	N should be higher than 3%; 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.

For more information

OSU Extension publications

The following OSU Extension Service publications are available online at <http://extension.oregonstate.edu/catalog/>

Applying Lime to Raise Soil pH for Crop Production (Western Oregon), EM 9057

Monitoring Soil Nutrients Using a Management Unit Approach, PNW 570-E

Nitrogen Uptake and Utilization by Pacific Northwest Crops, PNW 513

Postharvest Residue Management for Grass Seed Production in Western Oregon, EM 9051

Soil Acidity in Oregon: Understanding and Using Concepts for Crop Production, EM 9061

Soil Test Interpretation Guide, EC 1478

Other publications

Bailey, J. 1989. Potassium-sparing effect of calcium in perennial ryegrass. *J. Plant Nutrition* 12(8):1019–1927.

Borm, G.E.L. and W. van den Berg. 2008. Effects of the application rate and time of the growth regulator trinexapac-ethyl in seed crops of *Lolium perenne* L. in relation to spring nitrogen rate. *Field Crops Research* 105:182–192.

Catherall, P. and A. Parry. 1987. Effects of barley yellow dwarf virus on some varieties of Italian, hybrid, and perennial ryegrasses and their implication for grass breeders. *Plant Pathology* 36:148–153.

Chastain, T. and W. Young III. 1998. Vegetative plant development and seed production in cool-season perennial grasses. *Seed Sci. Res.* 8:295–301.

Christensen, N. and J. Hart. 1993. *Combating Take-all of Winter Wheat in Western Oregon*. Oregon State University Extension Service. EC 1423.

deWitt, C., W. Dijkshoorn, and J. Noggle. 1963. Ionic balance and growth of plants. *Versl. Land Bouwk. Onderz* 69:69.

Flowers, M., J. Hart, W. Young III, N. Christensen, C. Garbacik, M. Mellbye, T. Silberstein, and G. Gingrich. 2008. Exploring remote sensing applications in perennial ryegrass seed production. In: W. Young III (ed.). *2007 Seed Production Research at Oregon State University, USDA-ARS Cooperating*. Department of Crop and Soil Science. Ext/CrS 127.

Flowers, M., J. Hart, W. Young III, N. Christensen, C. Garbacik, M. Mellbye, T. Silberstein, and G. Gingrich. 2009. Yield estimation and the assessment of in-season nitrogen status of perennial ryegrass for seed production using remote sensing. In: W. Young III (ed.). *2008 Seed Production Research at Oregon State University, USDA-ARS Cooperating*. Department of Crop and Soil Science. Ext/CrS 128.

Flowers, M., J. Hart, W. Young III, C. Garbacik, M. Mellbye, T. Silberstein, and N. Anderson. 2010. In-season assessment of plant nitrogen status for perennial ryegrass seed production using remote sensing. In: *Proceedings of the 7th International Herbage Seed Conference*. April 2010, Dallas, TX.

Flowers, M., J. Hart, W. Young III, M. Mellbye, and C. Garbacik. 2010. Using remote sensing to assess the in-season nitrogen status of perennial ryegrass for seed production. *Agron. J.* 102:1441–1447.

Gangi, A. 1983. Floret fertility and seed yield in selected perennial ryegrass cultivars as affected by time and rate of N application. Ph.D. Dissertation, Oregon State University.

Gislum, R., P. Rolston, J. Hart, R. Chynoweth, B. McCloy, and W. Young III. 2007. Economical optimal nitrogen (ECO-N) application rate is all that matters for the growers. In: T. Aamlid, L. Havstad, and B. Boelt (eds.). *Proceedings of the 6th International Herbage Seed Conference (Seed Production in the Northern Light)*. June 18–20, 2007, Gjønnestad, Norway.

Hampton, J.G., T.G.A. Clemence, and P.D. Hebblethwaite. 1983. Nitrogen studies in *Lolium perenne* grown for seed: IV. Response of amenity types and influence of a growth regulator. *Grass and Forage Science* 38:97–105.

Hart, J. 2008. Reducing potassium fertilizer cost for grass seed production in western Oregon. Oregon State University Extension Service. *Crop & Soil News/Notes* 22 (November 2008):6.

Hart, J., N. Christensen, M. Mellbye, W. Young III, C. Garbacik, and T. Silberstein. 2009. Comparison of urea with polymer coated urea for perennial ryegrass seed production. In: W.C. Young III (ed.). *2008 Seed Production Research at Oregon State University, USDA-ARS Cooperating*. Department of Crop and Soil Science. Ext/CrS 128.

- Hart, J., M. Flowers, R. Roseberg, N. Christensen, and M. Mellbye. 2009. *Nutrient Management Guide, Soft White Winter Wheat, Western Oregon*. Oregon State University Extension Service. EM 8963-E.
- Hart J., M. Flowers, W. Young III, N. Christensen, C. Garbacik, M. Mellbye, T. Silberstein, and G. Gingrich. 2009. Fall N application for perennial ryegrass. In: W. Young III (ed.). *2008 Seed Production Research at Oregon State University, USDA-ARS Cooperating*. Department of Crop and Soil Science. Ext/CrS 128.
- Hart, J., D. Horneck, and R. Dick. 1988. Willamette Valley turf type tall fescue and turf type perennial ryegrass seed nutrient survey. In: *Proceedings of 39th Annual Northwest Fertilizer Conference*. Bozeman, MT.
- Hart, J., D. Horneck, R. Dick, M. Mellbye, G. Gingrich, R. Costa, and K. Wilder. 1988a. *Report to Department of Environmental Quality Field Burning Commission*. Project No. 09-88.
- Hart, J., D. Horneck, R. Dick, M. Mellbye, G. Gingrich, R. Costa, and K. Wilder. 1988b. Willamette Valley turf type tall fescue and turf type perennial ryegrass seed nutrient survey. Part I. *Soil and Water News* 3(2):1 & 4-7. Oregon State University Department of Soil Science.
- Hart, J., D. Horneck, R. Dick, M. Mellbye, G. Gingrich, R. Costa, and K. Wilder. 1989. Willamette Valley turf type tall fescue and turf type perennial ryegrass seed nutrient survey. Part II. *Soil and Water News* 4(1):1-5. Oregon State University Department of Soil Science.
- Hart, J., D. Horneck, M. Mellbye, G. Gingrich, W. Young III, and T. Silberstein. 2003. Potassium nutrition of perennial ryegrass. In: *Proceedings of the 5th International Herbage Seed Conference*. November 23-26, 2003, University of Queensland Gatton Campus, Australia.
- Hart, J., D. Horneck, M. Mellbye, G. Gingrich, W. Young III, and T. Silberstein. 2004. Part II of potassium and production of perennial ryegrass for seed. Oregon State University Extension Service. *Crop & Soil News/Notes* 18(1).
- Hart, J., D. Horneck, M. Mellbye, and R. Mikkelsen. 2003. Meeting potassium needs for Pacific Northwest grass seed production. *Better Crops with Plant Food* 87(3):18-23.
- Hart, J., D. Horneck, D. Peek, and W. Young III. 1990. Nitrogen and sulfur uptake for cool season forage and turf grass grown for seed. In: W. Young III (ed.). *1989 Seed Production Research at Oregon State University, USDA-ARS Cooperating*. Department of Crop Science. Ext/CrS 80.
- Hart, J., D. Horneck, and W. Young III. 1992. Ryegrass and tall fescue growth and seed yield response to lime and phosphorus. In: *Proceedings of the Western Phosphate/Sulfur Workgroup*.
- Hart, J., D. Horneck, W. Young III, and D. Peek. 1990. Nutrient uptake for selected forage and turfgrass cultivars. In: *Proceedings of 41st Annual Far West Regional Fertilizer Conference*. Spokane, WA.
- Hart, J., D. Horneck, W. Young III, and T. Silberstein. 1991. Potassium for grass seed nutrition. In: W. Young III (ed.). *1990 Seed Production Research at Oregon State University, USDA-ARS Cooperating*. Department of Crop and Soil Science. Ext/CrS 89.
- Hart, J., D. Horneck, W. Young III, and T. Silberstein. 1992. Potassium dynamics in grass seed production. In: *Proceedings of 43rd Annual Far West Regional Fertilizer Conference*. July 13-14, 1992, Coeur d'Alene, ID.
- Hart, J., D. Horneck, W. Young III, and T. Silberstein. 1993. Potassium dynamics in grass seed production. In: D. Armstrong (ed.). *Better Crops*. Potash and Phosphate Institute. Norcross, GA.
- Hart, J., R. Karow, and N. Christensen. 1999. Banded fertilizer influence on stand of peas, beans, and sweet corn. Oregon State University Extension Service. *Crop & Soil News/Notes* 13(4).
- Hart, J., M. Mellbye, G. Gingrich, T. Silberstein, and W. Young III. 2006. *Evaluation of the Use of the N Mineralization Test to Refine Spring Nitrogen Rates for Western Oregon Grass Seed Production*. Final Report for 2005-2006 to the Agricultural Research Foundation.
- Hart, J., M. Mellbye, G. Gingrich, W. Young III, T. Silberstein, and N. Christensen. 2004. Spring potassium and chloride application for grass seed production in the Willamette Valley. In: W. Young III (ed.). *2003 Seed Production Research at Oregon State University, USDA-ARS Cooperating*. Department of Crop and Soil Science. Ext/CrS 123.

- Hart, J., M. Mellbye, G. Gingrich, W. Young III, T. Silberstein, and N. Christensen. 2005. Spring potassium and chloride application for grass seed production in the Willamette Valley. In: W. Young III (ed.). *2004 Seed Production Research at Oregon State University, USDA-ARS Cooperating*. Department of Crop and Soil Science. Ext/CrS 124.
- Hart, J., M. Mellbye, and D. Horneck. 2002. Potassium and production of perennial ryegrass for seed—Part I. Oregon State University Extension Service. *Crop & Soil News/Notes* 16(7).
- Hart, J., M. Mellbye, and T. Silberstein. 2002. *Spring Potassium and Chloride Application for Grass Seed Production in the Willamette Valley*. Progress Report to the Agricultural Research Foundation/Oregon Seed Council.
- Hart, J., M. Mellbye, T. Silberstein, W. Young III, N. Christensen, and C. Garbacik. 2007. Evaluation of the N mineralization test to refine spring nitrogen rate for western Oregon grass seed production in 2006. In: W. Young III (ed.). *2006 Seed Production Research at Oregon State University, USDA-ARS Cooperating*. Department of Crop and Soil Science. Ext/CrS 126.
- Hart, J., M. Mellbye, T. Silberstein, W. Young III, G. Gingrich, S. Aldrich-Markham, and T. Thompson. 2006. Evaluation of the nitrogen mineralization soil test to refine spring nitrogen rate determination in western Oregon grass seed production. In: W. Young III (ed.). *2005 Seed Production Research at Oregon State University, USDA-ARS Cooperating*. Department of Crop and Soil Science. Ext/CrS 125.
- Hart, J. and G. Mueller-Warrant. 1990. *Effect of Surface Soil pH on Phosphorus Availability and Herbicide Efficacy*. Report to Department of Environmental Quality Field Burning Commission. Project No. 13-89.
- Hart, J., P. Rolston, M. Mellbye, T. Silberstein, W. Young III, B. McCloy, G. Gingrich, N. Christensen, and R. Gislum. 2007. Comparison of soil N tests for prediction of spring N rate in perennial ryegrass seed production. In: T. Aamlid, L. Havstad, and B. Boelt (eds.). *Proceedings of the 6th International Herbage Seed Conference (Seed Production in the Northern Light)*. June 18–20, 2007, Gjønnestad, Norway.
- Horneck, D. 1995. Nutrient management and cycling in grass seed crops. Ph.D. Dissertation, Oregon State University.
- Horneck, D. and J. Hart. 1989. A survey of nutrient uptake and soil test values in perennial ryegrass and turf type tall fescue fields in the Willamette Valley. In: H. Youngberg and J. Burcham (eds.). *1988 Seed Production Research at Oregon State University, USDA-ARS Cooperating*. Department of Crop Science. Ext/CrS 74.
- Horneck, D. and J. Hart. 1991. Response of tall fescue and perennial ryegrass to lime and phosphorous. In: W. Young III (ed.). *1990 Seed Production Research at Oregon State University, USDA-ARS Cooperating*. Department of Crop and Soil Science. Ext/CrS 89.
- Horneck, D. and J. Hart. 1992. Third-year response of tall fescue and perennial ryegrass to lime and phosphorous during a four year study. In: W. Young III (ed.). *1991 Seed Production Research at Oregon State University, USDA-ARS Cooperating*. Department of Crop and Soil Science. Ext/CrS 89.
- Horneck, D. and J. Hart. 2001. Spring potassium application on grass grown for seed. Oregon State University Extension Service. *Crop & Soil News/Notes* 15(8).
- Horneck, D., J. Hart, and W. Young III. 1992. Solution P in two soils amended with lime and P. In: *Proceedings of the Western Phosphate/Sulfur Workgroup*. August 1992.
- Horneck, D., J. Hart, and W. Young III. 1993a. Uptake of Ca, Mg, Zn, Mn, Cu, and B by five cool-season grass species. In: W. Young III (ed.). *1992 Seed Production Research at Oregon State University, USDA-ARS Cooperating*. Department of Crop and Soil Science. Ext/CrS 93.
- Horneck, D., J. Hart, and W. Young III. 1993b. Uptake of N, P, K, and S by five cool-season grass species. In: W. Young III (ed.). *1992 Seed Production Research at Oregon State University, USDA-ARS Cooperating*. Department of Crop and Soil Science. Ext/CrS 93.
- Horneck, D., J. Hart, and W. Young III. 1994. Effect of soil K on perennial ryegrass and tall fescue. In: W. Young III (ed.). *1993 Seed Production Research at Oregon State University, USDA-ARS Cooperating*. Department of Crop and Soil Science. Ext/CrS 98.
- Horneck, D., J. Hart, W. Young III, and T. Silberstein. 1992. Potassium for grass seed nutrition. In: W. Young III (ed.). *1991 Seed Production Research at Oregon State University, USDA-ARS Cooperating*. Department of Crop and Soil Science. Ext/CrS 89.

- Mellbye, M., G. Gingrich, N. Christensen, J. Hart, and M. Qureshi. 1997. Nutrient uptake by tall fescue under full straw load management. In: W. Young III (ed.). *1996 Seed Production Research at Oregon State University, USDA-ARS Cooperating*. Department of Crop and Soil Science. Ext/CrS 110.
- Mellbye, M., G. Gingrich, N. Christensen, J. Hart, W. Young III, and M. Qureshi. 1994. Nitrogen uptake by tall fescue under full straw load management. In: W. Young III (ed.). *1993 Seed Production Research at Oregon State University, USDA-ARS Cooperating*. Department of Crop and Soil Science. Ext/CrS 98.
- Mellbye, M., G. Gingrich, and J. Hart. 2001. Do grass seed fields in the Willamette Valley need boron fertilizer? In: W. Young III (ed.). *2000 Seed Production Research at Oregon State University, USDA-ARS Cooperating*. Department of Crop and Soil Science. Ext/CrS 112.
- Mellbye, M., G. Gingrich, and J. Hart. 2003. Response of cool season grass seed crops to boron fertilizer in the Willamette Valley, Oregon. In: *Proceedings of the 5th International Herbage Seed Conference*. November 23–26, 2003, University of Queensland Gatton Campus, Australia.
- Mellbye, M. and J. Hart. 2003. Micronutrients for Willamette Valley grass seed production. Oregon State University Extension Service. Crop & Soil News/Notes 17(2).
- Pirelli, G., J. Hart, S. Filley, A. Peters, M. Porath, T. Downing, M. Bohle, and J. Carr. 2004. *Early Spring Forage Production for Western Oregon Pastures*. Oregon State University Extension Service. EM 8852-E. <http://extension.oregonstate.edu/catalog/>
- Rolston, M., J. Hart, B. McCloy, R. Chynoweth. 2010. Perennial ryegrass (*Lolium perenne* L.) seed crop response to spring nitrogen: A comparison of New Zealand and Oregon results. In: *Proceedings of the 7th International Herbage Seed Conference*. April 2010, Dallas, TX.
- Rowarth, J., W. Archie, W. Cookson, J. Hampton, C. Sanders, T. Silberstein, and W. Young III. 1999. The link between nitrogen application, concentration of nitrogen in herbage and seed quality in perennial ryegrass (*Lolium perenne* L.). *J. Appl. Seed Prod.* 17:1–6.
- Rowarth, J., B. Boelt, J. Hampton, A. Marshall, M. Rolston, G. Sicard, T. Silberstein, J. Sedcole, and W. Young III. 1998. The relationship between applied nitrogen, nitrogen concentration in herbage and seed yield in perennial ryegrass (*Lolium perenne* L.). I. Cv. Grasslands Nui at five sites around the globe. *J. Appl. Seed Prod.* 16:105–114.
- Turner, J. 1989. Pacllobutrazol and nutrient treatment effects on Ovation perennial ryegrass. Ph.D. Dissertation, Oregon State University.
- Young, W. III. 1988. Seed yield and yield components of Pennfine perennial ryegrass (*Lolium perenne* L.) as influenced by time and rate of spring nitrogen and chemical dwarfing. Ph.D. Dissertation, Oregon State University.
- Young W. III, T. Chastain, T. Silberstein, and J. Rowarth. 1998. The relationship between applied nitrogen, nitrogen concentration in herbage and seed yield in perennial ryegrass (*Lolium perenne* L.). II. Cultivars in Oregon. *J. Appl. Seed Prod.* 16:115–124.
- Young, W. III, M. Mellbye, G. Gingrich, T. Silberstein, T. Chastain, J. Hart, and S. Griffith. 2003. Defining optimum nitrogen fertilization practices for grass seed production systems in the Willamette Valley. In: W. Young III (ed.). *2002 Seed Production Research at Oregon State University, USDA-ARS Cooperating*. Department of Crop and Soil Science. Ext/CrS 122.
- Young, W. III, M. Mellbye, G. Gingrich, T. Silberstein, S. Griffith, T. Chastain, and J. Hart. 1999. Defining optimum nitrogen fertilization practices for perennial ryegrass and tall fescue seed production systems in the Willamette Valley. In: W. Young III (ed.). *1998 Seed Production Research at Oregon State University, USDA-ARS Cooperating*. Department of Crop and Soil Science. Ext/CrS 112.
- Young, W. III, M. Mellbye, G. Gingrich, T. Silberstein, S. Griffith, T. Chastain, and J. Hart. 2000. Defining optimum nitrogen fertilization practices for perennial ryegrass and tall fescue seed production systems in the Willamette Valley. In: W. Young III (ed.). *1999 Seed Production Research at Oregon State University, USDA-ARS Cooperating*. Department of Crop and Soil Science. Ext/CrS 112.
- Young W. III, M. Mellbye, and T. Silberstein. 1999. Residue management of perennial ryegrass and tall fescue seed crops. *Agron. J.* 91:671–675.

Young, W. III, T. Silberstein, and J. Hart. 1990.

Nitrogen fertilizer requirements for grass seed production in non-burn post-harvest residue management systems. In: W. Young III (ed.). *1989 Seed Production Research at Oregon State University, USDA-ARS Cooperating*. Department of Crop and Soil Science. Ext/CrS 80.

Young W. III, T. Silberstein, and J. Hart. 1991. Nitrogen fertilizer requirements for grass seed production in non-burn post-harvest residue management systems. In: W. Young III (ed.). *1990 Seed Production Research at Oregon State University, USDA-ARS Cooperating*. Department of Crop and Soil Science. Ext/CrS 89.

Young W. III, T. Silberstein, and J. Hart. 1992. Nitrogen fertilizer requirements for grass seed production in non-burn post-harvest residue management systems. In: W. Young III (ed.). *1991 Seed Production Research at Oregon State University, USDA-ARS Cooperating*. Department of Crop and Soil Science. Ext/CrS.

Young W. III, T. Silberstein, M. Mellbye, G. Gingrich, J. Hart, and T. Chastain. 2003. Spring nitrogen fertilization practices in Oregon's Willamette Valley grass seed crops. In: *Proceedings of the 5th*

International Herbage Seed Conference. November 23–26, 2003, University of Queensland Gatton Campus, Australia.

Young, W. III, H. Youngberg, D. Chilcote, and J. Hart. 1997. Spring nitrogen fertilization of perennial ryegrass seed crop. *J. Prod. Agric.* 10(2):327–330.

Acknowledgments

The authors thank the following for their review and helpful comments during the development of this publication: Paul Marquardt, Oregon State University area Extension agronomist for Linn, Benton, and Polk counties; Steve Salisbury, Wilbur-Ellis Company; and Craig Vachter and Eric McKillip, Marion AG Service, Inc.

Richard Roseberg, Oregon State University Department of Crop and Soil Science, provided data used in Appendix F, "Foliar Nutrient Application to Grass Grown for Seed."

Thank you to Bob Schroeder, CPS, Tangent, OR, for providing the photo in Figure 12, and to Richard Chynoweth, New Zealand Foundation for Arable Research, for providing the photo in Figure 20.

Appendix A. Perennial Ryegrass is an Efficient Scavenger of Nitrogen

Nitrogen (N) is the most limiting nutrient for western Oregon crop production. Most crops use more than 100 lb N/a. Even though crop use is high, it sometimes is only moderately efficient. Any N not used by the crop usually is vulnerable to leaching by fall and winter rain.

Nitrate-N ($\text{NO}_3\text{-N}$) is the end product of soil microbial transformation and the form predominantly used by crops. When the nitrate form of N enters groundwater, it becomes a health hazard for humans and livestock using the water for drinking.

Perennial ryegrass seed crops are not likely to allow nitrate leaching to groundwater, as the crop efficiently uses N. Furthermore, the N remaining after harvest is used by the crop as regrowth begins in the fall. This situation is parallel to having a “built-in” cover crop.

Postharvest nitrate-N was measured in two western Oregon perennial grass seed fields for 3 years. Samples were collected from the surface to a depth of 3 feet. Even when no spring N fertilizer was applied, a small amount of $\text{NO}_3\text{-N}$ (about 10 lb/a) was measured (Figure 23). When N was applied within the recommended spring rate, 135 lb N/a, approximately 20 lb $\text{NO}_3\text{-N}$ /a remained after harvest. These measurements are a low amount of $\text{NO}_3\text{-N}$.

Doubling the spring N rate to 270 lb N/a tripled the amount of postharvest N measured to about 60 lb $\text{NO}_3\text{-N}$ /a. These data show that recommended rates of spring N are efficiently used by a perennial

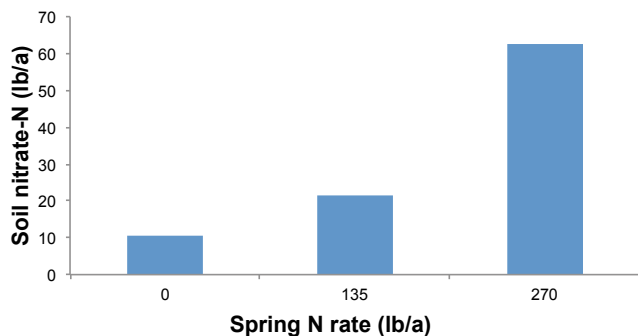


Figure 23.—Average amount of postharvest soil nitrate-N in 3 feet of soil from two western Oregon perennial ryegrass seed fields. Data are from 3 years of soil testing after spring N application at three N rates. Figure by John Hart.

ryegrass seed crop, leaving little $\text{NO}_3\text{-N}$ in the soil for potential loss to groundwater by leaching.

The data in Figure 23 are a sum of three sample depths. Figure 24 shows the amount of $\text{NO}_3\text{-N}$ at each sampling depth. Regardless of N rate, most of the residual N was measured in the surface foot of soil.

This information is significant for two reasons. First, it shows that spring N, when applied between mid-February and mid-April, is not lost by leaching from spring rain, even when an excess rate is applied. Second, the unused N is available to be used in the fall for growth, as most perennial ryegrass roots are in the top foot of soil as shown in Figures 25 and 26 (page 25).

Accumulation of residual soil $\text{NO}_3\text{-N}$ is not immediate (Figure 27, page 25). Two years of applying double the recommended spring N rate were needed to increase residual soil $\text{NO}_3\text{-N}$ in the field represented by Figure 27. In another field, increase occurred in the second year, showing that residual soil $\text{NO}_3\text{-N}$ varies by field and variety. The common factor was that residual soil $\text{NO}_3\text{-N}$ did not increase after the first year of applying 270 lb spring N/a,

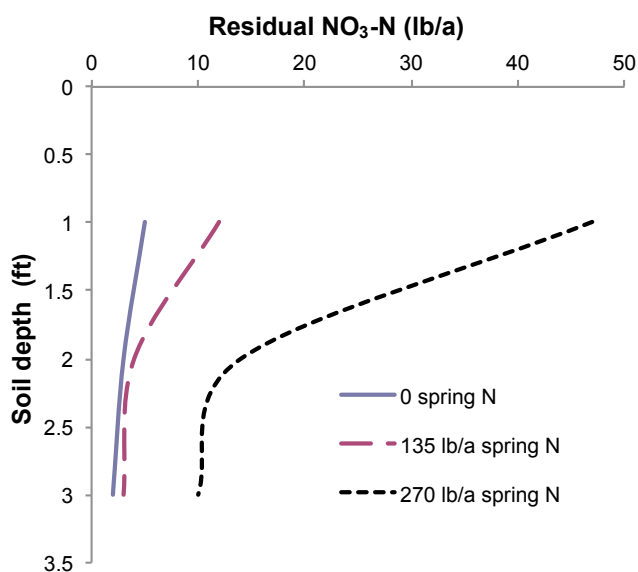


Figure 24.—Average distribution of postharvest soil nitrate-N from a western Oregon perennial ryegrass seed field. Data are from 3 years of soil testing after spring N application at three N rates. Figure by John Hart.

Appendix A—continued. Perennial Ryegrass is an Efficient Scavenger of Nitrogen

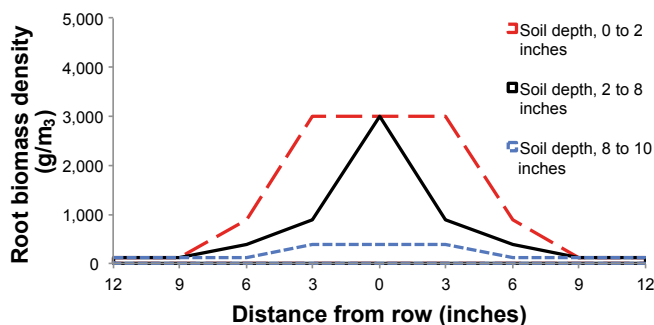


Figure 25.—Root distribution from a western Oregon first-year perennial ryegrass seed field. Figure by John Hart. Data from Tom Chastain.

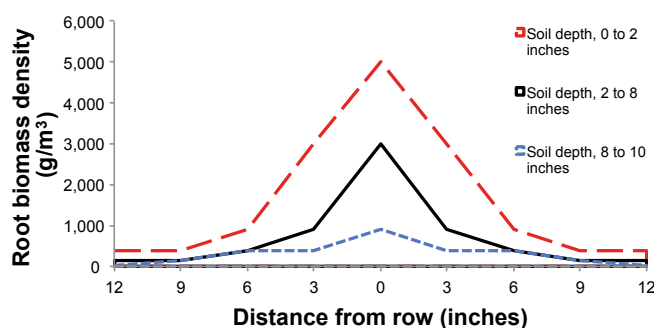


Figure 26.—Root distribution from a western Oregon third-year perennial ryegrass seed field. Figure by John Hart. Data from Tom Chastain.

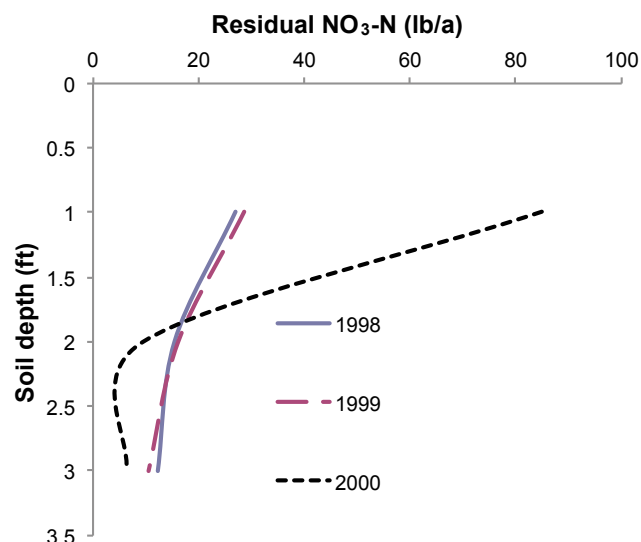


Figure 27.—Distribution of postharvest soil nitrate-N from a western Oregon perennial ryegrass seed field that received an annual spring application of 270 lb N/a. Figure by John Hart.

showing that the system has the capacity to hold and use N.

Nitrogen measured in the above-ground portion of a perennial ryegrass seed crop at harvest supports the concept that when N is applied at recommended rates, it is used by the crop (Figure 28).

When N was applied at 90 to 180 lb N/a in the spring, that amount was measured in the above-ground portion of the crop. The amount of N in the crop increased with increasing spring N rate until 200 to 225 lb N/a was measured with the application of 270 lb N/a in the spring. The amount of residual soil NO₃-N measured in treatments receiving 270 lb N/a in the spring is approximately the difference between the amount applied (270 lb/a) and the amount in the crop (200 to 220 lb/a), i.e., 50 to 70 lb/a.

Conclusion

Use of spring N at recommended rates, 120 to 160 lb/a, provides adequate N for a perennial ryegrass seed crop and minimal, if any, potential for loss of N to groundwater from leaching.

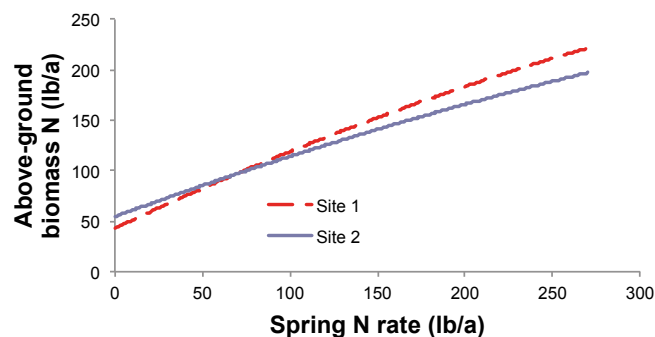


Figure 28.—The influence of spring N rate on the average above-ground biomass N at harvest from two western Oregon perennial ryegrass seed fields. Data are for 3 years of soil testing after spring N application at three N rates. Figure by John Hart.

Appendix B. Banding Fertilizer at Planting

Any fertilizer material banded with seed at planting delays germination and emergence by several days and has the potential to reduce the stand, regardless of the crop. Perennial ryegrass grown for seed has greater potential for stand reduction than many other crops, as it is usually planted when soil moisture is limited and without the benefit of irrigation.

To demonstrate the effect of banding fertilizer on germination, sweet corn was planted with an assortment of banded fertilizer materials on limed and unlimed soils (Table 8). Corn was planted in 32-inch rows at the rate of 26,000 seeds/a. Three replications were planted in an area with a soil pH of 5.4 and in an area with a soil pH of 5.9. All plants in each plot were counted approximately 1 month after planting.

The average stand was 75 percent of the seeding rate. The May 7 planting date was 1 of only 4 days without rain in May of 1998. After planting, almost 5 inches of rain fell during the remainder of May, approximately 3 inches above the 30-year average. The continual rain created a crust on the silt loam soil that inhibited seedling emergence.

The rain was beneficial, however, in ameliorating the effect of fertilizer placed with the seed. Drier and warmer weather may not have produced higher average stand counts, but stand counts from plots without fertilizer should have been higher if the rainfall had been normal.

Results of the individual treatments are shown Table 8. Where lime or mono-ammonium phosphate (MAP, 11-52-0, for example) plus lime was added, the corn stand was not significantly different from that of the treatment receiving no fertilizer at

planting. Changing the phosphorus (P) source from MAP to di-ammonium phosphate (DAP, 18-46-0, for example) substantially reduced the stand. Banding nitrogen (N) as urea with the seed reduced the stand approximately 50 percent.

The recommendation in the OSU fertilizer guide for sweet corn is to band less than 90 lb N/a plus K₂O, 2 inches below and to the side of the seed row. Following this recommendation resulted in a stand that was 70 percent of the seeding rate. An additional 30 lb N/a plus K₂O did not significantly decrease the stand further. A rate of 150 lb N/a plus K₂O reduced the stand to the lowest of all the treatments.

Conclusions

The amount of fertilizer that can be banded with seed depends on the fertilizer source, soil moisture, and distance of the band from the seed. Some fertilizer materials, such as ammonium thiosulfate, urea, and DAP should not be banded with or near the seed. Both urea and DAP increase pH, liberating water-soluble ammonia, which is toxic to germinating seeds. On the other hand, banding MAP or K₂SO₄ with or near the seed has little or no detrimental effect on stand establishment.

The recommendation to band less than 90 lb N/a plus K₂O and to separate the fertilizer band from the seed by at least 2 inches is reasonable. However, the stand may be reduced if the highest rate of material is used. When deciding how much material to band with the seed, consider the material, distance between the seed and the fertilizer, and the soil moisture that will be present through germination, emergence, and early growth.

Table 8.—Stand count of corn as influenced by fertilizer treatment.

Treatment	Rate (lb/a)	Stand (%)	
		Lime	No lime
No fertilizer	—	90	100
MAP (11-52-0)	100 P ₂ O ₅	86	99
DAP (18-46-0)	100 P ₂ O ₅	63	61
Urea	45 lb N	43	50
90 N + K ₂ O (Am nitrate + KCl)	30 lb N + 60 lb K ₂ O	70	—
120 N + K ₂ O (Am nitrate + KCl)	45 lb N + 75 lb K ₂ O	64	—
150 N + K ₂ O (Am nitrate + KCl)	60 lb N + 90 lb K ₂ O	44	—

Appendix C. Substantiating Potassium Requirement for Perennial Ryegrass Seed Production

Growers and field representatives often believe that OSU Extension Service nutrient recommendations are too conservative. In fact, these recommendations are liberal. Potassium (K) recommendations for perennial ryegrass seed production are an example.

In Table 6 (page 16), no K fertilizer is recommended when soil test K values are above 150 ppm. Above this soil test K concentration, no seed yield increase from K application has been measured. This conclusion is based on western Oregon research, where seed yield was measured in two perennial ryegrass fields with 3 years of K application.

At the high soil test K site, the initial 0- to 6-inch depth K soil test value was 168 ppm. The 3-year average seed yield for plots receiving K, either as fertilizer or from burning straw, was 1,482 lb/a (Table 9). Statistically, this yield does not differ from that where no K was applied and straw was removed (1,528 lb/a), indicating that soil test K was adequate for crop growth and seed production.

In contrast, seed yield increased after 2 years of K application in the field where initial soil test K was

low (78 ppm in the 0- to 6-inch depth), leading us to conclude that soil test K was inadequate.

Additional support for K fertilizer recommendations is found in straw K concentration from western Oregon seed production fields. Usually, when soil test K is below 100 ppm (Figure 18, page 15), tissue or straw K increases if soil test K increases. Straw K concentration increased about 0.5 percent as soil test K doubled from approximately 50 to 100 ppm. Little increase in straw K concentration was measured as soil test K increased beyond 100 ppm, indicating plant K sufficiency.

Table 10 offers additional confirmation of these conclusions. In this OSU research, yield and tissue K concentration increased with the total amount of K supplied. Seed yield was highest when straw K concentration was 0.89 percent.

These data are in agreement with nutrient solution concentration and potted greenhouse experiments. The critical K concentration was between 0.39 and 0.78 percent in the nutrient solution study and 0.6 percent in the potted experiment (Bailey, 1989, and deWitt, et al., 1963).

Table 9.—Perennial ryegrass seed yield from plots in two western Oregon grower fields.¹

Residue management	K rate (lb/a)	Yield (lb/a)							
		Low soil test K site				High soil test K site			
		Year 1	Year 2	Year 3	Average	Year 1	Year 2	Year 3	Average
Removed	0	1,152	1,307	1,559	1,339	1,477	1,533	1,573	1,528
Removed	30 (90)	1,122	1,422	1,542	1,362	1,402	1,379	1,651	1,477
Burned	0	1,085	1,420	1,603	1,369	1,429	1,625	1,421	1,492
Burned	30 (90)	1,064	1,516	1,513	1,364	1,407	1,277	1,747	1,477

¹Three years of K application. K application was 30 lb/a (35 lb K₂O/a) for the first 2 years and 90 lb/a (110 lb K₂O/a) for the third year.

Table 10.—Average 'Regal' perennial ryegrass seed yield from second year of trial, straw K content and concentration, and soil test data for treatments with straw removed and K applied to a silt loam soil.¹

Straw treatment	K fertilizer (lb/a)	Seed yield (lb/a)	K in straw (lb/a)	K in straw (%)	K from fertilizer and straw (lb/a)	Soil test K	
						0 to 1 inch (ppm)	0 to 6 inch (ppm)
Removed	0	1,307	29	0.39	0	57	36
Removed	30	1,422	39	0.51	30	71	37
Burned	0	1,420	63	0.78	63	118	44
Burned	30	1,516	65	0.89	95	184	84
LSD 0.05	—	180	—	—	—	—	—

¹Data are from second year of trial on a silt loam soil.

Appendix D. Sheep, Kiwis, Perennial Ryegrass, and Spring Nitrogen Fertilizer Application

Visits to other English-speaking countries such as England, Wales, or New Zealand reveal alternate meanings for common words. In New Zealand, a jug, rather than a tea kettle, is used to boil water; pegs or stakes are used to mark corners of plots; and a tariff is paid for a motel room. The list of differing word use is long enough that dictionaries have been published on the subject.

Travel to New Zealand demonstrates that a similar publication is needed for agronomic terms or practices. New Zealand perennial ryegrass seed growers apply early spring nitrogen (N) based on soil temperature. Livestock producers in Scotland, British Columbia, and western Oregon use air temperature to estimate timing of first or early-spring N application on perennial ryegrass pastures (Pirelli, et al., 2004).

Unlike in western Oregon, in New Zealand perennial ryegrass is often grown for forage and seed production in the same field or paddock. Spring N application is used to increase both seed yield and forage production.

For several years, Oregon grass seed growers have said that New Zealand producers have refined the timing of spring N application. The first spring N is applied when the soil temperature at 10 cm (4 inches) is 5°C (41°F) by 8 or 9 a.m. The rationale for this timing was puzzling until a conversation with a New Zealand research scientist clarified the reason for this practice.

The explanation is that early-spring N is applied to increase forage production and not for seed yield.

New Zealand producers want to graze fields as much as possible before “closing” them from grazing for seed production. Soil temperature is used to determine when perennial ryegrass will begin using N.

The 30-year average date when soil temperature reaches 5°C at a 10-cm depth in the Canterbury area of New Zealand is about the end of the second week in August. In the southern hemisphere, August is equivalent to February in the northern hemisphere.

Conclusions

The New Zealand timing for N application matches Oregon conditions and recommendations for early spring N application to perennial ryegrass. For early grazing of perennial ryegrass pastures, OSU recommends applying the first N when 200 heat units (HU) or growing degree days (GDD) have accumulated. The 30-year average for this date in western Oregon is Feb. 15. Both systems for predicting first N application for forage production rely on heat, although one uses soil temperature and the other air temperature. Both methods lead to the same outcome.

Oregon perennial ryegrass seed growers can use HU or GDD measurement to determine the earliest time the crop will use spring N. However, if N is applied at 200 GDD to a perennial ryegrass seed field, use only a low rate (e.g., 80 to 100 lb N/a), since only a small amount of N (50 to 60 lb/a) is used by the crop in the first month of growth after 200 GDD are accumulated. We have no data to indicate that early N application influences seed yield as long as all N is applied by mid-April. See pages 10–11 for more information.

Appendix E. Comparison of Urea, Polymer-coated Urea, and Urea with Urease Inhibitors for Perennial Ryegrass Seed Production

Ensuring that nitrogen (N) availability is synchronized with crop demand is a goal of all growers. As N fertilizer costs have increased, growers have sought to increase N use efficiency. The goal is to reduce N application rate or increase seed yield without increasing the N application rate.

One potential way to achieve this goal is the use of a controlled-release fertilizer, such as polymer-coated urea. Controlled-release fertilizer products have been available for decades. Urea or other fertilizer materials are coated with sulfur, starch, or other organic materials. If the coating maintains its integrity, coated urea will provide N gradually rather than in a large “dose.” This feature is desirable where even growth and color are important, such as in turf.

By matching release rate with crop demand, controlled-release N can also reduce N loss where leaching may move nitrate-N below the root zone. The potential for leaching loss of N is highest when the entire season’s N is supplied before or at planting to an annual crop such as corn. In rain-fed corn

production systems in the Midwest and southeastern U.S., N can be leached if all or a substantial amount is applied early in the growing season. A number of nitrification inhibitors and controlled-release materials were produced for this environment.

Leaching loss is not considered a problem for cool-season perennial grass seed production in western Oregon. Crop demand and N supply can be synchronized by timing N application to meet N demand and by splitting spring N application, common practices of most grass seed growers.

A more recent concern is volatile N loss from surface-applied urea when it remains on the surface of moist soil for several days. Volatile N loss can be reduced by protecting urea from contact with a soil enzyme, urease, or by inhibiting the action of this enzyme.

In New Zealand, urease inhibitors are sold as urea-coated sulfur or N-(n-butyl) thiophosphoric triamide (nBTPT). These products were evaluated for perennial ryegrass seed production in six trials at several locations in New Zealand. At no site was a significant difference in seed yield measured between perennial ryegrass fertilized with uncoated urea or either coating material. Although small seed yield increases from use of these products were consistently measured, they were statistically insignificant. By combining data for all sites, however, a significant seed yield increase, 200 lb/a or 7 percent, was measured when spring N rates were 130 to 170 lb N/a.

Western Oregon data from experiments using polymer-coated urea from 1998 through 2008 have been combined and reviewed. Results are summarized in Table 11, and the complete report is available in *2008 Seed Production Research at Oregon State University* (http://seed-ext.cropandsoil.oregonstate.edu/sites/default/files/Pub/2008/3-SR09-32-Hart_Christensen_Mellbye_Young_Garbacik_Silberstein.pdf).

Table 11.—Average annual seed yield with urea or polymer-coated urea as the spring N source.

Year	N rate (lb/a)	N from urea (lb/a)	N from polymer (lb/a)	Seed yield (lb/a)	Difference in seed yield (lb/a)
1998	135	95	40	2,148	
	135	135	—	1,998	+150
1998	135	95	40	2,144	
	135	135	—	2,078	+66
1998	180	100	80	1,935	
	180	180	—	1,986	-51
1999	135	95	40	1,517	
	135	135	—	1,461	+56
1999	135	95	40	1,409	
	135	135	—	1,403	+6
1999	180	100	80	1,767	
	180	180	—	1,775	-8
2007	160	80	80	1,432	
	160	160	—	1,233	+199
2007	160	40	120	1,561	
	160	160	—	1,421	+140
2008	140	70	70	1,090	
	140	140	—	1,017	+73
2008	140	70	70	1,357	
	140	140	—	1,420	-64
Average	—	—	—	—	+57

Appendix E.—*continued*. Comparison of Urea, Polymer-coated Urea, and Urea with Urease Inhibitors for Perennial Ryegrass Seed Production

Conclusions

The difference in seed yield from plots fertilized with polymer-coated urea vs. uncoated urea ranged from -64 to +199 lb/a. The average difference in seed yield was small, 57 lb/a or 3.5 percent more for polymer-coated urea. Seed yield from polymer-coated urea application was not consistently or significantly

different from yield from urea application ($p=0.05$), and no relationship existed between polymer-coated N supply and seed yield increase. For these reasons, application of polymer-coated urea is not recommended for perennial ryegrass seed production in western Oregon.

Appendix F. Foliar Nutrient Application to Grass Grown for Seed

Nutrients can be absorbed or “taken up” by plants through either roots or leaves. The primary route for nutrients to enter plants is through the roots. For nutrients such as nitrogen (N) and potassium (K), foliar application cannot supply a substantial portion of crop need. However, foliar nutrient application is useful when soil conditions restrict nutrient availability to roots.

For foliar application of nutrients to be effective, a dilute solution of the nutrient must be able to supply the amount needed by the plant. Solutions must be dilute to minimize leaf “burning” or desiccation. Thus, foliar-applied nutrient solutions commonly contain less than 1 percent N. A solution containing even 4 percent N is quite concentrated. It probably would burn leaves and might scorch or kill them early in the season.

Dilute solutions supply small amounts of nutrients to foliage. For example, a 4 percent N solution weighing 8.5 lb/gal and applied at 50 gal/a supplies 17 lb N. If additional solution is applied, liquid will drip from the leaves to the soil. If used by the plant, these nutrients will be assimilated through the roots.

Foliar nutrient application to fruit and nut trees

Since nutrient solutions can supply only a small amount of material with each application, they logically would be used to supply elements required by plants in relatively small quantities (less than 10 lb/a), such as boron (B), manganese (Mn), iron (Fe), zinc (Zn), or copper (Cu), Table 12. In very few situations, foliar applications can significantly increase the amount of phosphorus (P), magnesium (Mg), or sulfur (S) supplied to a crop.

The small quantities of Zn, Fe, and B used by plants make them likely candidates for foliar application where nutrient supply through soil is limited, usually by high pH, which limits Fe and Zn solubility, or “availability.”

Foliar B application to fruit and nut crops is an example of matching the amount of nutrient applied by foliar application to the amount needed by the crop. Furthermore, foliar application allows delivery to the plant part that most needs the nutrient.

Table 12.—Average amount of nutrients contained in 5.3 t/a of above-ground dry matter (seed and straw).¹

Nutrient	Amount (lb/a)
Nitrogen	140
Phosphorus	14
Potassium	180
Sulfur	16
Calcium	48
Magnesium	12
Boron	0.08
Copper	0.03
Manganese	3
Zinc	0.15

¹Pennfine[®] and Linn[®] perennial ryegrass.

Foliar B application to supply fruit buds with B initially seems illogical, as B is not mobile in the plant and should not move from the leaves to the fruit buds. However, a small amount of foliar-applied B is adsorbed by the flower bud. Also, when a sodium pentaborate solution is applied to leaves, the form of B absorbed by the plant is mobile for about 48 hours. This short-term mobility allows B movement to fruit buds. Foliar B applications are made in the fall so that fruit buds will have sufficient B in the spring.

A parallel example is a postharvest application of N to apples and pears. If N is withheld from a tree to reduce vigor or to develop color in fruit, leaf N concentration after harvest can be low enough that inadequate N is translocated from the leaves to the fruit buds, reducing flowering and potential fruit production the following year. In this situation, postharvest foliar application of 20 to 40 lb N/a will adequately supply the fruit buds for spring growth. However, when fruit trees with adequate foliar N concentration received postharvest foliar N, no change in leaf or fruit bud N concentration or yield was measured.

Foliar nutrient application to perennial ryegrass

Extrapolating the concept of “supplemental” foliar N or other nutrient application from fruit trees to perennial ryegrass is difficult unless the timing of application precedes a developmental stage.

Appendix F—*continued*. Foliar Nutrient Application to Grass Grown for Seed

Let's investigate routine foliar nutrient application to perennial ryegrass from the "boot" to "early heading" development stages in late May to early June. The first step is to examine nutrient use or demand by perennial ryegrass. Figure 3 (page 5) shows that peak above-ground accumulation of N and K occurs about mid-April, well in advance of the peak growth or biomass accumulation about 3 weeks later in early May. Anthesis typically occurs in mid-June, after N uptake is complete.

Perennial ryegrass naturally prepares for seed production by growing biomass, or a leaf photosynthesis "factory," with high nutrient content before seed production begins. As the seed fills, perennial ryegrass leaves send carbohydrates and nutrients to the seed. A 2,000 lb/a seed yield contains about 45 lb N. The above-ground portion of the plant contains more than three times that amount, approximately 160 lb N/a. At seed fill, perennial ryegrass should contain sufficient N for seed development.

Is foliar-applied N transported to seed?

Proponents of late-season foliar fertilization believe that May application provides nutrients that are readily transported to seed as they fill. To test this idea, foliar nutrients were applied to a perennial ryegrass seed stand at the Southern Oregon Research and Extension Center, near Medford, and at OSU's Hyslop Field Research Laboratory near Corvallis.

To determine whether late-season foliar-applied N is readily transported to the seed, a 10 lb/a urea-N solution was applied to perennial ryegrass in late May at OSU's Hyslop Field Research Laboratory when flag leaves were almost fully emerged and before seed formation began. The urea contained an isotope of N so the fertilizer could be traced.

In June, N was measured in the straw and seed. Approximately 70 percent of the foliar-applied N was in the plant (20 percent in the seed and 50 percent in the straw). Thus, some foliar nutrients applied when perennial ryegrass flag leaves are fully expanded are assimilated by the crop and moved to seed.

However, these data show that only a small amount, 2 lb N/a, was used for seed production. A 1,500 lb/a seed yield of perennial ryegrass contains

about 30 lb N. The amount supplied by the foliar application was less than 10 percent of the total found in the seed.

Does foliar fertilization increase yield?

At the Southern Oregon Research and Extension Center, four foliar fertilizer treatments were made:

- "Early" (materials applied at booting, approximately BBCH 41)
- "Late" (materials applied about 3 weeks later, approximately BBCH 51)
- "Early+Late"
- "Control" (no foliar fertilizers applied)

Each foliar fertilizer application included a tank mixture in water of Leffingwell NutraPhos Super K at 5 lb/a and SorbaSpray ZNP at 2 qt/a. NutraPhos Super K had an analysis of 7-13-34-0 + 12.5 Zn and was derived from potassium nitrate and zinc potassium phosphate complex. SorbaSpray ZNP had an analysis of 10-12-0-1 + 2 percent Zn, derived from urea, ammonium phosphate, phosphoric acid, and zinc sulfate.

These materials provided approximately 1 lb N, 1.25 lb P₂O₅, 1.75 lb K₂O, and 0.75 lb Zn/a per application. As a percentage of the total amount in the above-ground portion of a typical perennial ryegrass crop, the application supplied 0.7 percent of the N, 4 percent of the P, 0.8 percent of the K, and 500 percent of the Zn.

The data in Table 13 (page 33) are for 1 year. Similar treatments were made to perennial ryegrass, Kentucky bluegrass, and bentgrass for 3 years. The results and conclusions were similar for all grasses and years.

Perennial ryegrass seed yield, test weight, and "clean-out" were not consistently or significantly improved by foliar fertilizer application in boot and/or 3 weeks later. This statement was true regardless of the amount of soil fertilizer applied before the growing season. While yield was improved in certain instances, change in net return due to foliar fertilization was unpredictable, with both large gains and losses possible.

Appendix F—continued. Foliar Nutrient Application to Grass Grown for Seed

The seed yield reported in Table 13 is low due to water stress. The plot was established on a sandy soil, was not irrigated, and was in an area warmer than the primary grass seed production area of western Oregon. As a counter to these concerns, additional measurements were made in Marion County during 2000 and 2001 (Table 14). The conclusion was the same: application of foliar fertilizer did not increase

seed yield of any of the cool-season grass species in replicated experiments in grower fields.

The amount of nutrients supplied by a foliar application and moved to the seed is insignificant in terms of increasing yield. When a benefit is seen from foliar nutrient application, it is unlikely to result from nutrient supply, but rather from another mechanism, such as protection of flag leaf.

Table 13.—Perennial ryegrass seed yield and nutrient analysis at SOREC, 1990.¹

Variable	Treatments ²				LSD _{0.05} ⁵
	None	Early ³	Late ⁴	Early + late	
Seed yield (lb/a)	638	621	662	715	NS
Test wt (lb/bu)	17.7	18.8	20.3	19.1	NS
Clean seed (%)	72.1	75.8	78	69.3	NS
Seed nutrient concentration values					
N (%)	2.30	2.29	2.31	2.26	NS
P (%)	0.402	0.399	0.401	0.407	NS
K (%)	0.811 ^a	0.734 ^b	0.762 ^{ab}	0.742 ^b	0.064
Zn (ppm)	35.75	36.75	39.24	39.00	NS
Mn (ppm)	66.2	66.0	70.2	64.2	NS
Seed nutrient uptake values					
N (lb/a)	14.7	14.3	15.3	16.1	NS
P (lb/a)	2.56	2.48	2.65	2.91	NS
K (lb/a)	5.16 ^{ab}	4.55 ^b	5.03 ^{ab}	5.30 ^a	0.69
Zn (oz/a)	0.365	0.366	0.417	0.446	NS
Mn (oz/a)	0.67	0.66	0.74	0.73	NS

¹SOREC = Southern Oregon Research and Extension Center, Central Point, OR.

²Each application consisted of Leffingwell NutraPhos Super K at 5 lb/a and SorbaSpray ZNP at 2 qt/a, tank mixed in a solution applied at 25 gal/a.

³Early application when most seed heads were “in boot.”

⁴Late application 3 weeks after early, a time when seed heads were visible on approximately 10 percent of the ryegrass plants.

⁵Within a row, NS indicates no significant difference among all treatments. Differing letters following a value denote a significant difference as determined by using the protected least significant difference test.

Table 14.—Average seed yield from treatments receiving no foliar fertilizer or foliar fertilization containing N, P, K, plus micronutrients.¹

Species	Seed yield	
	No foliar fertilizer (lb/a)	Foliar fertilizer applied (lb/a)
Perennial ryegrass, 2000	2,679	2,675
Red fescue	1,834	1,874
Chewings fescue	1,370	1,390
Chewings fescue	1,148	1,172
Perennial ryegrass, 2001	1,308	1,236

¹6 lb/a 20-20-20 (with 0.02% B, 0.05% Cu, 0.1% Fe, 0.05% Mn, 0.0005% Mo, and 0.05 Zn) plus 10.6 lb/a 20-0-0. Application was made as heads began to emerge in 2000. In 2001, 11 lb/a of 27-0-0 was applied to perennial ryegrass.

Appendix F—*continued*. Foliar Nutrient Application to Grass Grown for Seed

Late-season protection of perennial ryegrass flag leaf and head is critical for seed fill generated by photosynthesis (carbon fixation).

Two foliar nutrient applications used in the above examples contained Zn. Many foliar nutrient mixtures contain one or more of the micronutrients Zn, Mn, or Cu. These nutrients are also components of fungicides. Foliar fertilizer applications may have a synergistic relationship with fungicides applied for rust control. In addition to supplying metallic materials, foliar fertilizer is a dilute salt solution that may desiccate pathogens on leaf surfaces.

Conclusions

For a foliar nutrient application to be beneficial, the plant must need the nutrient, the nutrient must be applied in a form that is mobile in the plant or can move to the point of use, and it must be applied before the plant needs/will use it. If all criteria are not met, foliar nutrient application will not be beneficial.

Research in western Oregon perennial ryegrass production has not shown foliar fertilization to be beneficial for increasing seed yield. Although small amounts of foliar-applied nutrients do move to the seed, the amount is not enough to increase yield. Based on these results, application of foliar fertilizers is not recommended for western Oregon grass seed production.

Appendix G. Micronutrients for Western Oregon Grass Seed Production

Willamette Valley growers are accustomed to applying micronutrients such as boron (B) to hops and red clover, zinc (Zn) to sweet corn in the Stayton area, chloride (Cl) to winter wheat, molybdenum (Mo) to broccoli and cauliflower, and copper (Cu) to onions grown on organic soils around the former Lake Labish. Since growers use micronutrients on many crops, a natural reaction is to ask whether micronutrients should be applied to perennial ryegrass fields.

Let's explore the need for the micro- or trace nutrients B, Cu, iron (Fe), manganese (Mn), Mo, and Zn in grass seed production. Use of Cl for grass seed production is discussed in Appendix H, "Chloride in Perennial Ryegrass Seed Production." The descriptive name for these nutrients, micro or trace, is indicative of the amount found in a crop. Table 15 provides amounts of some micronutrients in grass seed crops.

Table 15.—Average micronutrient content in seed and straw of tall fescue and perennial ryegrass.

Grass species	Weight	B (oz/a)	Cu (oz/a)	Zn (oz/a)
Tall fescue				
Straw	5,000	0.6	0.2	1.0
Seed	1,400	0.1	0.2	0.9
Total	—	0.7	0.4	1.9
Perennial ryegrass				
Straw	4,500	0.6	0.2	0.9
Seed	1,500	0.1	0.2	1.0
Total	—	0.7	0.4	1.9

Boron

Boron soil tests are naturally low (less than 0.5 ppm) in western Oregon. A survey conducted by OSU in the 1950s found that about 80 percent of valley grass seed fields had soil test B below 0.5 ppm, the amount considered "critical." Tissue and soil test B levels will increase with soil B applications as shown in Tables 16 and 17. For perennial ryegrass, an application of B approximately doubled soil test levels and flag leaf B concentration.

However, average seed yield was not changed by B application to perennial ryegrass, and only

Table 16.—Influence of soil B applications on soil test B, perennial ryegrass flag leaf B concentration, and seed yield.¹

Boron rate (lb/a) ²	Variety	Soil test B (ppm) ³	Flag leaf B (ppm) ³	Seed yield (lb/a)
0	SR 4200	0.3	12	1,736
1.25	SR 4200	0.5	19	1,618
0	DLF-1	0.1	10	1,595
1.25	DLF-1	0.9	37	1,687

¹Research conducted in western Oregon field research sites, 2000.

²Boron applied in March 2000 as dry granular fertilizer mixed with urea.

³Soil and plant samples collected May 24, 2000.

Table 17.—Influence of foliar B applications on soil test B, perennial ryegrass flag leaf B concentration, and seed yield.¹

Boron rate (lb/a) ²	Variety	Soil test B (ppm) ³	Flag leaf B (ppm) ^{3,4}	Seed yield (lb/a)
0	Express	0.3	13 ^a	1,846
1.25	Express	0.7	28 ^b	1,891
0	Brightstar II	0.4	16 ^a	1,885
1.25	Brightstar II	0.7	24 ^b	1,938

¹Research from western Oregon field research sites, 2000.

²Boron applied as Solubor liquid on March 21, 2000.

³Soil and plant samples collected May 24, 2000.

⁴Paired means followed by different letters are significantly different ($p=0.1$)



William Young, © Oregon State University

Figure 29.—Large-scale plots in commercial fields using grower equipment were used for research with B.

Appendix G—continued. Micronutrients for Western Oregon Grass Seed Production

one small seed yield increase from the application of 1.25 lb B/a was measured in field trials with other cool-season grass species during 2000. The application of B produced a seed yield increase in 10 percent of the situations, most likely a chance increase rather than treatment related.

Boron applied at 1 lb/a every 3 or 4 years may be used on a trial basis where soil test B is less than 0.3 ppm. To avoid potential toxicity, do not apply B with the seed at planting and do not use it every year.

Additional information about sites used in the B research (soil series and other soil test values) can be found in *2000 Seed Production Research at Oregon State University*, available at <http://seed-ext.cropandsoil.oregonstate.edu/Pub/2000/Default.htm>

Metallic micronutrients (Cu, Fe, Mn, and Zn)

Soil pH is a primary factor in the availability of “metallic” trace nutrients—Fe, Zn, and Mn. As soil pH increases, the solubility and availability of these nutrients decreases. The soil pH in Willamette Valley grass seed fields is usually below 6.0, certainly below 7.0, levels at which sufficient amounts of Fe, Mn, and Zn are available for grass seed production.

One often hears of increased grass seed yield from spring foliar micronutrient application. Foliar Zn, Cu, and Mn can act as fungicides as well as plant

nutrients. Fungicidal and nutritional responses of foliar nutrient application are difficult to distinguish, and plants may benefit more from the fungicidal activity of these elements than from increased nutrient availability.

Unlike other “metallic” trace nutrients, Cu availability is not influenced by soil pH. In Oregon, Cu availability is almost always sufficient for grass seed production. The only documented Cu deficiencies in Oregon are in organic soils such as the former Lake Labish and the Klamath Basin.

Molybdenum is a trace nutrient used in legume seed and some vegetable production. Legumes and brassica crops such as cauliflower need more Mo than other plant species, including grass seed crops. Soil pH regulates Mo availability, but in contrast to the trace metal nutrients, Mo availability decreases as soil pH decreases. Liming increases the availability of Mo.

Conclusions

Most soils in the Willamette Valley are not deficient in micronutrients for grass seed production. Growers should be skeptical about sales pitches that promote their use. Money spent on special micronutrient blends for grass seed production is more often than not an unnecessary expense (see Table 14, page 33).

Appendix H. Chloride in Perennial Ryegrass Seed Production

In several areas of the western U.S., potassium (K) application produced an increase in crop yield even when soil test K was adequate or high. Many of these observations were for wheat and barley. Meanwhile, in western Oregon, wheat producers began the practice of spring chloride (Cl) application to reduce yield loss from take-all root rot. These two practices raised the question of whether spring application of KCl could increase yield of perennial ryegrass for seed production.

OSU research in 1984 found that spring application of KCl did not significantly increase seed yield, although the thousand seed weight did increase (Table 18).

Table 18.—The effect of potassium chloride (KCl) application on seed yield and thousand seed weight.¹

KCl (lb/a)	Cl (lb/a)	Seed yield (lb/a) ²	1,000 seed weight (g) ²
0	0	1,770 ^a	1.610 ^a
165	75	1,884 ^a	1.654 ^b
500	225	1,890 ^a	1.647 ^b

¹First-year stand of 'Ovation' perennial ryegrass, 1984.

²Means with the same letters are not significantly different (P=0.05)

The 75 lb Cl/a rate (165 lb KCl/a) provided an increase in thousand seed weight and a trend of increased seed yield. The increase in seed yield was small, slightly more than 6 percent. This type of yield increase is indicative of a slight nutrient deficiency. The 225 lb Cl/a rate did not further increase thousand seed weight or seed yield.

The results from this research raised the question of which nutrient, K or Cl, was responsible for the differences measured. To determine the effect of each nutrient, a variety of treatments were applied to first- and second-year perennial ryegrass seed crops: potassium chloride (KCl), potassium sulfate (K₂SO₄), calcium chloride (CaCl₂), and no K or Cl treatments. This research was conducted with 'Ovation' perennial ryegrass in 1985 and 1986 on OSU's Hyslop Field Research Laboratory.

The K and Cl materials were applied during the first week of March in both years. Soil test K values ranged from 163 to 234 ppm, well above the critical level of 100 ppm for perennial ryegrass seed crops.

The application of K as K₂SO₄ did not increase seed yield (Table 19). Chloride, applied in the spring as KCl or CaCl₂, resulted in a small and sometimes significant seed yield increase. The yield increase sometimes resulting from KCl application is likely the result of overcoming Cl deficiency rather than improved K nutrition.

However, application of Cl increased seed yield only in 1985. As in 1984, the seed yield increase was small, only about 100 lb/a. The 1985 crop year was termed wet, and conditions in 1986 were considered dry. The dry conditions were not a detriment to seed yield, as yields were approximately the same both years.

Table 19.—The effect of K and Cl application on seed yield of first- and second-year stands of perennial ryegrass.¹

Treatment	Cl rate	Seed yield ² (year and stand age)			
		1985 1st	1985 2nd	1986 1st	1986 2nd
		(lb/a)			
Check	0	1,565 ^a	1,304 ^a	1,744 ^a	1,230 ^a
KCl	225	1,661 ^{ab}	1,407 ^b	1,762 ^a	1,158 ^a
K ₂ SO ₄	0	1,640 ^{ab}	1,314 ^a	1,794 ^a	1,144 ^a
CaCl ₂	225	1,714 ^b	1,384 ^b	1,714 ^a	1,214 ^a

¹'Ovation' perennial ryegrass, 1985 and 1986.

²Means with the same letters in the same column are not significantly different (P=0.05)

This research was conducted on small plots at a single site prior to elimination of burning as a residue management practice. Additional research was initiated for cool-season grass species grown for seed in 2003 and repeated in 2004. This research measured yield response to spring Cl application in larger plots over a range of soil and environmental conditions. Current grower practices of applying additional KCl after straw removal were followed.

Appendix H—*continued*. Chloride in Perennial Ryegrass Seed Production

In both years, the spring application of Cl increased Cl concentration in perennial ryegrass flag leaf samples with each increment of added Cl. The flag leaf tissue data demonstrate that spring-applied Cl is assimilated or “taken up” by the crop (Table 20).

However, neither Cl nor K application increased seed yield or seed weight (Table 21). Seed yield increase from application of K was not expected, as soil test K was adequate at both sites.

Research found no seed yield or seed weight increase from either Cl or K application even though Cl application routinely increased tissue Cl concentration.

In Tables 20 and 21, data are presented only from 2004. Data from 2003 and additional information for 2004 can be found in 2003 and 2004 *Seed Production Research at Oregon State University, USDA-ARS Cooperating* (Hart, et al., 2004 and 2005).

Conclusions

When soil test K level is adequate, the need for KCl fertilizer to supply either K or Cl to western Oregon grass seed fields is limited. Such need is likely to be caused by circumstances such as root disease or soil compaction, rather than by nutrient deficiency. When soil test K is above 150 ppm, maintenance application of potash fertilizer is not necessary to produce top grass seed yield.

Table 20.—Flag leaf tissue Cl and tissue K after spring application of Cl and K fertilizers to perennial ryegrass, 2004.

Treatment		Variety			
		‘Paragon’		‘Icon’	
K ₂ O (lb/a)	Cl (lb/a)	Tissue Cl (ppm) ¹	Tissue K (%) ¹	Tissue Cl (ppm) ¹	Tissue K (%) ¹
0	0	2,258 ^a	1.51 ^a	3,359 ^a	2.04 ^a
88	0	2,196 ^a	1.70 ^b	3,121 ^a	2.06 ^a
44	35	4,722 ^b	1.65 ^{ab}	6,402 ^b	2.17 ^a
88	70	8,502 ^c	1.75 ^b	9,602 ^b	2.19 ^a
176	140	14,745 ^d	1.92 ^c	13,697 ^d	2.22 ^a

¹Means with the same letters are not significantly different (P=0.1).

Table 21.—Seed weight and yield after spring application of Cl and K fertilizers on two perennial ryegrass seed fields, 2004.

Treatment		Variety			
		‘Paragon’		‘Icon’	
K ₂ O (lb/a)	Cl (lb/a)	Seed weight (g/1,000) ¹	Seed yield (lb/a) ¹	Seed weight (g/1,000) ¹	Seed yield (lb/a) ¹
0	0	1.71 ^a	1,996 ^a	1.94 ^a	1,588 ^b
88	0	1.61 ^a	1,966 ^a	1.87 ^a	1,570 ^{ab}
44	35	1.70 ^a	1,908 ^a	1.90 ^a	1,527 ^a
88	70	1.75 ^a	1,878 ^a	1.92 ^a	1,590 ^b
176	140	1.63 ^a	1,947 ^a	1.85 ^a	1,633 ^a

¹Means with the same letters are not significantly different (P=0.1).

Appendix I. The Influence of Spring Nitrogen Rate on Perennial Ryegrass Seed Yield and Yield Components

A goal of all growers is to produce high yields to optimize return on production expenses. It is commonly believed that seed yield of perennial ryegrass should increase in proportion to the amount of spring nitrogen (N) applied. While spring-applied N is one of the most important management inputs in perennial ryegrass seed production, other factors also play important roles in determining seed yield. A comparison of 2 years (1998 and 1999) in a Benton County perennial ryegrass field illustrates this point through analysis of seed yield components.

In 1998, statistical assessment showed the highest yield was produced by spring N rates between 135 and 270 lb/a. Within this range, no statistically significant difference in yield was seen. In 1999, the range of spring N producing the highest yield, again with no statistically significant difference in yield, was between 90 and 270 lb/a.

As N rate increased up to sufficiency, seed yield also increased. The yield increase was paralleled by a change in the number of fertile tillers (tillers bearing spikes). This relationship between spring-applied N and both fertile tiller number and seed yield illustrates the importance of fertile tiller number as a component of seed yield in perennial ryegrass.

Spikelets per spike and florets per spikelet also increased with spring-applied N rate. However, their numbers were similar for both years; therefore, these yield components were not the cause of the yield reduction from 1998 to 1999.

Seed weight was higher in 1998, when overall yield was higher, than in 1999. Seed weight increased with N rate in 1999. However, the increase in seed weight was not accompanied by an increase in seed yield for spring N rates above 90 lb/a.

Floret site utilization (FSU) is a measure of the efficiency of seed production. FSU is the ratio of the number of seeds produced by a crop to the number of florets and is expressed as a percentage [FSU = (seed number ÷ floret number) × 100]. Many cool-season grasses such as perennial ryegrass produce many more florets (flowers) than seed, so FSU is generally low, but it can be improved by some management practices.

Since FSU either does not change appreciably across N rates (1998) or declines with increasing N rate (1999), we can conclude that spring-applied N does not improve FSU. With only small changes in FSU across N rates and increasing floret numbers with increased N rate, the number of seeds produced increased with spring-applied N.

Moreover, FSU was generally lower across N rates in 1999 than in 1998. Thus, the seed yield reduction in 1999 compared to 1998 was most likely due to fewer seeds being produced across all N rates and to a lesser extent lower seed weight. The relationship of seed number and seed weight to seed yield is expressed as: seed yield = seed number × seed weight.

Conclusions

This examination of yield components reveals that the number of florets (florets per spikelet × spikelets per spike × fertile tillers per area) produced by the perennial ryegrass crop was essentially the same in both years. The rates of spring-applied N produced the same number of florets in both years. Thus, the seed yield potential was the same, but the number of seeds and seed weight were reduced in 1999.

The seed yield differences highlight the fact that N is not the only factor that influences seed yield in perennial ryegrass. Weather affects yield both directly and indirectly and can play a role in how effective N applications are in improving seed yield. Spring rainfall (April–June) was much above the long-term average (148 percent of normal) in 1998, while conditions were very dry in 1999 (67 percent of normal rainfall). Dry conditions in 1999 prevented the crop from realizing the seed yield potential established by the spring N application, and seed yields were lower regardless of N rate. As a consequence, the return on investment for N application was lower.

These data also show that the potential for increased perennial ryegrass seed yield exists with application of 120 to 160 lb spring N/a, and additional N does not increase seed yield potential or seed yield.

Appendix J. Barley Yellow Dwarf Virus and Perennial Ryegrass Nitrogen Rate

Barley yellow dwarf is caused by a virus that is transmitted by aphids to cereals and grasses, including perennial ryegrass. The virus is not seed-borne, nor is it transmitted from the aphid to her offspring.

Aphids acquire and transmit the virus by feeding on infected plants and then migrating to non-infected plants. After acquiring the virus in a period of feeding lasting at least 15 minutes, the aphid can transmit the virus in as few as 12 hours. Once an aphid acquires the virus, it can transmit *Barley yellow dwarf virus* (BYDV) for life.

Because the virus is present in sap, plants become systemically infected. Therefore, once perennial ryegrass plants are infected, the infection is permanent, and BYDV symptoms can reappear during subsequent growing seasons. BYDV is usually more severe during seasons with longer periods of cool, moist weather—conditions that also promote aphid population increase.

Disease symptoms can be confused with nutrient deficiencies such as nitrogen (N) or sulfur (S) deficiency or with other stresses; therefore, the presence of BYDV must be confirmed by serological testing. Affected leaves may have yellow blotches, which may become reddish to purplish (Figure 30). These tissues may turn brown during hot, dry conditions and are perhaps more sensitive to frost or cold injury than are healthy tissues. Often the leaf tissue next to the midribs stays greener than the rest of the leaf, and the youngest leaves may retain normal color. BYDV can also cause plants to be stunted.

Plants may appear asymptomatic, a situation that is more common in corn. Sometimes perennial ryegrass leaf blades of affected plants will have normal color, but plant height and sward growth may still be reduced. While some perennial ryegrass cultivars may exhibit decreased leaf production, others may have a marked increase in foliage. Depending on the cultivar and pattern of seasonal productivity, BYDV can change the proportion of perennial ryegrass vegetative tillers to fertile tillers.

Root development of perennial ryegrass was reduced by BYDV in UK studies, even in cultivars with increased shoot growth (Catherall and Parry, 1987). Stand loss was observed for the second-year



Cynthia Ocamb, © Oregon State University

Figure 30.—Barley yellow dwarf symptoms on perennial ryegrass: yellowish to purplish leaf tips.

seed crop of non-treated perennial ryegrass plots in OSU Extension aphid control trials located on commercial grass seed farms. This stand loss could be a consequence of reduced root development.

Usually a peak aphid population develops in spring and fall unless weather conditions are adverse. Aphid vectors that transmit BYDV and are commonly found in the Willamette Valley include the bird cherry-oat aphid (*Rhopalosiphum padi*), rose-grass aphid (*Metopolophium dirhodum*), corn leaf aphid (*Rhopalosiphum maidis*), and English grain aphid (*Sitobion avenae*).

Virus strains transmitted primarily by *Rhopalosiphum padi* are now called *Cereal yellow dwarf virus* (CYDV)-RPV, while those transmitted by *Sitobion avenae* are called BYDV-MAV. Virus strains transmitted by both aphid species are called BYDV-PAV. *Metopolophium dirhodum* is reported to transmit BYDV-PAV strains and possibly CYDV-RPV, while *Rhopalosiphum maidis* is reported to transmit BYDV-MAV and an additional strain, BYDV-RMV.

Testing for these viruses by serological methods requires use of antisera for each strain, and plant clinics can routinely test plant samples for BYDV-MAV and PAV as well as CYDV-RPV. Strains of BYDV (SGV and RMV) are thought to be present in some perennial ryegrass seed fields, but no commercially produced antisera are currently available for use in serological testing for these two strains.

Appendix J—continued. Barley Yellow Dwarf Virus and Perennial Ryegrass Nitrogen Rate

In the spring of 2008, perennial ryegrass plants were collected from western Oregon seed production fields and serologically tested for the MAV, PAV, and RPV strains. One or more strains of yellow dwarf virus was detected in 37 of 44 fields examined, indicating that the disease is common in western Oregon (Figure 31). All three strains were commonly detected in the same field. The relatively few fields that tested negative for all three yellow dwarf virus strains contained plant samples with leaf tip discoloration. SGV and RMV strains may have been present, or the plants may have been exhibiting symptoms of another condition.

Since BYDV and known aphid vectors are common in western Oregon, perennial ryegrass seed growers need to understand the management actions that are known to increase or decrease potential infection and yield loss. At OSU's Hyslop Field Research Laboratory, a perennial ryegrass N rate experiment seemed to be infected with BYDV during 2008. To take advantage of the situation, all plots in two second-year stands were visually evaluated during the spring of 2008 and 2010. The objective was to determine the percentage of perennial ryegrass plants with yellowish to purplish leaf tips or stunting, characteristic symptoms of BYDV. Visual ratings were made with no prior knowledge of plot treatments. During 2008, a small number of plants was collected from the plots and serologically tested for strains PAV and RPV.

Results were analyzed for the relationship between N rate and severity of virus symptoms

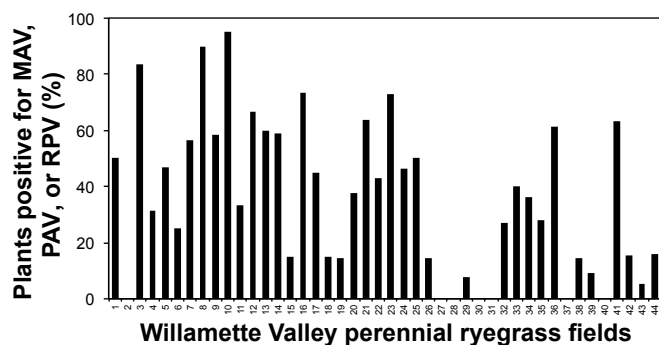


Figure 31.—Perennial ryegrass plants positive for MAV, PAV, or RPV from 44 seed fields in western Oregon during 2008. Between 30 and 60 plants from each field were serologically tested using DAS-ELISA. Figure by C. Ocamb.

in each plot. Perennial ryegrass plants that were positive for RPV included plants from high N rate treatments (80 lb N/a in the fall + 200 lb N/a in the spring). Thus, the stunting seen in these treatments during 2008 was probably due to effects of BYDV.

The following statements can be made based on the data collected (see Figure 32, page 42).

- During the 2 years that visual evaluation was performed, stunting was more pronounced for treatments receiving 80 lb N/a or less in the spring; the rate of fall-applied N had only a slight effect on stunting and generally only when less than 80 lb/a of spring N was applied.
- Stunting differed by year. Stunting was obvious under all spring N rates during 2008, while almost no stunting was noted during 2010 in plots receiving more than 80 to 120 lb N/a in the spring. This observation can be explained by widespread BYDV in the 2008 plots, whereas little virus was encountered in the 2010 plots.
- Leaf tip discoloration (yellowish to purplish) was less frequent than plant stunting. The percentage of plants with yellowish to purplish leaf tips more closely paralleled the incidence of plant stunting during 2008; in 2010 leaf tip discoloration decreased quickly at or above 80 lb N/a of spring N.
- Stunting decreased when spring N was applied at a rate required for maximum seed yield, 80 to 120 lb N/a. Little stunting was noted for treatments receiving more than 120 lb N/a during 2010, suggesting that the stunting noted in the treatments receiving 160 lb N/a or greater during 2008 was not due to N limitations but rather to the effects of BYDV infections in the plants.
- In 2008, maximum seed yields were obtained when spring N rates were 80 lb/a or greater, even though a considerable percentage of plants were still symptomatic. Increasing rates above 80 lb N/a reduced leaf discoloration and plant stunting but did not result in seed yield increase. Application of 80 to 120 lb N/a in spring was associated with peak yield under the BYDV pressure of 2008, regardless of the level of N applied the previous fall.

Appendix J—continued. Barley Yellow Dwarf Virus and Perennial Ryegrass Nitrogen Rate

Conclusions

Fall N or additional spring N is not needed to combat BYDV. If BYDV virus is widespread in a perennial ryegrass seed field, and stunting is obvious, increasing the spring N rate above 120 to 160 lb/a will not likely assist in increasing seed

yields, although the stand may look healthier. Nitrogen rates that create a lush plant canopy may indirectly promote BYDV spread within affected fields, especially when weather conditions are favorable for the aphid vectors.

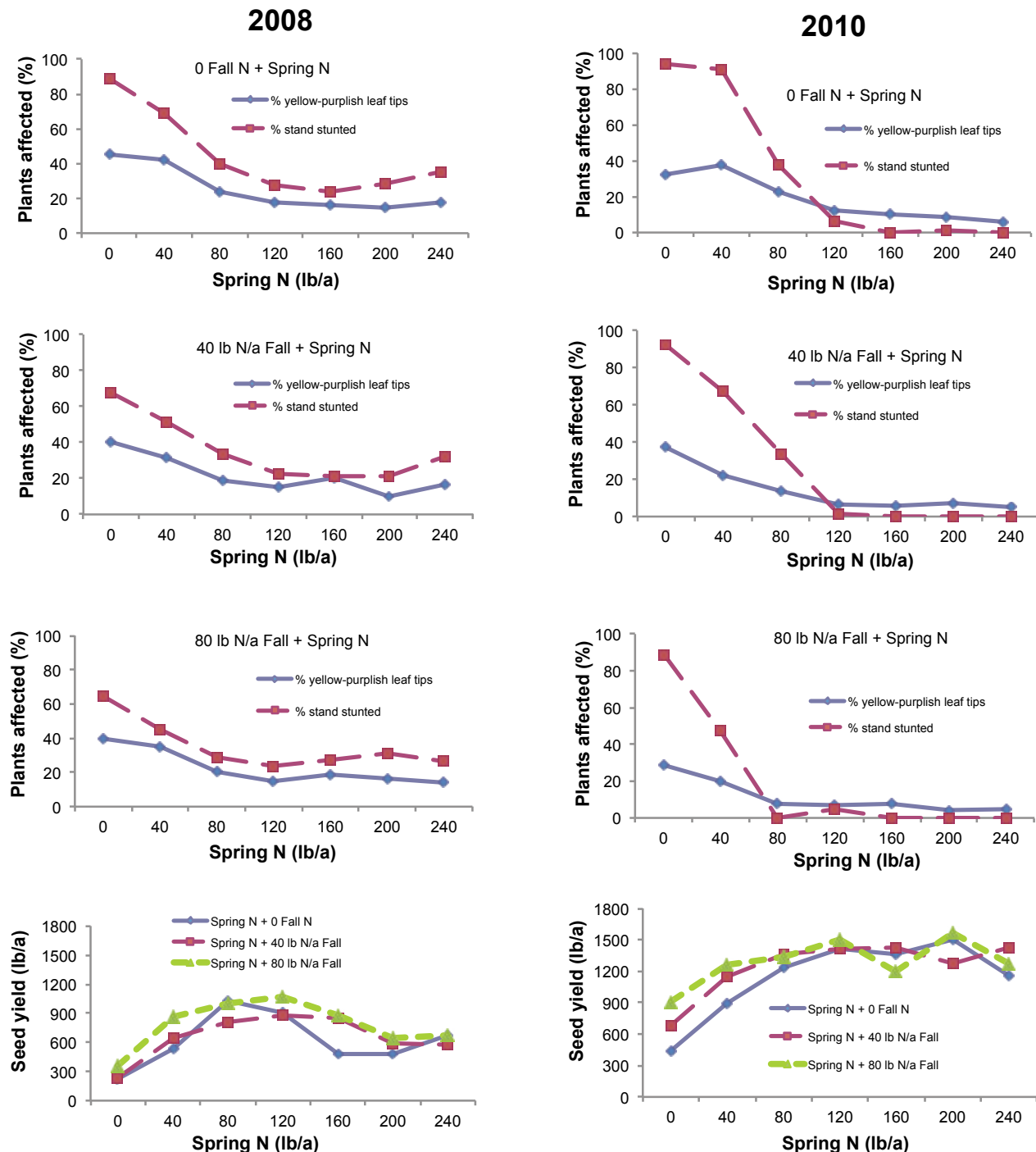


Figure 32.—Average percentage of plants from visual rating with yellow to purplish leaf tips and stunting, and perennial ryegrass seed yield from N rate experiment, Hyslop Field Research Laboratory, 2008 and 2010. Figure by C. Ocamb.

Appendix K. Western Oregon Research on which this Publication is Based

1981–1982: The influence of nitrogen (N) rate and timing on ‘Linn’ and ‘Pennfine’ perennial ryegrass yield components and yield was measured at OSU’s Hyslop Field Research Laboratory. Nitrogen application rates varied from 0 to 240 lb/a, and N was applied in combinations before spikelet initiation (vegetative stage) and at spikelet initiation.

Nitrogen application increased the seed yield potential by increasing the number of fertile tillers and the number of florets per spikelet. Nitrogen applied during the vegetative stage produced the highest number of fertile tillers at peak anthesis, while N applied at spikelet initiation produced the greatest number of florets per spikelet. Splitting N application equally between the vegetative stage and spikelet initiation can increase fertile tiller number at peak anthesis and ensure adequate N supply for seed set and development.

1982–1983: Effects of 16 combinations of 4 N rates (0, 54, 81, and 108 lb N/a) applied at the double-ridge (DR) stage of development, and the same 4 rates applied at the spikelet initiation (SI) stage, were measured on seed production of two older cultivars, ‘Linn’ (forage type) and ‘Pennfine’ (turf-type). In a second experiment (1989–1991), effects of 60, 100, and 140 lb N/a applied at the DR stage were also measured on two more recently developed turf-type cultivars, ‘Regal’ and ‘Pleasure’. In both experiments, between 25 and 42 lb N/a was applied in the fall. Research was performed at OSU’s Hyslop Field Research Laboratory.

Seed yield of the cultivar ‘Linn’ was near maximum at 54 to 81 lb N/a, but ‘Pennfine’ seed yield was the highest at 108 lb N/a. Growth stage when N was applied did not affect seed yield of either cultivar. Also, splitting the N application was not superior to applying all of the N at one time. Responses of ‘Regal’ and ‘Pleasure’ seed yield to N rates varied among years. In years without severe lodging, seed yields of ‘Regal’ and ‘Pleasure’ were the highest at 140 lb N/a.

1982–1986: Restrictions on the use of open field burning as postharvest residue management for cool-season grass seed production began to be implemented. Growers were searching for alternative residue management options. Following experiences

with wheat straw and N immobilization, on-farm research examined the use of fall and spring N treatments in conjunction with urea-sulfuric acid in an attempt to decompose straw after chopping or residue after baling. None of the chemical treatments produced the same yield as did open field burning. Fall N increased seed yield when spring N rates were limiting.

1984–1986: Application of KCl, K_2SO_4 , and $CaCl_2$ were examined in combination with paclobutrazol in first- and second-year perennial ryegrass seed production stands at OSU’s Hyslop Field Research Laboratory. In 1984, compared to treatments receiving no chloride (Cl), 75 lb Cl/a (165 lb KCl/a) provided an increase in thousand seed weight and a trend of increased seed yield. However, the 225 lb Cl/a rate did not further increase thousand seed weight or seed yield. The increase in seed yield was small, slightly more than 6 percent.

The 1985 and 1986 data showed the seed weight increase was due to Cl, and the presence or absence of potassium (K) had no effect. In 1985, the increase in seed weight also created an increase in yield. 1986 was a very dry year. The K and Cl treatments did not increase yield.

1985–1986: Climatic and soil conditions in western Oregon should be conducive to denitrification, yet N fertilizer balances show little unaccounted-for N. This study directly measured denitrification in a perennial ryegrass cropping system. Microbial activity was greatest in the late spring and often showed a secondary peak in late fall. Denitrification rates were most highly correlated with soil water content and soil respiration rate. Losses of N through denitrification were small, less than 1 lb N/a annually.

1987: A residue management shift from open field burning to removal of straw after baling was recognized as an interruption of nutrient cycling on which nutrient management recommendations were made. As an initial measure of changes created by differing straw management practices, a survey of more than 70 western Oregon grass seed fields was performed. Measurement of biomass nutrient content and soil test values from depths of 0 to 1, 1 to 3, and 3 to 6 inches documented nutrient removal with

baling and soil test stratification (especially soil pH) with stand age and straw management.

1988–1990: Before applying nutrients as fertilizer, growers must choose an application rate and time to apply the material. Choice for application time should include consideration of plant assimilation and nutrient mobility. To determine above-ground nutrient assimilation, above-ground biomass samples of 'Linn' and 'Pennfine' perennial ryegrasses were collected on six dates from initiation of spring growth to physiological maturity. Seasonal and daily nutrient assimilation and growth were determined.

Grass growth followed a sigmoidal pattern when plotted for time or days and a linear pattern when measured for heat units. Nutrient accumulation preceded dry matter production or growth for perennial ryegrass. For example, by the latter part of April, 'Linn' perennial ryegrass had accumulated about 40 percent of its dry matter, compared to 50 percent of its sulfur (S), 73 percent of its potassium (K), 95 percent of its N, and essentially the season total for phosphorus (P).

As postharvest residue management changed from open field burning to straw removal after baling, the effects of postharvest residue management and K fertilizer application were investigated in two commercial perennial ryegrass seed fields for 3 years. Removing straw decreased soil test K concentration in the surface 6 inches of soil. Even when soil test K was initially low, below 75 ppm, yield increases from K fertilizer application varied yearly.

The decline in soil pH in the surface 3 inches of perennial grass seed fields as a stand ages was documented in a 1987 survey. Phosphorus is routinely top-dressed to this acidic environment. Phosphorus supply to a turf-type perennial ryegrass, 'SR 4000', was evaluated in a commercial field with an initial pH of 5.2 and soil test P of 12 ppm. Different rates (0 to 200 lb P₂O₅/a) and methods of P application (surface band or broadcast) were investigated on limed and unlimed areas. No interaction between lime application and P application rate or method had a measurable effect on seed yield, nor did seed yield increase following lime or P application.

1989–1991: A long-term investigation to consider the interaction between postharvest residue management and soil N and K was established. Research was conducted on two perennial ryegrass and two

tall fescue fields. Removal of straw following seed harvest removes significantly more K than that "lost" in the seed crop alone. As a result, soil test K is lower when crop residues are removed. On the other hand, changing to a nonthermal cropping system did not result in a significant loss of N, as grass straw contains only about 1 percent N.

1990–1991: In southern Oregon, the high value of sod-quality seed led some growers to supplement soil-applied fertilizers with foliar fertilizers in an attempt to increase seed yield. To evaluate this practice, a variety of foliar products and N rates were evaluated on private growers' fields as well as at the Southern Oregon Research and Extension Center (SOREC).

Kentucky bluegrass, perennial ryegrass, and bentgrass seed yield, test weight, and clean-out were not consistently or significantly improved by foliar fertilizer application during boot and/or 3 weeks later. This was true regardless of the amount of soil fertilizer applied before the growing season. While yield was improved in certain instances, change in net return due to foliar fertilization was unpredictable, with both large gains and losses present.

1995–1996: Much of the land in western Oregon used for cool-season grass seed production is marginally productive for many other crops due to limited soil drainage. The role of riparian areas bordering grass seed fields for water quality maintenance was measured by monitoring groundwater quality every 2 weeks from November 1995 through June 1996 in a perennial ryegrass seed field and bordering riparian areas.

Nitrate in shallow wells (A and C horizons) was mostly undetectable and less than 3.8 mg/L in the field and lower in the riparian zone. Both crop and riparian area processes reduced shallow groundwater nitrate to low levels

1996: First-year seed yield was increased by N rate but not by timing when 40 lb N/a was applied in early March and 120 lb N/a was applied between early March and mid-April. During the same time, perennial ryegrass tissue N concentration was correlated to seed yield, supporting the idea that tissue concentration can be used to predict N sufficiency. When perennial ryegrass N concentration is insufficient, spring N can be supplemented with a mid-April application and seed yield maintained.

1995–1998: Growers desire a method to predict spring N rate for perennial ryegrass seed production. Plant tissue testing to determine the in-season plant N status provided promise in a single New Zealand trial. To evaluate the use of tissue N concentration sufficiency for perennial ryegrass seed production, ‘Linn’ and ‘Buccaneer’ were planted at the OSU Hyslop Field Research Laboratory, with combinations of N ranging from 0 to 200 lb/a applied in fall, late winter, and early spring. This research concluded that N concentration in above-ground biomass 2 weeks after N application at spikelet initiation is a useful predictor of likely relative yield where N is the only limiting factor.

1998–2002: Large-scale on-farm trials were conducted in perennial ryegrass, tall fescue, fine fescue, and annual ryegrass over several seasons to evaluate optimal spring N rate (Figure 33). Experimental plots in a Benton County commercial perennial ryegrass seed field and one in Marion County received the same treatments for 3 years. An additional site in Marion County was added for 2 years.

Spring N rate of 120 to 160 lb/a was adequate for 2,000 lb/a seed yield or more. Increasing N rate above this range did not increase seed yield. Soil test results at optimal use rates showed little potential for leaching losses, as applied N was efficiently used by the crop.

1998–2008: Ensuring that N availability is synchronized with crop demand is a long-standing and universal goal of growers. In an effort to meet their goals, growers experimented with a controlled-release fertilizer, polymer-coated urea. By matching release rate with crop demand, controlled-release N is an alternative to synchronizing N application to meet N demand and/or using split spring N application, common practices of most grass seed growers.

Between 40 and 120 lb N/a was supplied by polymer-coated urea in 10 experiments during a 10-year period. The seed yield increase from polymer-coated urea application was not consistent or significantly different from urea application, and no relationship existed between polymer-coated N supply and seed yield increase. For these reasons, use of polymer-coated urea is not recommended for perennial ryegrass seed production in western Oregon.

2000: Boron (B) is the most widespread micronutrient deficiency in western Oregon. However, crops



© Oregon State University

Figure 33.—During 1998 to 2002, large-scale on-farm trials were conducted in perennial ryegrass to evaluate optimal spring N rate. This aerial view clearly shows N rate differences; plots receiving no spring N were quite yellow.

vary widely in B need, with dicotyledonous plants having a higher requirement than monocotyledonous plants such as grasses. Most grass seed fields in western Oregon have very low B soil test values, which raised questions about B need.

To test the need for B in perennial ryegrass seed production, 0 and 1.25 lb B/a were soil- and foliar-applied with spring N at two on-farm sites. Perennial ryegrass seed yield did not increase with B application.

Late-season (May) foliar fertilizer application is promoted as necessary to hold or increase seed yield. A field-scale replicated comparison of a foliar fertilizer application containing N, P, K, B, copper (Cu), iron (Fe), manganese (Mn), molybdenum (Mo), and zinc (Zn) with no foliar fertilizer application in a Marion County ‘Palmer III’ commercial perennial ryegrass seed field showed no yield increase from the foliar fertilizer treatment. Average seed yield was 2,679 lb/a from the untreated plots and 2,675 lb/a with the application of the foliar material. The results and conclusion are the same as for work performed in 1990 and 1991 at the Southern Oregon Research and Extension Center (SOREC).

2003–2004: Field representatives for agricultural chemical suppliers and some agricultural testing laboratories began recommending spring K application based on reported perennial grass seed yield increase from application of spring-applied K. To determine whether spring K application increased perennial grass seed yield and whether the yield increase was from application of K or Cl, two replicated large-scale plots were established in Linn and Marion county commercial perennial ryegrass seed fields. No seed yield and seed weight increase from either Cl or K application was measured, even though Cl application routinely increased tissue Cl concentration.

2004–2006: The N mineralization (N_{min}) soil test has the ability to accurately predict N fertilizer needs in spring for winter wheat grown in western Oregon. Growers desire a similar spring N rate prediction tool for production of cool-season grasses.

Results in 2006, on six western Oregon on-farm sites seeded to perennial ryegrass, were similar to those measured the previous 2 years. The N_{min} test correctly predicted spring N rate in four of the six fields. The test does not predict spring N rate for cool-season grass as well as it does for wheat.

2007–2012: Growers desire a method to predict spring N rate for perennial ryegrass seed production. Plant tissue testing to determine the in-season plant N status is one measurement providing promise for N management refinement. However, tissue testing can be costly, time consuming, and difficult for growers to adopt.

A possible solution to these problems is remote sensing. Research was conducted at four sites in 2007, 2008, and 2009 (both on-farm and at OSU's Hyslop Field Research Laboratory). Critical whole-plant N concentration values were 2.2 percent at an early sampling and 2.8 percent at a midseason sampling. A critical N uptake value of approximately 160 lb N/a was found at midseason. Significant

relationships were found between spectral measurements and both whole-plant N concentration and N uptake across site-years at midseason. Additionally, critical values obtained from these relationships were similar to those found through tissue testing, indicating that spectral measurements may be used to replace tissue testing at midseason in perennial ryegrass.

2008–2012: Fall N is recommended for tall fescue seed production, as it substantially increases seed yield by promoting fertile tiller development and to a lesser degree spikelet number. Recommendations for fall N application to perennial ryegrass were based on the tall fescue data and observations from other research. To substantiate fall-applied N requirement for perennial ryegrass seed production, a fall (0, 40, and 80 lb N/a) by spring (0 to 240 lb N/a in 40 lb/a increments) factorial experiment was conducted at Hyslop Field Research Laboratory (Figure 34). A first planting was made in 2007 through 2008, with a second planting in 2009 and 2010. Seed yield increased with spring N rate, but did not change with fall N application.



Figure 34.—Combinations of fall and spring N were evaluated in perennial ryegrass at Hyslop Field Research Laboratory. The light green color in the foreground is a low spring N rate.

Carol Garbick, © Oregon State University