Wheat Management Systems in the Pacific Northwest

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Wheat-growing environments in the Pacific Northwest include: humid in western Washington and the Willamette Valley of Oregon; humid/subhumid in far eastern Washington, northeastern Oregon, and adjacent northern Idaho; semiarid in east central Washington, north central Oregon, and southern Idaho; and arid (irrigated) in the Columbia Basin of Washington and Oregon and the Snake River plains of southern Idaho. In Washington State, the full range of growing conditions occurs across a distance of less than 640 km (400 miles). Much of the precipitation in northeastern Washington is as snow, and winter wheat may be covered by snow for up to 5 months. In contrast, winter wheat is rarely under snow continuously for more than 1–2 weeks in south central Washington. Conditions for many wheat diseases—flag smut, dwarf bunt, common bunt, snow mold, take-all, Fusarium foot rot, Fusarium scab, Cephalosporium stripe, Pseudocercosporella foot rot, Pythium root rot, Rhizoctonia root rot, Septoria leaf blotch, stripe rust, leaf rust, stem rust, powdery mildew, wheat streak mosaic, and barley yellow dwarf—occur somewhere in the region. Diseases or pathogens present in the region but not of sufficient importance to justify control at this time are Rhizoctonia sharp eyespot, cereal cyst nematode, and Helminthosporium (common) root rot. About the only major wheat diseases not present or confirmed to occur in the three northwestern states are soilborne wheat mosaic, wheat spindle streak mosaic, and tan spot.

The goal when growing wheat should be to achieve the yield potential determined by the total supply of available water, i.e., the water available in the rooting zone at the time of planting plus water captured as precipitation and/or irrigation between planting and crop maturity. If available water is sufficient for a yield of 4.0 t/ha (60 bu/A), then the yield should be near or at 4.0 t/ha. If the available water is sufficient for 6.7 t/ha (100 bu/A), the yield should be near or at 6.7 t/ha. If the water stored and captured as natural precipitation alone or supplemented with irrigation is sufficient for 13.4 t/ha (200 bu/A), the yield should be 13.4 t/ha. It makes no sense and is inconsistent with the need to conserve resources to have or apply enough water for 13.4 t/ha but harvest only 6.7 t/ha. Regardless of the environment, the strategy in growing wheat should be to make water the yield-limiting factor. Most of the wheat in eastern Washington, northeastern Oregon, and northern Idaho (the Inland Northwest) is grown on rolling hills of wind-deposited silt loams (loess). These soils are highly erodable. Thus, the overall goal in producing wheat on these soils is to *achieve the yield potential as set by available water while also controlling soil erosion.*

Four wheat management systems have evolved in the Pacific Northwest according to available water: irrigated, where annual precipitation is less than 25–30 cm (10–12 in.); rainfed wheat-fallow rotation, where annual precipitation is 25–45 cm (10–18 in.); rainfed annual-cropped in the Inland Northwest, where annual precipitation is 45–50 cm (18–20 in.) and above; and rainfed annual-cropped west of the Cascade Mountains, where annual precipitation ranges between 50 and 100 cm (20–40 in.) or more. Irrigation is sometimes used when annual precipitation is greater than 25–30 cm for stand establishment or as a supplement for greater yield. In the irrigated and rainfed annual-cropped areas, wheat may be grown every year or as a component of a 2-, 3-, or 4-year rotation.

Attainable vs. actual yields at some Washington locations

It has been estimated that every centimeter of available water beyond the first 10 should result in 185–190 kg of wheat per hectare (7 bu/A per inch of water). The first 10 cm supports the development of wheat plants, but not grain yield. As examples, attainable yields are 3.3–3.7 t/ha (50–55 bu/A) at Lind for wheat after fallow, 7.4–8.1 t/ha (110–120 bu/A) at Pullman for wheat after peas, and 12.1–13.4 t/ha (180–200 bu/A) at Quincy for irrigated wheat (Fig. 1A). The yield at Lind is based on 25 cm of annual precipitation with 30% efficiency (i.e., only 7.5 cm of the 25 cm is actually stored during the fallow year) and 90% efficiency during the crop year. The yield at Pullman for wheat after peas is based on 50 cm of annual precipitation, with about a 5-cm carryover following peas and 90% efficiency during the crop year. The yield at Quincy is based on 90% availability of the 20 cm received as precipitation each year and 70 cm supplied as irrigation.

At Lind, yields are commonly 3.3–3.7 t/ha (50–55 bu/A) and sometimes 4.0–4.7 t/ha (60–70 bu/A), and water is almost always the yield-limiting factor (Fig. 1B). At Pullman, a yield of 8.7 t/ha (130 bu/A) was achieved in experimental plots as early as 1954, and yields in this range are obtained routinely in test plots, provided the soil is fumigated and the foliage is protected all season against rusts and aphids (13). In most fields within this rainfall area, however, actual yields average 60–75% of the attainable, as set by the available water (Fig. 1C). Best yields in most years near Quincy are 10–12 t/ha (150–180 bu/A) under irrigation; a record wheat yield of more than 14 t/ha (209 bu/A) was harvested in 1961, with the cultivar Gaines grown under irrigation in central Washington. Normally, however, yields are only 6.7–8.7 t/ha (100–130 bu/A) (Fig. 1D). Yields of irrigated wheat are commonly greater by 25–50% if the soil is fumigated. In western Washington, rainfed wheat grown no more frequently than once every 3 years in the same field yields 8.7–10.0 t/ha (130–150 bu/A), which is very near the potential in the area; more commonly, the yields are 60–75% of the potential. Any crop that yields less than its potential is either seeded too late or affected by some biotic or abiotic constraint other than shortage of water.

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Decisions necessary to achieve yield potential of wheat

Achieving the yield potential of wheat depends on a succession of decisions that determine the extent to which diseases and pests will limit the yield and also whether the crop has the growth potential to take full advantage of the available water. Growers in the irrigated and the two annual-cropped areas (Inland Northwest and west of the Cascades) must decide first whether to grow wheat every year or every second, third, or fourth year in the same field. Their next decision is method of tillage: no-tillage (direct drilling), minimum or stubble-mulch tillage, or conventional tillage with use of a moldboard plow. These two decisions are not easily changed; several years may be required to convert an entire farming operation from a 2-year to a 3-year rotation or to continuous wheat, and a grower who sells his moldboard plows and buys chisel plows or direct-drill equipment cannot switch back to conventional farming without another major investment. Having decided on a rotation and method of tillage, however, the grower then makes a series of more

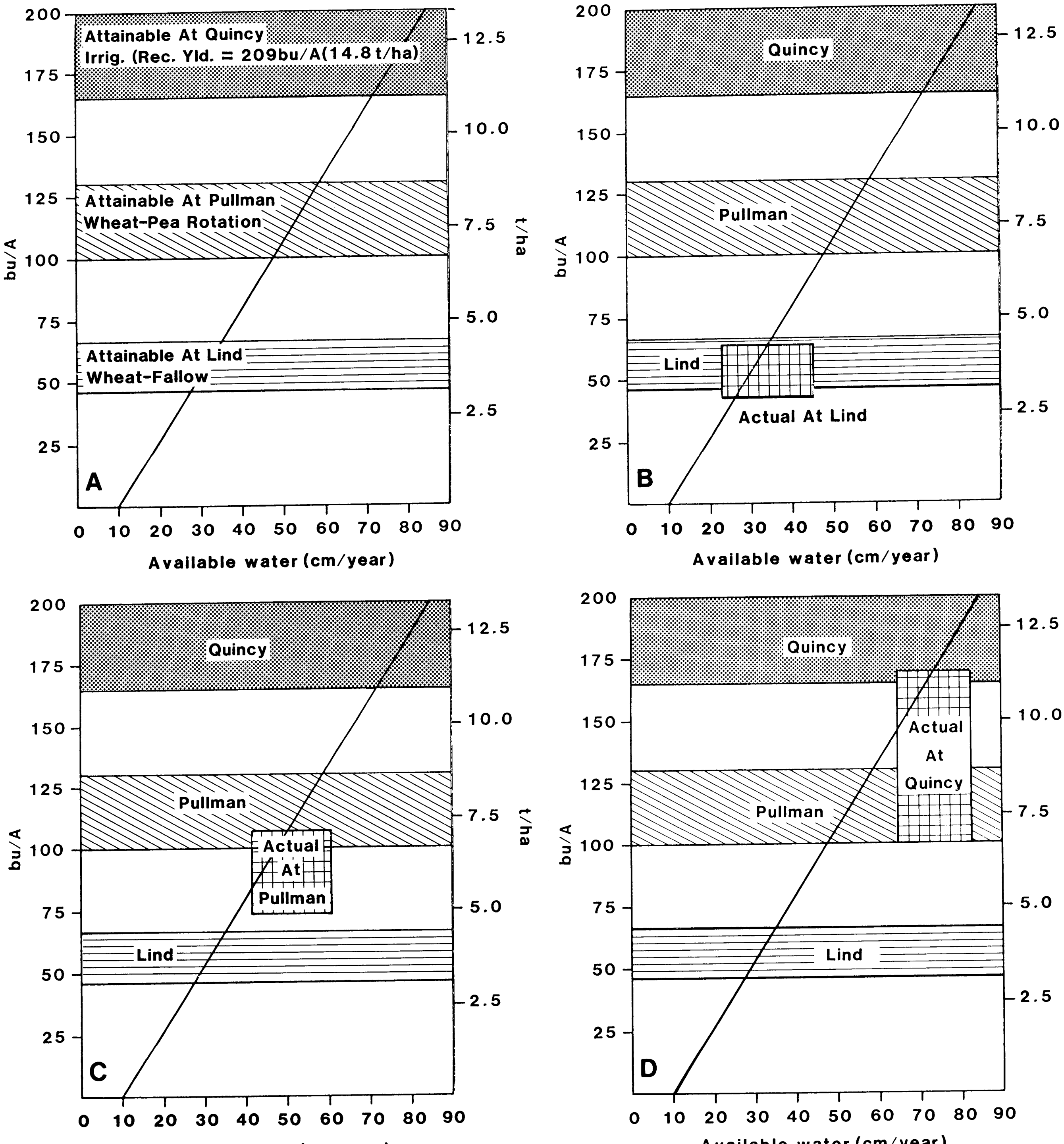

Fig. 1. Relationship between available water and wheat yields in Washington State. **(A)** The horizontal bars indicate the range of attainable yields and available water at Lind for wheat after fallow, Pullman for wheat after peas, and Quincy for irrigated wheat. The relationship is based on 500 kg/ha per 2.5 cm of available water (7 bu/A per inch of available water) beyond the first 10 cm (4 in.) and has been verified repeatedly by best yields for the respective areas. **(B)** Actual (box) compared with attainable (horizontal bar) yield at Lind for wheat after fallow. **(C)** Actual (box) compared with attainable (horizontal bar) yield at Pullman for wheat after peas. **(D)** Actual (box) compared with attainable (horizontal bar) yield at Quincy for irrigated wheat.

flexible decisions, such as the rate and method of fertilization and herbicide treatment, the choice of cultivar, the kind of seed treatment, and whether to use an in-furrow soil treatment at the time of planting. A major decision made every year is the time of sowing. Delayed seeding is one method of avoiding several important wheat diseases, but a late-sown crop is also less likely to take full advantage of the available water. It makes little difference if the crop yields 75% of the potential because of disease or because it was sown too late to take full advantage of the available water.

The final succession of decisions is made after the crop has emerged. The grower must decide whether to apply a foliar fungicide or, if the crop is irrigated, whether to apply the water in many small amounts or in a few large amounts during the growing season. The timing of harvest must be such that the grain is sufficiently dry to store well. During harvest, the grower must decide how to spread the residue or whether to remove or burn the residue.

Rainfed wheat-fallow rotation

Neither rotation nor method of tillage is an option in the low to intermediate (semiarid) dryland wheat-fallow area of the Pacific Northwest. A few growers have attempted to grow consecutive crops of spring wheat (with no interim fallow), but the most productive and popular cropping system uses one crop of winter wheat every 2 years, with fallow to store water in the alternate years. The best—and most common—method of tillage is a stubble-mulch (dust-mulch) system, whereby the crop residue is partially mixed with the top 5–10 cm of soil and partially exposed on the soil surface. Residue managed in this way helps prevent soil erosion. In addition, since most precipitation occurs between October and May, the top 5–10 cm (2–4 in.) of soil maintained as a dust mulch during the summer serves as a barrier to loss of water stored in the profile. Special deep-furrow drills have been designed to place seed into moist soil beneath the dust mulch while simultaneously moving a portion of the mulch and crop residue into ridges between the wheat rows. This ridge-furrow configuration helps trap snow, which concentrates a supply of moisture near the young plants and also provides insulation against winter injury (22).

Achieving the yield potential of wheat in this management system requires that the crop be seeded in autumn (i.e., late August to early September), before seed-zone moisture is lost. The dust-mulch delays but does not prevent moisture loss from the soil, and eventually the drying front extends below the depth accessible to the deep-furrow drill. The earlier the date of seeding, the better and more vigorous the stand entering the winter and the more likely the crop to achieve the yield potential set by available water. Unfortunately, early-seeded wheat on fallow is also most vulnerable to Pseudocercosporella foot rot (7), dryland foot rot (*Fusarium culmorum* and *F. graminearum*) (11), barley yellow dwarf (1), wheat streak mosaic (5), stripe rust, and flag smut.

Wheat streak mosaic is a problem mainly of wheat seeded in late July to early August (5). There is no agronomic advantage to seeding wheat this early, and therefore seeding in late August or early September provides a practical control for this disease. Damage from snow molds, caused mainly by *Typhula* spp. but also by *F. nivale* and occasionally *Sclerotinia borealis*, is managed in northeastern Washington by seeding a tolerant cultivar (e.g., Sprague) in late August (3,9). Dryland foot rot is a problem of wheat sown as late as mid-September but can be controlled by using less nitrogen fertilizer (12). This disease is most severe in wheat managed for yield greater than is possible with available water. Plants in a field having water for 4.0 t/ha (60 bu/A) but fertilized for 5.4–6.0 t/ha (80–90 bu/A) become water stressed sometime during or after heading and consequently become very susceptible to Fusarium foot rot. Applying no more nitrogen than needed to reach the yield potential as set by available water is the best control for this disease. Stripe rust can be managed with resistant cultivars; the most stable control has been with cultivars having a nonspecific (horizontal) resistance to all races of the fungus. Typical of experience elsewhere, each new cultivar with race-specific (vertical) resistance has favored the evolution of a new race of the stripe rust pathogen. Triadimefon (Bayleton) is labeled for use against stripe rust on Pacific Northwest wheat and is used as a backup to specific host resistance and to a limited extent to complement the nonspecific resistance (20). Flag smut is now rarely seen because of more resistant cultivars and the widespread use of carboxin (Vitavax) as a seed treatment (19). Pseudocercosporella foot rot is also no longer a major problem because most growers with early-sown wheat apply a benzimidazole-type fungicide (benomyl [Benlate PNW, a special formulation for the Pacific Northwest], thiabendazole [Mertect 340F], thiophanate-methyl [Topsin-M]) to the foliage in early spring (3,4,6,8).

Barley yellow dwarf is the only wheat disease that cannot be controlled with present technology in the low to intermediate rainfall area for wheat on fallow. In both southern Idaho and eastern Washington, the wheat-fallow areas border on irrigated areas where corn is becoming a major crop. Corn is a symptomless reservoir of barley yellow dwarf virus (BYDV) and also serves as a host for aphid vectors of BYDV (1). As corn matures, viruliferous winged aphids are carried with the prevailing winds to nearby early-sown fields of winter wheat on fallow. Insecticides applied in the seed furrow at planting help deter secondary spread of the virus but give only partial and sometimes no actual control of the disease. The only control is to seed in mid- to late October, which growers have adopted because even the relatively low yield potential of a late-sown crop is greater than the yield of wheat severely damaged by BYD.

Rainfed annual-cropped in the Inland Northwest

Areas in the Inland Northwest receiving 45–50 cm or more of precipitation each year can be cropped annually. Fallow is sometimes used in the rotation to control weeds or to comply with some government acreage reduction program but offers no advantage in water supply in years of normal precipitation. The three basic options for crop rotation are: 1) winter wheat every third year after two spring crops (e.g., peas, lentils, spring barley, or spring wheat), 2) winter wheat every other year after one spring crop, and 3) winter wheat every year. The three basic options for tillage are: 1) conventional (moldboard plow followed by one or more secondary operations to prepare a seedbed), 2) chisel plow (followed by secondary tillage operations to prepare a seedbed), and 3) no-tillage (direct drilling with no seedbed preparation). The most challenging and risky (disease and pests) management system in this region is continuous direct-drilled wheat. Direct drilling conserves soil and energy and the potential yield is higher owing to the greater amount of water conserved, but actual yields are typically lower with no-tillage than with minimum or conventional tillage because of greater damage from take-all (21), Pythium root rot (17), Cephalosporium stripe, and Rhizoctonia root rot (25) and because of competition from weeds.

The major diseases in the rainfed annual-cropped Inland Northwest include Cephalosporium stripe, Pseudocercosporella foot rot, leaf rust, and stripe rust for winter wheat seeded early after peas or lentils; Pythium root rot and leaf rust for late-seeded wheat (regardless of the rotation); and take-all if wheat (or barley) is grown without benefit of rotation or tillage (i.e., continuous, direct-drilled spring or winter wheat or barley). Cephalosporium stripe can be controlled with most 3-year rotations (2), stripe rust with use of resistant cultivars and Bayleton to complement the high-temperature resistance of wheats to stripe rust, leaf rust with use of Bayleton, and Pseudocercosporella foot rot with use of benzimidazole fungicides. Stem rust can be a problem of late-seeded and latematuring winter wheat and some spring wheat cultivars and may be controlled with Bayleton if warranted. Pythium root rot is possibly the most important disease of late-sown wheat in the Inland Northwest, especially in fields managed with reduced tillage. Yields are commonly limited to only 60–75% of potential because of this disease (13,16). It can be partially managed by use of metalaxyl (Apron) as a seed treatment (18) but is best controlled by seeding early so that seedlings emerge in warm, well-drained soils. Leaf rust and stem rust are also minimized as problems if the wheat is sown early. Cultivars with resistance to leaf rust are now becoming available. There is no advantage to burying crop residue by plowing for control of Pseudocercosporella foot rot; on the contrary, this disease may actually be more severe in fields managed with conventional tillage than in those managed with minimum tillage or no-tillage (17).

The best combination of practices to minimize the effects of all the important diseases of annual-cropped wheat in the Inland Northwest begins with a 3-year rotation of winter wheat/spring barley (or spring wheat)/spring peas (or lentils), and then back to winter wheat. Substitution of the second spring cereal for the peas or lentils will control Cephalosporium stripe but favors take-all, especially if reduced tillage is used and rainfall is above normal. The cultivars sown should have nonspecific resistance to stripe rust and the seed should be treated with a fungicide that controls common bunt. Winter wheat sown after peas or lentils should be planted as early as seed-zone moisture permits, to escape Pythium root rot and leaf rust. Finally, the lush wheat crop, typical of crops managed in this way, should be sprayed in the spring to control Pseudocercosporella foot rot.

Unfortunately, economic pressures force many farmers to grow wheat at least every other year. The price of land is determined by the most valuable crop that can be grown on it, which is winter wheat. In addition, acreage restrictions are based on the number of acres historically sown to wheat, and the grower who sows half his farm to wheat (2-year rotation) receives a greater "wheat allotment" than the grower who plants only one-third of his farm to wheat each year (3-year rotation). In addition, labor is distributed more evenly with the 2-year rotation, with half the farm being sown in the fall and half in the spring. The best 2-year rotation is winter wheat after peas (or lentils). As with the 3-year rotation, the cultivars should have nonspecific resistance to stripe rust, fields should be seeded early (September) to minimize the effects of Pythium root rot and leaf rust, and a benzimidazole-type fungicide should be applied in March or April to control Pseudocercosporella foot rot. The 2-year rotation, with peas or lentils grown in one of the years, controls take-all but not Cephalosporium stripe. Although no cultivar is resistant to Cephalosporium stripe, some are distinctly less susceptible than others and should be used in combination with the 2-year rotation. Significant control of Cephalosporium stripe can be achieved by not seeding until October, but as pointed out earlier, the disadvantage with this method is that wheat seeded late is more vulnerable to Pythium root rot and leaf rust and also is less likely to take full advantage of available water.

Continuous winter wheat is seeded (or emerges) late by necessity, since soil moisture is rarely adequate for stand establishment before mid-October. Wheat in this management system usually enters the winter in the two- to three-leaf stage rather than with the several tillers typical of wheat sown in September. Late-sown wheat is rarely affected by either Pseudocercosporella foot rot or stripe rust, and the control tactics available for these two diseases can therefore usually be omitted with continuous winter wheat. Cephalosporium stripe is also less important in late-sown wheat than in early-sown wheat but can still be important if minimum tillage or no-tillage is practiced. Take-all and Pythium root rot likewise are favored by reduced tillage. Thus, some form of tillage, preferably conventional, together with Apron seed treatment must be practiced for the present if the objective is to grow continuous winter wheat in areas of the Inland Northwest receiving 45–50 cm (18–20 in.) or more of precipitation annually.

Wheat under irrigation

Irrigation in the Pacific Northwest ranges from application of only 10–20 cm (4–8 in.) of supplemental water for wheat in the fallow area to total irrigation for maximum production in the Columbia Basin and Snake River Plains areas. Supplemental irrigation may be applied in either the fallow or the crop year as a means to boost the attainable yield while still using a wheat fallow rotation and stubble-mulch tillage. This practice can control Fusarium foot rot provided the rate of nitrogen is not applied for a yield greater than can be supported by the available water. Pseudocercosporella foot rot is usually the most common disease of wheat grown on fallow with supplemental irrigation and is controlled best with a benzimidazole-type fungicide applied in February or March.

The major diseases of wheat irrigated for maximum production are take-all if wheat is grown without rotation (14), leaf rust and stripe rust if irrigation is through overhead sprinklers (either solid set or pivot), and barley yellow dwarf if wheat is sown early. Pseudocercosporella foot rot and Fusarium scab (23) both occur occasionally under sprinkler irrigation; Fusarium scab can be minimized or eliminated by not growing wheat after corn.

The best management for irrigated wheat is to grow it in rotation with a row crop such as potatoes. Take-all is rarely if ever a problem in such a rotation, regardless of the tillage method. Alfalfa is also a good rotation crop unless allowed to become infested with grassy weeds that serve as a source of inoculum for the take-all fungus. Alfalfa stands used for seed are sometimes 8–10 years old before killed by herbicides and tillage; such stands are notoriously grass-infested, and take-all can sometimes be severe even in the first wheat crop sown into such a field. The seeding date must be delayed to control barley yellow dwarf, and the cultivars with greatest resistance to leaf rust should be used and sprayed with Bayleton if necessary.

Again, because of economic constraints, including the lack of alternative crops, growers commonly sow wheat into the same field two, three, or more years consecutively before switching to some other crop such as corn, potatoes, or alfalfa. Take-all becomes progressively more severe during consecutive crops of wheat but then declines as the soil becomes microbiologically suppressive to the disease (15). Actual yields may drop to 30–50% of attainable yields during the years of severe disease but, after take-all decline, may recover to 80 or even 90% of a crop free from the disease. To minimize the effect of take-all and accelerate or maximize the benefits of take-all decline, the grower must: 1) use considerable and frequent tillage between the harvest of one crop and the sowing of the next, 2) delay the seeding date relative to the best agronomic date to allow inoculum to disappear, 3) ensure adequate levels of phosphorus and trace nutrients, and 4) apply nitrogen as ammonium with nitrapyrin (N-Serve) or KCl to delay nitrification (24).

Rainfed annual-cropped west of the Cascades

This area probably has the highest yield potential of any nonirrigated wheat-producing area in the United States. The soils are mostly acidic and the climate is cool and moist, with mild, open winters. This climate is also highly favorable to several wheat diseases, mainly stripe rust and take-all (when the soils are limed) but also Septoria nodorum leaf blotch, barley yellow dwarf, leaf rust, and occasionally Fusarium scab (*F. nivale*). Curiously, Pseudocercosporella foot rot is sporadic, in spite of favorable conditions. G. W. Bruehl (*personal communication*) has suggested that conditions may be too favorable, with the result that the fungus depletes its food resources through prolific and continuous sporulation on the infested crop residue before the next wheat crop is sown in a typical 2-year rotation or possibly even in wheat monoculture.

As for wheat under irrigation, take-all is controlled best in western Oregon and Washington by virtually any 2- or 3-year rotation away from wheat, barley, or other susceptible member of the Gramineae. Some growers, however, plant continuous wheat and take advantage of take-all decline. Wheat monoculture is most successful if some form of tillage is used, if the ammoniacal form of nitrogen is applied as several applications with N-Serve or KCl to delay nitrification, if the soils are limed only sparingly if at all, and if seeding date is delayed (24). Some liming is necessary for best wheat growth, but excessive liming is highly favorable to take-all and delays the onset of take-all decline. Some growers successfully use a wheat-oat rotation for take-all control.

Stripe rust is managed best by use of cultivars with nonspecific resistance, but even on these, the disease can develop into epidemic proportions in years of favorable temperature and moisture (10). Because of its tolerance of wet soils, the rust-susceptible cultivar Yamhill is commonly grown in the Willamette Valley and sprayed with Bayleton. The proportion of fields treated with this fungicide is greater west of the Cascades than in any area of the Pacific Northwest east of the Cascades. Much of the area once planted to Yamhill, however, is now planted to the cultivar Stephens, which has nonspecific resistance to stripe rust. Septoria nodorum leaf blotch is mainly a problem in the Willamette Valley and is controlled with fungicides or a tolerant cultivar such as Hill 81.

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