Integrated Pest Management for Wheat: IPM in a Wide-Ranging System

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Concepts and practices of integrated pest management (IPM) and sustainable agriculture have been used in wheat management by farmers and plant pathologists for years, long before the terms were proposed. However, considerable progress has been made in IPM for wheat during the last 25 yr. The IPM in this discussion is based on the accumulated knowledge of classical epidemiology and pathogen biology and the application of that knowledge. The emphasis is on integrated control of the rusts in the Pacific Northwest (PNW), taking into consideration IPM for control of other pests (weeds, insects, and especially diseases) and environmental limitations on local crop management within the region. The system is currently used in the PNW. However, most of the principles and concepts also apply to wheat management elsewhere in North America and in other continents.

Effect of Environment on Wheat Management

Wheat is grown under a wide range of environmental conditions in North America (Fig. 1), and it is the environment within those wheat-growing regions that determines how the crop is managed, the types and market classes of wheat grown in each region, and the importance of diseases and pests and how they are controlled. Wheat classes are designed for certain end uses, such as breads, cakes and cookies, pasta, oriental noodles, and sponge cakes. Certain environments are more favorable for each of the classes and for growing winter or spring wheat. The major market classes of wheat in each region are soft red winter wheat in the southeast, soft white wheat in Michigan and New York, hard red winter wheat in the south central states, and hard red spring and durum wheat in the north central states, California, and Arizona (Fig. 1). However, all of the types and classes plus hard white spring and winter wheat have been grown in the PNW, and all but soft red winter wheat are currently grown in that region.

The reason for the diversity of types and classes of wheat is that the PNW has unique and variable environmental conditions. When compared with other regions of North America, the PNW is a region of low humidity and high light intensity, mild winters, cool springs and summers, and especially cool night temperatures in the summer. Most of the region has deep, fertile soils. When water is adequate, the growing conditions are nearly optimal for wheat production. Thus, management for high yields is possible. Consequently, the mean yield in the PNW is almost two times the mean yield for the United States, and the maximum yield in the PNW can be four to five times the mean U.S. yield (1). Another general difference between the west and the area east of the Rocky Mountains can be seen by comparing the monthly precipitation at Pullman, Washington, and St. Paul, Minnesota, two cities at about the same latitude (Fig. 2). Most rainfall in the west occurs during the winter months, while most rainfall in the east occurs during the summer months. The winter rainfall pattern in the PNW elevates yield potential but also favors development of certain diseases.

The variation in rainfall and temperature within the three PNW states of Washington, Oregon, and Idaho is as great as the total variation east of the Rocky Mountains. Wheat-growing areas of the PNW range from mountain and river valleys to vast prairies and semidesert. For example, wheat is grown in the Snake River area of southern Idaho; the Columbia Basin, Palouse prairie, and mountain valleys of northern Idaho and eastern Oregon and Washington; the Willamette Valley of western Oregon; and the Skagit Valley of northwestern Washington (7). Each of these areas (which are separated by large mountain ranges) has its own crop management systems, its own set of disease problems, and its own set of rust races. In addition, there is considerable environmental variation within some of the regions.

Figure 3 is a modification of a map developed by Douglas et al (5) showing agronomic zones of the PNW. Zone 1 has more than 40 cm (16 in.) of precipitation annually, which is adequate for growing a crop every year. In zone 1 of northern Idaho and eastern Oregon and Washington, soft white winter wheat is most commonly rotated with barley and/or spring wheat and large-seeded annual legumes. Crops in zone 1 of western Washington and Oregon are more diverse, and rotations are usually more complex than in the other zones. Zone 2 is a transition zone, with 35–40 cm (14–16 in.) of precipitation per year. Annual cropping can be practiced in most years, but summer fallow rotations may sometimes be necessary. Soft white or club wheat classes are primarily grown in zone 2. Zones 3 and 4 have 25–35 cm (10–14 in.) of precipitation per year, which is usually only adequate for growing a wheat crop every other year. Wheat or barley is rotated with a year of summer fallow to ensure adequate water for a crop. Because of the winter rainfall pattern, a dust mulch is maintained during the summer fallow period to prevent water evaporation. To utilize the maximum amount of water in the soil profile, winter wheat is planted as

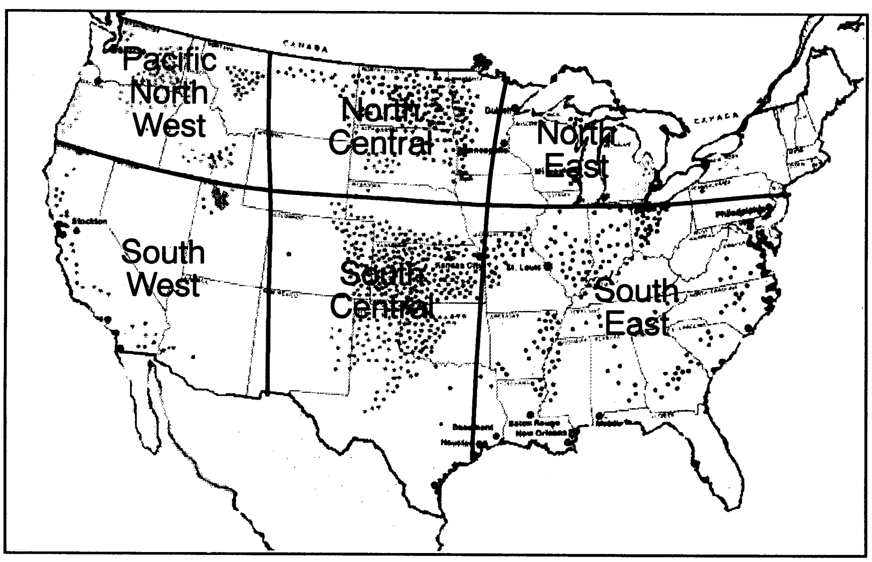

Fig. 1. Wheat production regions of the United States.

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early as possible (late August to early September) and several inches deep, so that it is in moist soil. Some farmers in zones 3 and 4 irrigate in order to grow annual crops or to assure establishment of a good stand, especially in the shallow soils of zone 4. The hard red wheats are the major wheats grown in the dryland, summer fallow fields of zones 3 and 4. Club wheats are grown mostly in the eastern and northern summer fallow area bordering on zones 1 and 2. In zone 5, precipitation is less than 25 cm (10 in.) per year, and irrigation is almost always necessary to grow a crop. Soft white wheats are usually grown in the irrigated fields in rotation with various other irrigated crops in zone 5.

Newly developed cultivars of the specific classes and types of wheat must therefore be adapted to the diverse environments and management systems of each zone and should have resistance to the diseases that occur in each zone. Rotation is generally beneficial for control of several of the wheat diseases, but it is not always practiced in the annual cropping areas of zones 1 and 2 and the irrigated areas of zones 3, 4, and 5. Under the annual cropping system, some farmers grow wheat every year in the same field. In the summer fallow zones, rotation with crops other than barley is rare, and when wheat is not rotated with barley, the effect on diseases is similar to the effect of continually growing wheat. Reduced tillage is important for control of wind and water erosion in the PNW and has become a more common practice in recent years. The environment created by reduced tillage is more favorable for diseases that are affected by crop residue on the soil surface.

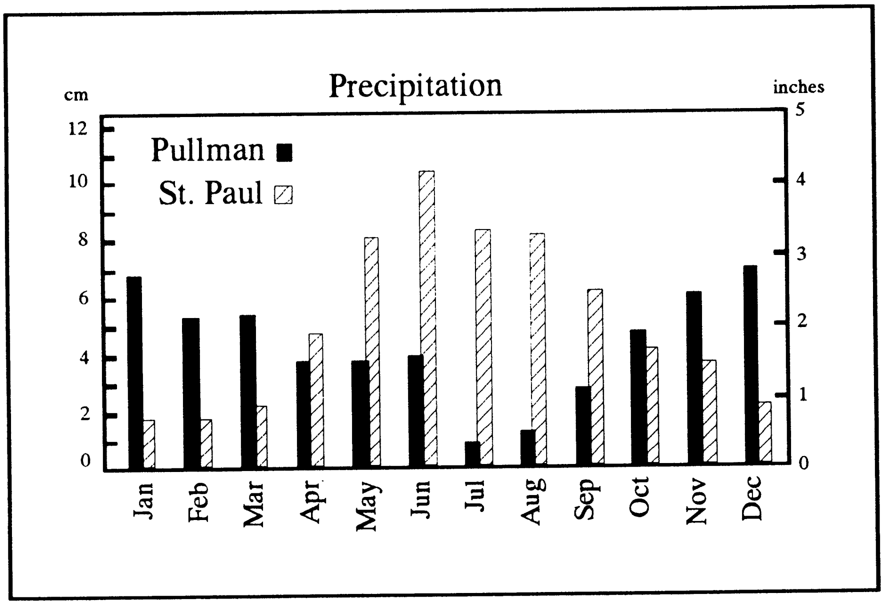

Fig. 2. Monthly precipitation at St. Paul, Minnesota, and Pullman, Washington.

Diseases in the Pacific Northwest

Most of the North American diseases and pests of wheat can be found in the PNW (Fig. 3). Common bunt, flag smut, and dwarf bunt are and have been unique to the PNW. These three diseases are problems in winter wheat and are affected by the date of planting in the fall. Early planting reduces common bunt, late planting reduces flag smut, and very late or very early planting reduces dwarf bunt. Flag smut and dwarf bunt do not occur on spring wheat in the PNW. The three smuts are both soilborne and seed-borne, and the older, traditional seed treatments are not effective against soil-

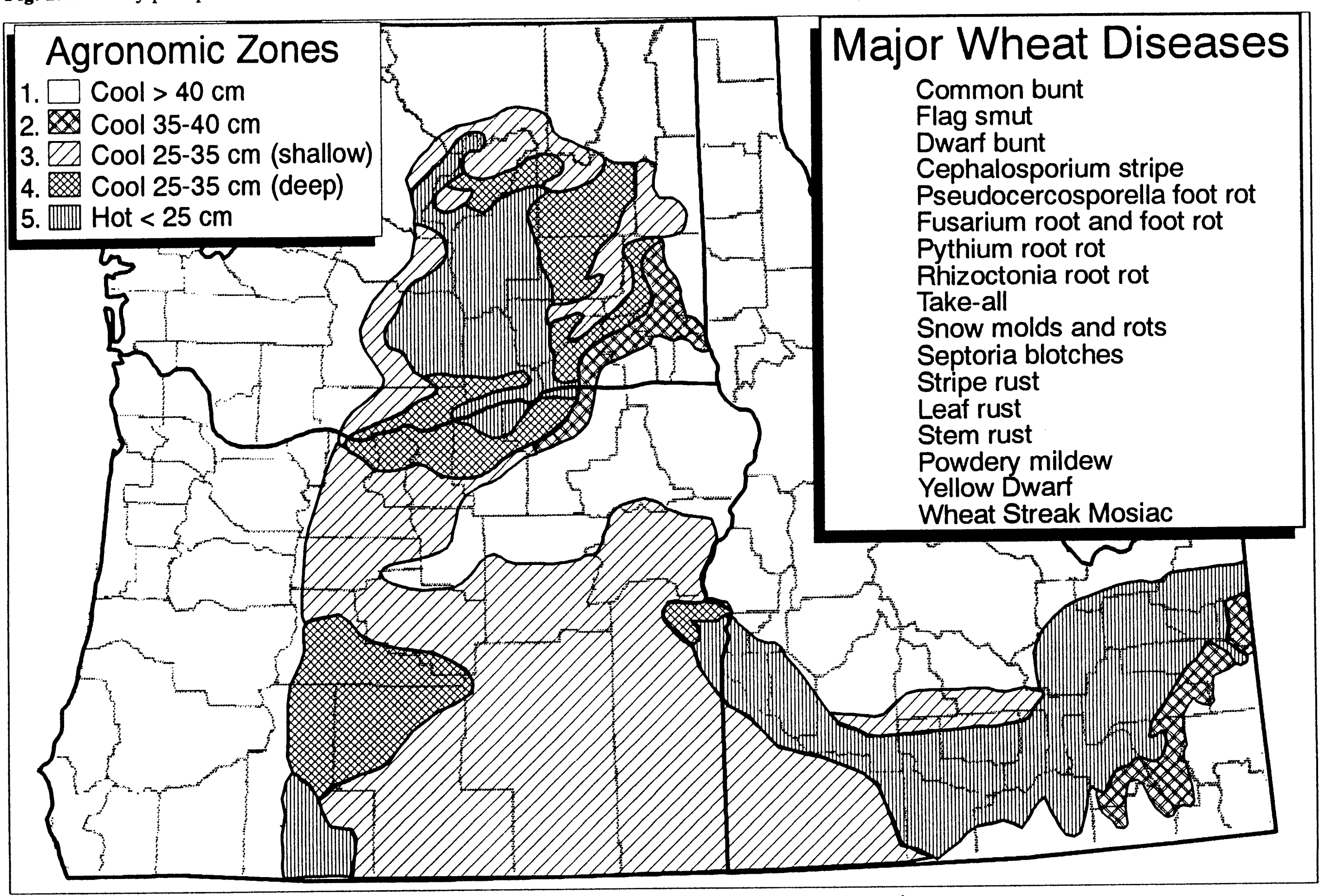

Fig. 3. Agronomic zones of the Pacific Northwest and the major wheat diseases that occur in the regions.

borne smuts. Resistance to common bunt and dwarf bunt has often been of short duration because of the appearance of new races of the pathogens. The use of hexachlorobenzene and pentachloronitrobenzene seed treatments in the mid-1950s was a major breakthrough for control of soilborne common bunt, and the use of carboxin seed treatments for control of flag smut was a major breakthrough in the late 1960s. Seed treatment continues to be the most effective and practical method for their control. The necessary use of seed treatments for control of common bunt and flag smut is probably the best example of the value and safe use of chemicals for cereal crops. The small amount used per acre has made possible profitable wheat production in the PNW. Dwarf bunt is more difficult to control with seed treatments because infection occurs in the winter. However, a new seed treatment, difenoconazole, has shown great promise and may play a significant role in controlling dwarf bunt in the future.

Cephalosporium stripe, Pseudocercosporella foot rot, Fusarium root and foot rot, Pythium root rot, Rhizoctonia root rot, and take-all are soilborne diseases that infect underground plant parts or the basal stem. Consequently, rotation and tillage are important control methods, and minimum tillage usually increases these diseases. Resistant cultivars are important for control of Cephalosporium stripe and Pseudocercosporella foot rot. Foliar fungicides are used to control Pseudocercosporella foot rot, and seed treatment is beginning to be used for control of take-all.

Some diseases are more important in certain regions and zones, as, for example, flag smut in zones 3 and 4 of south central Washington and north central Oregon and the snow molds and dwarf bunt in areas of zone 1. Cephalosporium stripe is most severe in the shallow dryland soils and higher rainfall zones, Pseudocercosporella foot rot is most severe in the wetter zones, and the Septoria diseases occur primarily in the zones of western Washington and Oregon where rainfall is more frequent and abundant. Diseases such as yellow dwarf and wheat streak mosaic that depend on aphids and mites for dispersal and transmission occur widely but sporadically. Powdery mildew is common but seldom causes damage to the crop.

The rusts are distributed throughout the PNW region and are the most widely destructive of the wheat diseases. The environment in most of the PNW is favorable for severe stripe rust and leaf rust in most years, and both diseases occur every year in certain areas. Stem rust is less frequently severe but occasionally causes high losses in certain management systems. Fortunately, most of the losses have been prevented by an effective integrated rust control program.

Control of Wheat Rusts

The IPM program for managing the rusts works within the framework of the management systems for producing a crop under the existing environmental conditions and for control of the other diseases and is based on predicting the diseases, loss assessment information, and control with resistant cultivars and fungicides. Prediction consists of: 1) determining the relationship of the diseases to management and weather; 2) monitoring the distribution, prevalence, and severity of the diseases; and 3) determining the virulence of races and the vulnerability of host cultivars. Loss assessment is aimed at obtaining data that can be used to set priorities, evaluate management systems, and determine the relationship of losses to disease measurements. Resistance is aimed at understanding the characteristics of resistance, screening for resistance, and developing methods of managing resistance. Chemical control consists of integrating the use of seed treatments and foliar treatments with resistance and other controls.

Predicting the rusts and assessing the losses. The rusts of wheat are indigenous to the PNW and do not depend on inoculum dispersed from the south, as in the northern Great Plains. Critical periods for pathogen survival are the late summer months and winter months. The management practices needed to produce a continuous wheat crop provides continuous hosts for growth of these obligate parasites. Winter and spring wheat, early and late plantings, and irrigated and rainfed wheat are planted and grown at different times within the region, often in adjacent fields. Wheat and barley are sometimes grown in the summer to prevent wind erosion, to produce feed for livestock, or to comply with requirements of conservation programs. Weeds and volunteer wheat may grow in fields of other crops, especially irrigated crops, and along the borders of fields. These plants provide sources of inoculum for development of rust epidemics. Therefore, inoculum produced during the summer and early fall on the various host plants is carried by the wind to newly emerging plants to continue the disease cycle.

Figure 4 shows the development of stripe rust, leaf rust, and stem rust in the PNW. During fall, the rusts increase in the local fields and the inoculum may be spread downwind to distant fields. Early planting of winter wheat contributes to development of the epidemic by providing more time in the fall for development of rust. Stripe rust and leaf rust survive in living wheat leaves during the winter, and when the plants begin to grow more rapidly in the spring, the rusts also begin to increase more rapidly. Stripe rust, which develops best at low temperatures, increases most rapidly in early spring (March to May). Leaf rust, which has a more moderate temperature requirement for optimum growth, increases slowly until late May (late jointing to boot stages of growth for winter wheat). If moisture is present, leaf rust then develops even more rapidly than stripe rust. Both rusts can infect and increase on spring wheat as soon as the seedlings emerge. Stem rust does not usually survive during the winter on living plants but survives instead as teliospores on crop residue. These teliospores infect barberries, which then supply the primary inoculum for wheat. Therefore, crop residue on the soil surface is an important epidemiological factor for stem rust. Stem rust epidemics develop in June and July.

To determine the distribution, prevalence, and severity of the rusts, virulence of races, and vulnerability of host cultivars, spring and winter wheat trap plots consisting of commercial cultivars, new breeding lines, and cultivars and

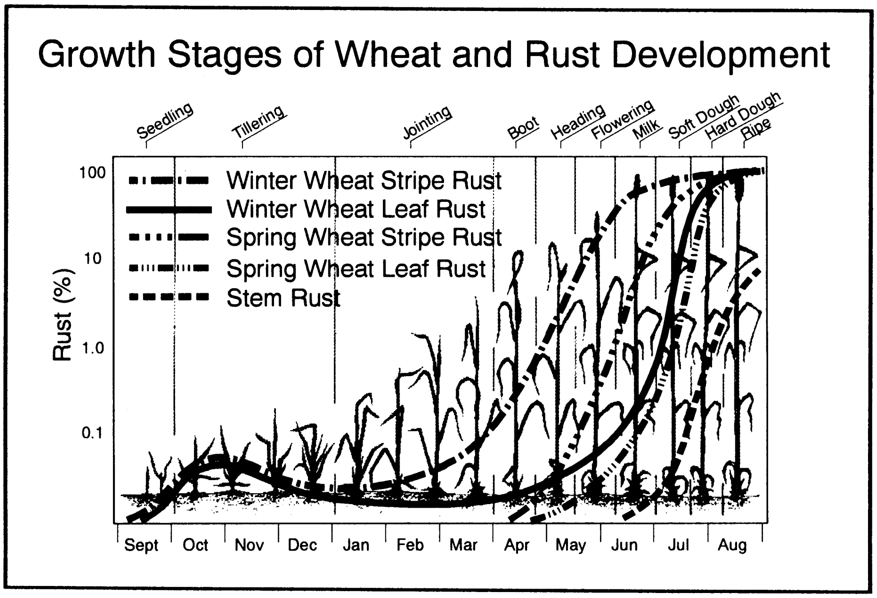

Fig. 4. Development of stripe rust, leaf rust, and stem rust in the Pacific Northwest.

lines that differentiate races are planted at sites throughout the region. Plants in those plots and in commercial fields are checked periodically at various growth stages during the growing season to determine severity of the rusts and susceptibility of the plants. In addition, samples of rust from the plots and fields are tested under controlled temperatures. The monitoring data are used to provide growers and wheat breeders with an early warning of the appearance of new races and the vulnerability of cultivars and breeding lines (7).

Models for predicting rust in the PNW based on the relationship of disease severity to weather, especially winter and spring temperatures and spring precipitation, have been developed and tested (2–4,6). With use of the models and the monitoring data, rust epidemics in the PNW have been accurately forecasted since 1979. Field data on losses caused by the rusts and the relationship of losses to rust intensity are obtained annually for the major winter and spring wheat cultivars under various crop management systems at key sites in the PNW. The monitoring data, the models, and the loss data are used to make decisions regarding selection of alternative control practices.

Control with resistant cultivars. Resistance is the preferred control for wheat diseases, but it is not always feasible or available for all of the diseases. Because of the number of diseases and races that must be controlled and the various other characteristics that must be incorporated into a locally adapted cultivar, it is currently not possible to develop a cultivar that has genes for resistance to all of the diseases of wheat in the region and genes conferring all of the agronomic and quality characteristics that are needed. However, cultivars adapted to the various zones have been developed that are resistant to certain diseases.

Severe stripe rust epidemics in the late 1950s and early 1960s were the major stimulus for improving stripe rust resistance. Resistance to stripe rust in North American wheat cultivars is primarily of two types: seedling resistance and high-temperature, adult-plant (HTAP) resistance. The seedling resistance is characterized by race specificity and low infection types at all stages of plant growth and at a wide range of temperatures. Race-specific resistance has been used in some cultivars, especially the club wheats. It has been highly effective in multiline cultivars but has short durability in nonmultiline cultivars. Within 3 yr after the release of new cultivars with high race-specific resistance, new virulent races have attacked them. In contrast, HTAP resistance has been effective against all North American races of stripe rust for more than 30 yr (7). This type of resistance has certain unique characteristics that make it more durable (8–10). HTAP resistance is characterized by a range of infection types and a shift in the range depending on temperature and stage of plant growth. Seedlings of cultivars with HTAP resistance are susceptible at all temperatures. As plants with HTAP resistance age, they become more resistant at high temperatures (temperatures that commonly occur during late spring in North America) but remain susceptible at low temperatures. At high temperatures, the flag leaves are most resistant. Resistance in plants grown under controlled environmental conditions can be reversed by changing the temperature. Because of those characteristics, cultivars with only moderate HTAP resistance may be less resistant when environmental conditions (unusually warm winters and unusually cool springs) are highly favorable for early development of stripe rust epidemics. Both high race-specific resistance and slow rusting resistance are used to control leaf rust in the PNW. Currently, all of the major soft white winter, hard red winter, and spring wheat cultivars have HTAP stripe rust resistance; the major spring wheat cultivars have slow rusting resistance to leaf rust; and many of the spring wheats have resistance to stem rust. However, stripe rust and leaf rust resistance in the club wheats is primarily race-specific. Consequently, chemical control is necessary when the race-specific resistance becomes ineffective or to complement the other types of resistance when environmental conditions are unusually favorable for epidemics.

Control with fungicides. Severe epidemics of stripe rust and leaf rust were predicted for 1981. At that time, some of the cultivars were susceptible to one or both of the rusts, and there were no fungicides registered in the United States that would provide practical control of the diseases. However, we had data on the effectiveness of several systemic fungicides in the PNW and data on how to use the fungicides to obtain economical control (6). Using that data, we were able to justify the emergency registration of triadimefon. That was the first major commercial use of foliar sprays to control cereal rusts in the United States. That year, use of the fungicide prevented losses of more than 26,000 t (1 million bushels) in the state of Washington. Similar losses were prevented in Oregon and Idaho. Since then, greater losses have been prevented by the use of foliar fungicides. Chemicals are now part of an integrated rust control program in the region. Triadimefon and propiconazole are now registered for control of the diseases. More recently, seed treatment with triadimenol has become part of the rust control program. Several new, nonregistered treatments appear to have potential for the future (6,11). The seed treatments can be used in combination with foliar sprays when cultivars are very susceptible, alone when yields are too low for economical control with foliar sprays, and in combination with moderate HTAP resistance to stripe rust or slow leaf rusting resistance.

Guidelines have been developed for reasonable, economical use of fungicides based on the foregoing information. Factors considered in developing the guidelines were: 1) managerial systems (regional and individual), 2) weather (local and regional), 3) type of rust (stripe, leaf, and/or stem), 4) other diseases and pests and their interactions, 5) race virulence and host vulnerability, 6) kind and degree of resistance, 7) severity of rust at different growth stages, 8) yield losses in relationship to severity, 9) fungicide effectiveness at various rates and schedules, 10) potential yield when rust is controlled and not controlled, and 11) economics (costs vs. benefits of control).

Delivery of Information

The system for delivery of information on control of wheat diseases in the PNW is primarily an informal network with fellow scientists; research, extension, and advisory people; and the growers. Examples of the network are organizations such as STEEP (Solutions to Environmental and Economic Problems), the Western Regional Coordinating Committee for Cereal Diseases, Western Wheat Workers, and Tri-State Wheat Workers. The system involves cooperation with industry and public and private advisors, reports to wheat commissions and wheat grower groups, topical talks to various groups on results of research and on disease situations, establishment of field plots on private farms as well as on experiment stations, and news releases to newspapers and agricultural periodicals.

The informal IPM program for the control of wheat diseases in the PNW has provided an early warning to growers so they can take rational action to prevent widespread, destructive epidemics even when the environment has been unusually favorable for the diseases.

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