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Managing Snow Mold Diseases of Winter Cereals and Turf

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Most snow mold pathogens cause plant injury only under prolonged snow cover, so snow mold diseases are severe primarily in regions where snow cover persists for more than 100 days. Even within these regions, disease occurrence and severity varies greatly from year to year. When disease is severe, individual fungal colonies coalesce, resulting in substantial losses in plant stand (20). In other years, pathogen growth is limited and losses are insignificant. Infection foci develop with a pattern and species composition determined by snow cover, microhabitat (28) and inoculum load.

Several approaches to the control of snow mold diseases have been investigated, including the use of resistant cultivars, snow removal, modified management practices, fungicides, and biological control. To date, the greatest success has been achieved with fungicides and resistant cultivars, but recent progress in biological control indicates strong promise in this area as well. Since most control measures must be initiated before snowfall (before disease severity is known), their cost-effectiveness is particularly important.

Disease resistance

Initial studies in Washington and Idaho, USA to identify adapted winter wheat lines with snow mold resistance were not encouraging (18, 30). A massive effort to screen lines from the

World Wheat collection (45, 47) identified numerous lines with some resistance to *Typhula idahoensis, T. incarnata,* and *Microdochium nivale* (syn. *Fusarium nivale*). These lines were used in the development of the resistant cultivars Sprague, John, and Andrews, which are commonly grown in the snow mold-prone areas of the Pacific Northwest, USA (7, 5, 31).

The initial work in Japan identified winter wheat cultivars that carried some resistance to speckled snow mold (*Typhula ishikariensis*) (48). Another study also identified lines with resistance to *Sclerotinia borealis* or *Typhula* spp. (2). Unfortunately, none of these lines were resistant to both *S. borealis* and *T. ishikariensis,* which are the most important pathogens in the region. Several varieties were subsequently developed with speckled snow mold resistance derived from PI 173438 (1). The development of winter wheat cultivars resistant to *Typhula* spp. represents a major success in snow mold disease management.

Pink snow mold, caused by *M. nivale*, is an important disease of cereals and turf in regions where snow cover is intermittent. There have been innovative studies of screening techniques for this pathogen that are designed to facilitate selection for resistance (32), but no commercial cultivars have been developed specifically for resistance to pink snow mold. However, there is a correlation between resistance to speckled snow mold and pink snow mold (5). Thus, cultivars resistant to speckled snow mold are used where pink snow mold is a problem.

In turf and forage grasses, the development of snow mold resistant lines has been only partially successful. There is great variation among and within grass species in susceptibility to snow molds (20, 51) and lines with improved resistance to snow mold pathogens have been identified (41, 49), but only a few cultivars have been developed as a result of these studies. Also, this resistance has not always been confirmed in subsequent testing (14, 15). As a result, work in this area is proceeding slowly.

Snow removal

Mechanical snow removal is not practical for field crops. In fact, it can increase plant injury because plants that deharden under snow in early spring are very sensitive to freezing injury after the snow cover is removed (18). Snow removal is occasionally used in late spring on golf greens to reduce snow mold injury and hasten greening. It is practical in this situation because of the small acreage involved and the high value of the turf.

Spreading dark-colored materials such as peat, coal dust or fly ash to hasten snowmelt and reduce snow molds has also been examined (7, 10, 23). Blackeners are often ineffective because of unfavorable weather conditions after dusting. For example, snow falling after application reduces effectiveness. Also, the crop may not respond to early snow removal if cold, wet weather occurs after snow melt. This technique is used occasionally on golf courses to hasten snow melt and reduce winter injury. Use of blackeners is a recommended snow mold management technique for winter wheat production in northern Japan, where it generally hastens snow melt by 1-2 weeks (N. Iriki, pers. comm.).

Cultural practices

Early fall plantings of winter wheat survive and recover from speckled snow mold damage better than small plants from later seeding (18, 30, 48). Fields seeded very late sometimes escape infection, but if the plants do become infected, they die (18). In contrast, the foliage of early-sown plants is often destroyed by snow mold, but the plants generally regrow from the crown and recover. Field and growth chamber studies (4, 6) confirmed that larger plants survive speckled snow mold and pink snow mold better than smaller plants, but more sclerotia are produced on the larger plants, leaving a larger load of inoculum in the soil. Improved survival for older plants has also been reported for the low-temperature basidiomycete (LTB, syn. *Coprinus psychromorbidus*) on wheat (13) and for wheat and barley infected with *Pythium paddicum*, *P. iwayamai*, and *T. incarnata* (50).

Nitrogen fertility has a major effect on disease development. Snow mold development on turfgrass is enhanced under excessive nitrogen fertilization, particularly if nitrogen is applied late in the growing season and delays cold hardiness (43). Monthly applications of certain composts are effective in suppressing a wide range of turfgrass diseases, including *Typhula* snow molds (34).

Although seeding date has a substantial effect on response to snow mold, other agronomic factors at seeding, such as tillage management, seeding equipment, or seeding depth do not affect snow mold epidemics (6, 18, 30).

Several studies have demonstrated that rotation with non-host crops reduces snow mold development. Severity of *T. idahoensis* was lower in winter wheat following several years of spring wheat than in that following winter wheat (7). In another study, fewer sclerotia of *T.*

idahoensis were present in soil after alfalfa production than in rotations with winter wheat (19). Also, little snow mold occurred on wheat following rotations with legumes such as alfalfa, sweetclover, or pea, but snow mold severity increased with each succeeding winter wheat crop (30).

Snow mold pathogens have a wide host range, so they can persist on winter annual or perennial weeds in the absence of a host crop (7). On turf, the susceptible host is always present, so disease progress is limited by weather conditions and endemic biological controls. Even in field crop situations, changes in antagonist populations or shifts in microbial ecology in soil associated with different cropping systems, e.g. permanent pasture vs. fallow or continuous spring cereals, may have an impact on survival of inoculum (19), but these factors are not well understood.

Fungicides

Seed treatments have been examined for management of snow mold diseases (e.g. 26, 44) and are widely used to control seed-borne infection by *M. nivale* in northern Europe (35). The main advantage of seed treatments over foliar applications is the small amount of fungicide applied, which minimizes costs, non-target activity, and the risk of spills and fungicide drift.

Foliar fungicide application to control snow mold on field crops is generally not cost effective. Although fungicides can provide effective control of snow molds on cereals (9, 21, 44), epidemics occur sporadically, and it is not possible to determine in advance if fungicide applications will be required. For a foliar fungicide treatment to be cost-effective over years, it must produce a very substantial benefit (e.g. increased yield, improved product quality or income stability) in years when disease is severe. As a result, most of the work on foliar fungicide application has focused on amenity turf, especially golf greens, due to its high value (12, 22). An exception to generalizations about the cost-effectiveness of foliar fungicides for winter cereals is the case of winter wheat production in Hokkaido, Japan. Producers often apply both seed treatments and foliar applications of fungicide for snow mold management. This is cost-effective to the growers because snow mold injury occurs in most years, and even more importantly, the government subsidizes the cost of the fungicide (N. Iriki, pers. comm.).

Even on high value turf, management of snow mold diseases with foliar fungicides is a challenge. Snow mold pathogens generally occur in complexes, with various components of the

complex differing in timing of infection, sensitivity to fungicide, optimum conditions for disease development and strategies for surviving sub-optimum conditions (28, 39, 43). Since it is critical that all of the components of the complex be controlled to minimize potential damage to the turf, multiple applications of fungicide are utilized where they are economically feasible. For example, as many as four applications of fungicide are made to golf greens in Canada; applications in the early fall are targeted primarily at *M. nivale*, and those applied in late fall focus mainly on *Typhula*/LTB.

Another important issue with fungicide use is persistence. Many snow mold pathogens are active beneath the snow from late fall until after snow melt in spring. To provide adequate control, fungicides must either provide very effective control in the fall, so there is little inoculum remaining to produce disease in the spring, or be persistent, so that they are still active against the pathogen several months after application. In recent years, persistent pesticides of all kinds have been carefully reviewed for potential problems related to toxicity, accumulation and movement in the environment. Some of the most toxic and persistent fungicides, such as those based on mercury and cadmium, have been banned in most countries, and the use of many other persistent fungicides is being reduced or increasingly restricted. Restrictions on the use of persistent fungicides will almost certainly result in reductions in the range of fungicides available for snow mold management. These persistent fungicides are being replaced with fungicides that have activity against a narrower range of pathogens, or with fungicides that have a greater risk of loss of efficacy due to development of resistance in pathogen populations. For example, the fungicide benomyl was widely used as a seed treatment to control *M. nivale* on cereals; pathogen populations in some regions are now so resistant to benomyl that it is used in selective media to isolate *M. nivale* (36). New active agents and formulations are still being brought to the marketplace (11), but alternatives to fungicides are required.

Biological control

Many studies have examined biological control of snow molds as an alternative to fungicides. As for many host-pathogen systems, laboratory studies on biological control of snow mold have been encouraging, but successful field tests are rare and no products are available commercially. Work is continuing in this area, despite the absence of commercial success, and the results are promising.

Suppressive composts

Monthly applications of relatively small amounts (5 kg/100m^2) of suppressive composts during the growing season can suppress many turfgrass diseases, including snow mold caused by *Typhula* spp. (34). Heavy applications (100 kg/100m^2) of certain composts to golf greens in late fall are also effective. A major problem with the use of suppressive composts is variation in the effectiveness of a compost among years and sites (33).

Pink snow mold (M. nivale)

In greenhouse trials with infested seed, common seed saprophytes such as *Alternaria* and *Epicoccum* spp. inhibit the development of *M. nivale* on wheat and barley during germination and early growth (3). A recent study tested over 400 rhizosphere bacterial strains and identified an isolate that worked well against *M. nivale* in greenhouse tests; however, it was not effective in field trials (17). In another study, fluorescent pseudomonads suppressed this pathogen on turf (46).

Gray and speckled snow mold (T. incarnata and T. ishikariensis)

Some species of *Trichoderma* are antagonistic to oversummering sclerotia of *T. incarnata* and may reduce inoculum potential for gray snow mold. Sclerotial viability was greatly reduced after sclerotia were first incubated with *Trichoderma* cultures for 6 days, then surface disinfected and placed onto fresh media (16).

Typhula phacorrhiza (TP) was initially thought to be an unreported pathogen of turfgrass, but it was not pathogenic to creeping bentgrass in inoculated field tests. Instead, it suppressed the development of gray snow mold (8, 25, 27). In Japan, a TP-like fungus suppressed snow mold of perennial ryegrass (29). In Canada, TP isolates from corn residue varied in their ability to suppress gray snow mold in field tests over a 3-year period (52). There were positive correlations in performance of isolates across years and several isolates reduced gray snow mold as effectively as a fungicide treatment (52). In contrast, an isolate of TP that showed suppressive activity on creeping bentgrass was ineffective against gray or pink snow mold on winter wheat (24). This may have been a result of the inoculation method or differences in microenvironment between wheat and turfgrass.

One possible problem with the use of *T. phacorrhiza* as a biocontrol agent is its potential phytopathogenicity. Some *T. phacorrhiza* isolates were pathogenic on wheat in controlled environment and field studies (37, 38). Also, Millett (pers. comm., Univ. of Wisconsin) has found TP associated with large snow mold patches on golf courses. In other field tests, TP isolates were not pathogenic on a range of turfgrass species (51).

Acremonium boreale

This sclerotial low-temperature-tolerant fungus is widely distributed across Canada. It is an antagonist of other snow mold pathogens and is weakly parasitic on two grass species (40), but it did not suppress *M. nivale* or LTB in controlled environment trials (42).

Conclusions and Vision for the Future

In general, cultural techniques for snow mold management are only occasionally applicable to cereal production systems, but often are used for high value turf. This is due to the cost of these measures, and the often sporadic occurrence of the diseases that they are designed to manage. This pattern also applies to biological controls, which require inundative application at high rates to be effective. High rates mean high costs per hectare, which precludes the use of biocontrols on a field scale. For cereals, crop rotation provides an important exception to this pattern. Inclusion of spring annual/non-host crops in rotations results in a rapid reduction in disease potential, probably due to reduced inoculum density in soil, as well as changes in soil microbe populations.

Although new fungicides to control snow mold pathogens are still being brought into production, increasingly stringent requirements for environmental safety will continue to reduce the arsenal of fungicides available to crop and turf managers. Also, multiple applications (including different families of fungicides) are often required to provide reliable control. As a result, fungicide seed treatments to reduce seed-borne and early fall infection are commonly used in cereal production, and foliar fungicides are generally applied only to high-value turf. Loss of efficacy due to the development of fungicide resistance in pathogen populations is also a concern.

Breeding for snow mold resistance continues to be the main control strategy for winter cereals. Progress is being made in both identification of the genetic factors that control resistance

and in improved screening techniques to speed selection of resistant lines. Breeding for resistance appears feasible for turf grasses as well, but only a very few resistant cultivars have been developed.

Despite the fact that there are no commercial biological control agents available, biocontrol shows promise for the future, especially for use on high value turf. Biocontrol agents originally designed for such high-value applications may eventually be available for lower value agricultural systems as well. Although biocontrol agents and organic amendments show promise in reducing snow mold diseases, more research is needed before commercial products become available.

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