Principles of Crop Rotation Workshop: Wheat and Barley Diseases

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I. The Diseases

Crop rotation is one tool that should be used in an integrated management strategy to reduce the damage from plant diseases. Other tools include use of resistant crop cultivars, adjustments in soil fertility levels, optimizing cultural practices, and where appropriate, using chemical disease control. Diverse crop rotations reduce the risk of catastrophic losses caused by pests, but a rigid crop rotation plan reduces the grower's ability to make financial gains if other factors, such as global market economies, make some crops more desirable. Crop selection should be thought of as long-term investing. In the short term, crop rotation may not return the largest profits to the producers if the lower value crops need to be grown, but in the long term it will be sustainable because yields will be maintained. On the Canadian prairies, several leaf and root diseases of wheat and barley may be managed by crop rotation and significant levels of control may be achieved in this semi-arid environment.

The major leaf spot diseases encountered on wheat and barley in the prairie region are:

Wheat

i) **tan spot** caused ***byPyrenophora tritici-repentis*** (Died.) Drechs. [anamorph ***Drechslera tritici-repentis*** (Died.) Shoem.],

ii) **septoria blotch** caused by ***Septoria nodorum*** (Berk.) Berk. in Berk. & Broome [telomorph ***Leptosphaeria nodorum*** E. Muller], and ***Septoria tritici*** Roberge in Desmaz [telomorph ***Mycosphaerella graminicola*** (Fuchel) J. Schrot. in Cohn].

Barley

i) **net blotch** caused by ***Pyrenophora teres*** (Died.)Drechsl. f. ***teres*** and ***P. teres*** f. maculata

ii) **scald** caused by ***Rynchosporium secalis*** (Oud.) Davis

Leaf spot diseases occur every year but do not always cause economic losses unless abundant moisture occurs and inoculum is present from residue of previous crops. Sutton and Vyn (1990) reported yield losses of 20% due to tan spot and septoria blotch in continuous wheat crops as compared to rotations using wheat following non-cereal crops. Yield loss in wheat due to leaf spot infection was 28% greater in rotations with consecutive wheat crops than in rotations where cereals were not grown back to back at Indian Head, SK (Bailey, Lafond, & Derksen, AAFC, unpublished data).

The major root diseases are:

i) **common root rot** caused by a complex of fungal organisms known as *Cochliobolus sativus* (Ito & Kurib.)Drechsl. ex Dastur [anamorph *Bipolaris sorokiniana* (Sacc. in Sorok.) Shoem.] and some red *Fusarium* spp. primarily, F. *culmorum, F. uvenuceum,* and *F. grumineurum,* and

ii) **take-all** caused *byGaeumannomyces gruminis* (Sacc.) Arx & Olivier var. *tritici* Walker

Common root rot occurs in all soils and insidiously results in small but consistent losses every year. Take-all may be present in numerous soils but is more dependent on the local environment and host/residue rotation for symptom expression and resultant damage. Losses due to common root rot average 10% annually whereas losses due to take-all range from 1540%. Cook and Veseth (1991) noted that following soil fumigation, wheat yields were greater by 70% in fields where wheat had been grown for three or more consecutive years, 22% in fields where wheat was grown in alternate years of a two-year rotation, and 7% in fields where wheat was grown every third year following spring barley and either peas or lentils. Yield loss in wheat due to common root rot infection was 11% less with more diverse rotations such as spring wheat-canola-spring wheat-lentil or spring wheat-pea-spring wheat-lentil, or wheat-sunola-canary seed-lentil or spring wheat-flax-winter wheat-peas as compared to continuous wheat production at Indian Head, SK (Bailey, Lafond, & Derksen, AAFC, unpublished data).

II. How Causal Organisms Survive Between Susceptible Crops

Persistance on crop residues is the most important mechanism of survival of pathogens on wheat and barley. The biological characteristics of these pathogens are shown in Table 1. Many survive between highly susceptible hosts on other types of cereals and related grasses and crops. They can exist as either conidia, fragments of mycelium, or as sexual spores within an over-wintering structure such as a pseudothecium. Of all the fungal agents that cause important diseases of wheat and barley, C. *sativus,* the causal agent of common root rot, is the only one able to survive in soil apart from the residue. It produces thick-walled, darkly pigmented conidia which protects the organism from dessication and UV light destruction. Most of the pathogens of wheat and barley may also infect and be spread by seed (Table 1). However, seed-borne spread is usually of little importance relative to the large amount of inoculum originating from the residue.

Table 1. Biological characteristics of the major pathogens causing disease on wheat and barley in the Canadian prairies.

Disease	Host Specificity	Survival	Spore Types	Dispersal Mechanisms	Preferred Environment
Common root rot	barley, wheat oats, triticale, rye, canary seed	soil, residue, seed, conidia mycelia	pigmented conidia	wind, water, cultivation, seed, residue	hot, dry soil
Take-ah	wheat and other cereals	mycelia in residue	pigmented runner hyphae	root to root, infested soil & debris	cool, moist soil
Tan spot	wheat	residue, mycelia pseudothecia,	conidia, ascospores	wind, residue	humid, wet cool -warm
Septoria leaf blotch	wheat, barley	residue, seed, pseudothecia pycnidia,	conidia, ascospores	rainsplash (conidia) wind (ascospore)	wet canopy warm - hot
Scald	barley	mycelia, seed,residue	conidia	rainsplash	cool, wet
Net blotch	barley	seed, residue mycelia, pseudothecia	conidia ascospores	wind	warm - hot, wet

III. Factors Affecting the Rate of Inoculum Disappearance

A. Environmental Factors

A highly variable climate in the Canadian prairies makes environment the major factor determining which diseases will be economically damaging. The normally arid conditions (e.g. 175-280 mm precipitation and > 300 mm evaporation from May to September) frequently allows growers to plant cereals on the same land, and in many cases practice cereal monoculture, without serious losses from disease. Bailey et al. (1992) found that hot dry conditions in Saskatchewan from 1987-1992 resulted in low foliar disease severities and prevented the detection of any consistent and significant effects of reduced tillage on losses due to disease. However, in wetter years from 1993- 1994, disease was more severe and yield losses due to disease were measurable.

Generally, leaf diseases are more severe as you move from the brown to the dark brown to the black soil zones on the prairies which usually coincides with increasing rainfall. For most diseases, the probability of an outbreak is greatest in areas where rainfall is higher, providing that inoculum is present. Therefore, the risks associated with inadequate crop rotation are highest on average in the black soil zone.

The rate of residue decomposition determines the ability of the inoculum to carryover from season to season but this is affected by the local environment. The rate of cereal residue decomposition decreases with reduced water potentials (lower than -0.1 MPa) and lower temperatures (Surnmerell & Burgess 1989a). It was also found that barley residue decomposes more rapidly than that of wheat and partially or completely buried residue decomposes more rapidly than that retained on the soil surface.

B. Biological Activity

A knowledge of the biology of the fungi causing diseases helps explain the importance of residues. ***P. tritici-repentis*** forms ascospores and conidia and both can serve as sources of primary inoculum. Ascospores are dispersed over short distances of probably only a few centimetres, while conidia can be widely dispersed (Schilder & Bergstrom 1992). Once conidia are produced, the disease can move from field to field (Rees & Platz 1992). On native prairie in Saskatchewan, 95% of all ascospores were found from April to June while 95% of conidia were found from June to August (Morrall & Howard 1975). Conidia were trapped starting in April-May and the number of conidia greatly exceeded that of ascospores. In winter wheat, conidia were captured from late April through to mid-July (McFadden & Harding 1989). Similar results were recorded in North Dakota on spring wheat (Krupinsky 1992). In both studies, ascospores were rarely found and may be of minor importance as a source of inoculum in the prairies.

In other locations, such as in Ontario (Wright & Sutton 1990), the United States (Zhang & Pfender 1992), and Australia (Summerell & Burgess 1988a, 1988b), ascospores of ***P.*** *tritici-repentis* were present early in the growing season while conidia were formed later. In Ontario, pseudothecial development was protracted and took 8 to 10 months to complete (Wright & Sutton 1990). Ascospores were released from April to June and most conidia in June and July. Epidemics were characterized by a prolonged simple-interest phase initiated by ascospores, followed by a shorter compound-interest phase resulting from conidial infection. Evidence suggests ascospores infect mainly the lower leaves and conidia the upper leaves. Presence of crop residues under circumstances when ascospores are formed could lead to infections early in the spring. This was demonstrated by a shift from a clumped distribution of infection under conventional tillage to a random distribution under reduced tillage, indicating the role of residue in spreading disease under conservation tillage systems (Schuh 1990).

In contrast to ***P.*** *tritici-repentis*, pycnidiospores of S. nodorum and S. *tritici usually* move short distances as they are rain-splash dispersed while ascospores, which form in the spring, are wind-borne and may move greater distances (Holmes & Colhoun 1975). In Saskatchewan in winter wheat, ascospores of S. nodorum were trapped from late April to mid-July while pycnidiospores first appeared in June (McFadden & Harding 1989).

The location of infested straw relative to the soil surface is a factor influencing survival of pathogens. In Kansas, the number of ascocarps of ***P.** tritici-repentis* developing on straw near the soil was less than half of that found in straw above the soil surface (Zhang & Pfender 1992). In Australia and Ontario, ascocarp development was faster on prostrate straw than in standing stubble (Sumrnerell & Burgess 1988b, Wright & Sutton 1990). Pseudothecial initiation and maturation requires moist conditions and moderate temperatures, but the survival on crop residue is greater in dry, cool conditions (Summerell & Burgess 1989c).

Continuous production of wheat or barley is not recommended for several reasons. Besides increasing inoculum levels in soil, this practice may lead to selection of strains of a pathogen that are more virulent to the crop. The virulence of C. *sativus* to either wheat or barley may be increased in five years of continuous wheat or barley production (Conner & Atkinson 1989). El-Nashaar and Stack (1989) isolated more aggressive strains of C. *sativus* on wheat from a 90 year continuous wheat rotation, suggesting that wheat monoculture can shift the pathogen population. A highly aggressive strain may be able to sporulate more thus contributing greater amounts of inoculum to the soil. Bailey (unpublished data) observed that white and tan colored isolates of C. *sativus* caused less disease and produced fewer spores than the brown and black colored isolates.

Also known to occur with monoculture is the phenomenon of disease suppressive soils, such as take-all decline of cereals. With suppressive soils, a soil-borne pathogen may become established and increase in the initial years of cropping, but then diminishes with continued culture of the crop (Bruehl 1987, Cook 1982). The decline effect is lost when a different crop is introduced into the production cycle. It may take up to seven years before the effects of take-all decline reduce disease severity to tolerable levels and during this time severe losses in yield may be expected. Manipulating crop rotations to take advantage of take-all decline does not provide a satisfactory method for management of this disease. However the identification of micro-organisms responsible for the phenomenon have led to the development of biological control agents for more successful disease control.

Studies of other micro-organisms living on the residue may show important interactions with pathogens that may be exploited for new means of disease control. These other organisms may interact with the pathogens through competition for substrate or by antagonistic inhibition of pathogen development. Pfender et al. (1993) identified fungi that can be sprayed on wheat crop residue that compete for sites of pseudothecial production (i.e. primary inoculum) by ***P.** tritici-repentis.* Some of these organisms have provided a small degree of enhanced control of tanspot.

C. Management Strategies

Tillage

Survival of *P. tritici-repentis* and S. *nodorum* is reduced when the residue containing these fungi are buried by tillage, but these fungi may survive for several years when left above ground (Rees & Platz 1992). Incorporation below the soil surface physically prevents expulsion of ascospores of *P. tritici-repentis* and also reduces pseudothecial development because the requirement for light is not met (Summerell & Burgess 1988b). Contact of straw with soil also leads to straw tissue breakdown and displacement of *P. tritici-repentis* and S. *nodorum* (Pfender & Wootke 1988). Tillage tends to leave mainly crowns and basal internodes on the soil surface and few pseudothecia of *P. tritici-repentis* develop on these substrates (Summerell & Burgess 1988a, 1988b, Zhang & Pfender 1992). In one study, the density of inoculum in disked plots was only 9% of that found in no-till plots. This was related, in part, to the reduction in the amount of residue on the soil surface, but in addition, the residue in disked treatments produced fewer ascocarps than residue in no-till (Zhang & Pfender 1992). Despite reduced ascocarp production in the disked treatments, their number was higher than the minimum required to produce a moderate to severe disease infestation.

Reduced Tillage

The change from conventional to reduced tillage will result in more crop residue being returned to the soil surface so the surface of the soil will be moister and cooler than under conventional tillage (Bailey & Duczek 1995). These changes influence the development of residue- and soil-borne pathogens resulting in some diseases increasing in importance, others decreasing, and some remaining the same. Take-all of winter wheat in Kansas became more severe and resulted in lower yields when plants were grown in plots shaded with surface residue thus bringing soil temperatures down 10 °C cooler than in exposed plots (Bockus et al. 1994). By lowering soil temperature, crop residues in no-till soils prevented summer inoculum from being inactivated. In addition to temperature and moisture changes, the lack of physical disturbance influences the soil microbiological population. A review of the effects of tillage on soil fertility by Robson and Taylor (1987) indicated that there were more fungi, actinomycetes, bacteria, facultative anaerobes, and denitrifying microbial populations in zero tilled soils than in ploughed soils. Also, vesicular-arbuscular mycorrhizal fungi, which increase the uptake of nutrients in plants, produced more spores in the top 8 cm of soil with zero tilled soils.

The distribution of conidia of C. *sativus* in the soil profile also changes under zero-tillage with more inoculum present in the top profile (Duczek 198 1, Mathieson et al. 1990, Reis & Abrao 1983, Salas & Stack 1989). Tillage re-distributes conidia to lower profiles. In wheat, the site of fungal penetration was principally through the crown and basal stem where stubble was retained but was through the subcrown internode and lower crown where stubble was incorporated (Summerell et al. 1990). This reflects the distribution of the inoculum resulting from different management practices.

Crop Rotation

Continuous wheat production is not recommended as foliar disease severities are higher under this practice regardless of tillage (Bailey at al. 1992, Sutton & Vyn 1990). Evidence indicates that reducing inoculum levels decreases disease severity and reduces crop damage (Adee & Pfender 1989). However, significant reductions may not be achieved by a one year break between susceptible crops. Recovery of P. tritici-repentis from residues left on the surface was reduced 50% after 2 years (Summerell & Burgess 1989b, 1989c). In North Dakota, ascospores and conidia of ***P.** tritici-repentis* were produced on wheat straw that had been in the field for two winters (Krupinsky 1992). Survival of S. *nodorum* for two years in dry tissue has likewise been documented (Sclaren 1966). For S. *tritici* in Saskatchewan, Pedersen and Hughes (1992) showed that a one year rotation between spring wheat crops is sufficient to reduce disease levels when the environment is unfavorable for disease development but that two years are needed when conditions for disease are favorable. In Florida, two years between wheat crops was better than one year to reduce S. *nodorum* disease development (Luke et al. 1983). However, a one year rotation was not effective when infected seed was used. Moisture and temperature are among the important factors that will influence the length of time necessary between cereal crops to reduce levels of disease. The unpredictable climate on the prairies suggest that the interval needed between wheat crops to reduce disease in this region will vary. Also, consecutive plantings of similar crops such as barley and wheat, could lead to increased disease severity because *Septoria* spp. originating on wheat can overwinter and sporulate on barley residue thus preventing a decrease in the level of initial inoculum (Duczek & Bailey, AAFC, unpublished data).

Crop diversity lowers the incidence of leaf spot and root disease in cereals. Rotation utilizing nonhost crops is the most effective means of reducing the severity of and also the number of infecting propagules in the soil. For example, the lowest incidence of common root rot and level of inoculum in soil occurred when barley followed bromegrass; it was most severe following two or more barley crops and intermediate after oats (Piening & Orr 1988). Levels of common root rot inoculum were higher in cereal fields, particularly following barley and decreasing after crops of wheat, rye and oats, than in either fallow or canola fields (Chinn 1976a, 1976b). However, the decline of C. *sativus* inoculum in soil is slow, and therefore a long rotation may be needed to provide effective control. Conidia can remain viable for at least four years after a susceptible crop is grown (Ledingham 1961). Chinn and Ledingham (1958) estimated that after two years 40% of conidia remain viable in soil collected from the field. A laboratory test indicated that viable conidial numbers did not decline after nine months when soil was dry but dropped to 2% when soil was saturated. To lower inoculum levels and reduce the risk of disease, almost any annual oilseed, pulse crop, or a perennial forage crop can be used. Cereals, canary seed, and wheatgrass forage species should not be used because the fungus sporulates on the crowns of these crops and inoculum levels will therefore be maintained or increased (Duczek et al. 1994).

Resistance

Resistant cultivars may reduce damage to the crop but likely will not reduce the survival of the pathogen (Summerell & Burgess 1988b). In Australia, *P. tritici-repentis* conidia developed on residues of wheats with different resistances to foliar symptoms as well as on residues of barley and oat. For S. *nodorum,* however, the number of pycnidiospores produced was greater on leaves from susceptible compared to resistant cultivars (Gough 1978). Rate reducing resistance which slows sporulation of fungi may reduce inoculum potential and lower the initial risk for the following year.

Fungicides

Even though crop residue on the soil surface acts as a source of primary inoculum within a field, secondary inoculum coming from an outside source may create epidemics in fields, regardless of the tillage practice used, if weather conditions are conducive. Jenkyn et al. (1995) found net blotch on winter barley was more severe in the autumn when straw residue from the previous crop was left on the surface. By spring, there were no consistent differences between treatments that removed the residue by burning and ploughing or that left the residue by non-inversive minimum tillage. Similarly, Prew et al. (1995) observed no effect of straw disposal methods for septoria leaf spot severity on winter wheat. Fungicide applications to the plots increased yield but there was no interaction with straw disposal method. Fungicide use may not affect the rate of inoculum disappearance but will reduce damage and may lower the risk of disease in the following year. This strategy will be most effective and economical in wet years when the risk level is at a maximum.

IV. “Rules of Thumb” Behind Current Recommendations for Disease Control Using Crop Rotation

The current recommendations suggesting burial of crop residue and several years rotation with non-cereal crops are too general and not always practical. Crop rotation is a key factor in residue management for disease control but decisions regarding the choice of crops in rotation should be based on levels of risk, damage thresholds, and economics. Once information is gathered on things such as location, weather patterns, previous crop histories of a field and the neighbouring fields, and previous diseases observed, then a risk assesment may be made based on knowledge of the pathogens likely to be encountered. The risk of most diseases may be lowered by understanding and managing the interactions between pathogens and crop residue through modifying local environmental conditions by crop rotation and limited tillage and other management practices.

Similarility among crop types often leads to greater risks with disease problems. Crops of similar types should not be grown in consecutive years. For example, a rotation of wheat following barley may not be effective in controlling leaf spots on wheat because one of the fungi in the complex causing septoria leaf blotch reproduces on barley residue, even though it does not cause leaf spot problems on barley. However, a short break of one or two years out of cereals usually can provide adequate management of all the leaf spot diseases on cereals. In some situations, rotation alone is not sufficient to give control. Common root rot is ubiquitous where cereals are grown because the fungus produces a lot of inoculum that survives for a long time in soil and low levels of spores in the soil can cause high levels of disease in the crop. Rotation alone is not practical for control and it should be used in conjunction with other sustainable strategies such as use of resistant cultivars, shallow seeding, and correct fertilizer application.

The ideal rotation should be four to seven years long with 50% of the interval devoted to cereals (spring and winter types) and the remainder divided among pulses, flax, other oilseed crops, and forages. The smallest rotation interval between cereals could be one year but two to four years is more desirable for disease control depending on the disease. Longer rotations are more desirable for control of common root rot whereas one or two years is desirable for take-all and the leaf spot diseases. Key points to remember are:

- most root and leaf diseases become more severe under continuous cereals,
- do not plant cereals more than two years in a row,
- use a range of cereals such as wheat, barley, triticale, oats, and rye; do not grow the same type of cereal crop year after year,
- wheat and barley have more similar disease problems than oats and rye,
- grasses and canary seed carry diseases similar to cereals,
- growing wheat or barley after grasses or hay-grass mixtures increases the risk of root diseases,
- take-all causes more damage in wheat than in barley,
- most oilseed, pulse, and forage crops are not susceptible to the same diseases as cereals,
- use cereals as a breakcrop to interrupt the disease cycles of sclerotinia, blackleg, and ascochyta of oilseed and pulse crops, and
- sow disease-free seed of resistant varieties for added protection.

V. Research Required Towards Risk Assessment in the Management of Specific Diseases

Disease Forecasting and Monitoring

Monitoring and forecasting are useful tools for disease management. In Germany, economic thresholds have been established for control of some fungal pathogens in wheat; foliar fungicides are recommended when ***S.tritici*** on leaves reaches 50% severity and S. ***nodorum*** on the heads reaches 12% severity (Habermeyer & Hoffmann 1994). In the Canadian prairies, a decision guide was developed recommending that a one time application of propiconazole on spring wheat should increase yield by 6-11% if leaf spot incidence (pathogen complex of S. ***tritici, S. nodorum, P. tritici-repentis)*** was greater than 50% on the flag leaf, flag - 1, or flag-2 leaves at the time between flag leaf emergence and early-mid flowering growth stages; multiple or later applications of the fungicide did not result in higher yield (Duczek, AAFC, personal communication). Hershman et al. (1994) found that after growth stage 55, the best indicator to predict whether fungicides should be applied to control ***Septoria*** on wheat in Kentucky was on flag-2 leaf if severity was greater than 25%.

Some forecasting tools have been developed that educate the producer by showing them how to identify and assess the level of risk in fields. These should be developed for use by the producer directly and not an intermediary. These must include instructions as to montioring individual fields at different growth stages, sample collection, and handling techniques. Kits should include a guide with color plates to teach growers how to distinguish the pathogen or disease from other fungi and diseases. The guide should also give instructions for producers to assess the risk level in a field and the potential economic value of control by calculating if, when, and how much fungicide should be applied. Most research on monitoring and disease forecasting has been directed at crops in regions where the primary method of control has been achieved with fungicides and often for crops with high cash value. These tools should have much broader application. Monitoring and disease forecasting should also enhance application of innundative biological control agents or biofungicides, improve crop rotation planning and risk assessment, and help preserve the integrity of crop resistance which forms the basis for decision support systems.

Decision Support Systems

Decision support systems should become an integral part of integrated pest management systems to provide tools for synthesis and analysis of relevant information on numerous aspects of crop production. These systems should directly assist farmers through economy of pesticide application (dose and frequency) and by integrating other control procedures that will be equally effective. Computerized systems developed to date such as EPIPRE in wheat have primarily been used for providing recommendations on timing for field monitoring, when to use fungicides, and choice of fungicides (Rabbinge & Rijsdijk 1983, Zadoks 198 1). Surprisingly, the ultimate benefit derived from EPIPRE was not from its decision support system but from its information system. The information educated farmers in disease awareness and in monitoring techniques. It influenced general crop protection practices by preventing the introduction of high-input routine spraying practices by demonstrating to growers and extension agents that these intensive practices were not necessary.

Databases for these systems need to be developed to include decision making processes for crop rotation and other agronomic practices. These databases must include estimations of damage thresholds in order to illustrate what constitutes an acceptable level of plant disease. Disease eradication or elimination is not necessary for most situations. Some disease on crops should be tolerated but at levels that maintain economic and aesthetic acceptability.

To get these practices adopted by producers it must be demonstrated that the recommendations have value and applicability. Detailed cost benefit analyses of alternative practices demonstrate the economic value of changing systems. Data collected often lack economic details of chemical versus non-chemical control measures. Individual farm demonstrations help to show the practicality of the production practices and instill enthusiasm for promoting the successful technologies. Regional demonstrations help to show that the technologies can be used successfully by more than one individual. Successful adoption will involve an educating process that will take considerable time.

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