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Disease and Insect Management in Organic Small Grains

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Introduction

Organic winter wheat at the Quinn Farm, Big Sandy, MT. Photo: Susan Tallman, NCAT

Managing the complex biological system of an organic small grain farm can be a challenge, particularly in terms of disease and insect management.

Because synthetic fungicides and insecticides are generally not allowed in an organic system, prevention is the main strategy for avoiding pest problems. Successful prevention usually involves many different strategies in combination, rather than relying on a single one.

The purpose of this publication is to outline various strategies that make up a good organic disease and insect management plan, as well as to describe some specific diseases and insects that affect small grain crops. Although this publication pertains to various regions of the country, the main focus is on the Plains states—where most organic small grains are grown.

The National Organic Program Standards

The National Organic Program Regulations section § 205.206 specifies the crop pest, weed, and disease management practice standard as a hierarchy of practices (NOP, 2010). The foundation of any organic pest-management strategy is crop rotation, sanitation, and cultural practices such as variety selection.

The second tier in the hierarchy is mechanical and physical methods that may include introduction of natural predators, natural traps, and repellents, and development of habitat for natural enemies.

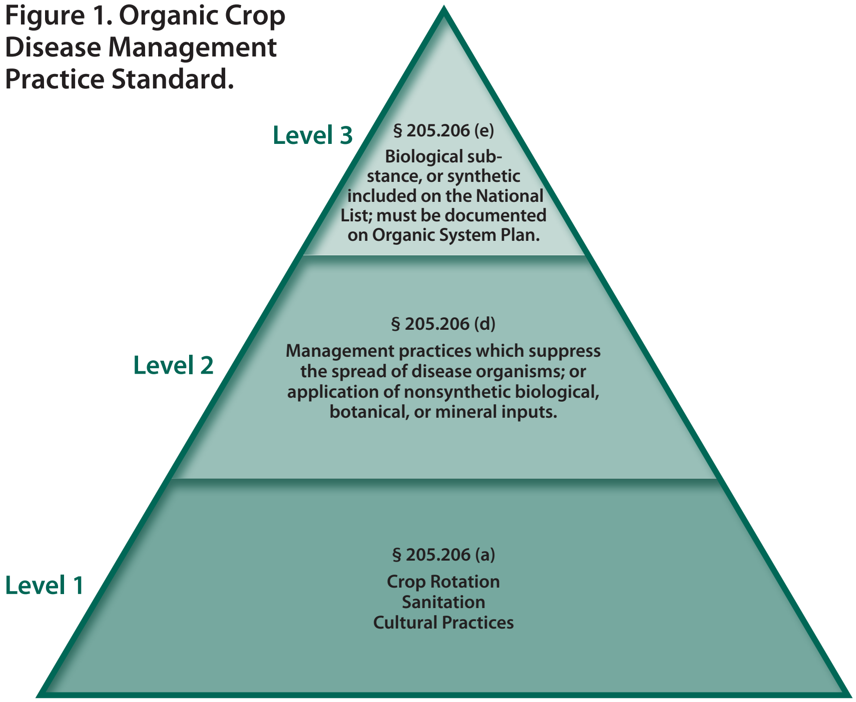
The third tier of the hierarchy is the use of biological or allowed synthetic substances for the control of pests. These methods are allowed only (and are most effective) when the foundational practices in the first and second tiers are in place. These third-tier measures are for use once a disease or pest is present, after the first levels of prevention strategies have failed. Understanding foundational biological principles, rather than simply substituting organic inputs for conventional ones, is a key to good organic management.

Disease Management

Climate and Location

Two important determining factors for disease development are climate and location. Areas with low humidity generally have much less disease pressure than areas with high humidity, since it usually takes six to 12 hours of continual leaf wetness for a fungal leaf disease to develop (Burrows, 2009). This probably explains why the Great Plains states are the top organic-grain-producing states in the nation. If you live in a region of the United States with high humidity and heavy disease pressure, you need to consider carefully whether organic small-grain production is right for you.

Figure 1. Organic Crop Disease Management Practice Standard.



Cultural Practices

There are several cultural practices to help prevent diseases, including variety selection, delayed planting, and irrigation timing.

Resistant Varieties

The first step in disease management is selecting a variety with disease resistance. Choose varieties that are specific to your area and that have been bred with resistance to local diseases. For example, stem rust is a common grain disease that can be managed by good variety selection. State Extension stations conduct annual variety trials that list the resistance levels of different varieties. Check their annual reports for recommendations.

While resistant varieties provide the first line of defense, there is no one variety of grain that is resistant to every disease. Prioritize your selection of resistant varieties by the diseases most common in your area.

Seed Quality

Find the plumpest, highest-germinating seed possible, and plant in high density to account for any loss of stand due to damping off. When possible, select Certified seed from a reputable dealer. Make sure the seed is a pure variety, and that you know what you are buying. In general, Certified seed should be purchased every third year. Regular use of Certified seed will help manage seed-borne diseases such as smut and bunt.

Certified Seed

The term "Certified seed" does not refer to certified organic. Rather, it denotes seed that is produced under conditions that assure its purity and vigor. "Certified seed is produced from foundation, registered, certified, or other approved seed stocks. This seed is two generations from foundation seed. Certified seed cannot be used to produce Certified seed again without the approval of the state certification agency, which can approve production only under extreme conditions" (Ulmer and Stuber, 1997).

Double-certified seed is seed that is considered both Certified (from Foundation seed) and certified organic. Currently, the chance of locating double-certified seed is very slim (Zwinger, 2009). However, the Organic Seed Alliance continues to work toward increasing the quality and amount of organic seed used in field crop production. Their website is *www.seedalliance.org*.

Further Resources

Selecting Quality Seed of Cereal Grains. 1990. NDSU Extension circular, A-500. J.L. Helm and L.A. Spilde.
www.ag.ndsu.edu/pubs/plantsci/smgrains/a500w.htm

Rotation

Rotation is another tool for disease management. Fungal diseases such as tan spot and Septoria survive on stalk residue. Fusarium head blight is also carried in the residue of wheat, barley, and corn. Moving to a legume or oilseed in rotation will help break this disease cycle. (For more information on designing an organic small grains crop rotation, consult the ATTRA publication *Organic Small Grain Production Overview*.)

Delayed Planting

Planting when soil temperatures are warmer can help manage soil-borne fungi such as Pythium and Rhizoctonia. Typically, these fungi are more of a problem in larger-seeded crops such as garbanzo beans and corn. However, if you have had problems with these diseases in the past, try delaying your spring planting until soil temperatures are warm enough to allow optimal seed germination and plant establishment (Burrows, 2009).

Irrigation Timing

If you are growing grains using irrigation, do not irrigate during the flowering stage. Flowering is the susceptible period for Fusarium head blight and ergot. If you are able to control timing of water application, do not water during this period.

Crop Scouting

Crop scouting is an essential part of disease management. The earlier you can detect diseases in the field, the more time you have to respond. Hone your skills in disease diagnosis. Local Extension agents often have identification guides available in print and online versions. Likewise, most land-grant universities have Extension pathologists on staff and diagnostic labs where growers can send any questionable plants for diagnosis.

If you discover a disease in your fields, there are several options. If the disease is not a serious problem for further infestation, or harmful for human or animal consumption, you may choose simply to live with the reduced yield. Another alternative is application of biological or allowed synthetic substances. Check the ATTRA Biorationals: Ecological Pest Management Database (*www.attra.ncat.org/attra-pub/biorationals/*) for allowed organic substances for specific diseases. Extreme cases may require terminating the affected portion of the crop before the disease gets out of hand.

Further Resources

Contact your local Natural Resource Conservation Service (NRCS) office for conservation planning and programs that offer assistance in implementing conservation practices. Assistance is available through the Environmental Quality Incentives Program (EQIP) for planning and implementing a wide range of conservation practices such as an Integrated Pest Management plan for organic production. Contact your local NRCS field office for information.

Storage Environment

Finally, manage for storage diseases in addition to in-crop diseases. Storage mold can be managed by constantly checking grain moisture during harvest. Hand-held grain moisture meters are available to purchase (Grey, 2009). Discontinue harvest when the grain moisture content exceeds 12%. If there is concern about the grain's moisture content, use aeration in the bin to dry the grain. High moisture levels and elevated bin temperatures lead to mold, grain deterioration, and insect infestation.

Further Resources

Grain Moisture Content Effects and Management. NDSU Extension publication AE-905 (Revised). 1995. Dr. Kenneth J. Hellevang, PE, Extension Agricultural Engineer. *www.ag.ndsu.edu/pubs/plantsci/crops/ae905w.htm*

Energy-Efficient Grain Drying Resources. ATTRA. *www.attra.ncat.org/attra-pub/graindrying.html*

Buckwheat Harvesting, Drying, and Storage. Dr. Bill Wilcke. *www.nysaes.cornell.edu/hort/faculty/bjorkman/buck/guide/dry.html*

Using Farm Moisture Testers. Iowa State Extension, PM-1633. 1995. Charles Hurburgh. *www.extension.iastate.edu/Publications/PM1633.pdf*

Specific Grain Diseases

Special thanks to Dr. Mary Burrows and Dr. Bill Grey of Montana State University for providing information on specific grain diseases and their management.

In addition to general cultural practices, there are some specific diseases of which organic small grain growers should be aware. Some are relatively harmless and will only slightly decrease yields. Others are more serious and can lead to crop failure or be detrimental to livestock and human health.

Proper identification of these serious diseases is important in order to decide the best management strategy. What to do with the crop will depend on weather conditions, the pathogen level, and the amount of susceptible host material. In most cases, the presence of disease will simply reduce the crop yield. In extreme cases, the diseased portion of the crop should be terminated to reduce potential infection of other areas.

It is difficult to make specific threshold and management recommendations for each disease within the scope of this publication. Land-grant universities often have plant pathology labs that will diagnose a disease and provide specific management recommendations. Contact your local Extension agent for more information.

> **Further Resources**
>
> Several websites offer forecasts for small grain disease incidence:
>
> **MoreCrop** is a website that predicts incidence of small grain diseases in the Pacific Northwest. *http://pnw-ag.wsu.edu/MoreCrop*
>
> **North Dakota State University Small Grain Disease Forecasting Model** *www.ag.ndsu.nodak.edu/cropdisease*

Tan Spot and Septoria

Tan spot and septoria are fungal leaf diseases that are widespread in wheat, but are not as serious as other diseases. These fungal pathogens survive on the infected residue of a previous wheat crop. In the spring, the fungal fruiting bodies will produce spores that infect the newly planted seedlings, thus perpetuating the disease cycle. Incorporating infected plant residue will reduce the spread of these diseases.

Tan spot on wheat. Photo: Dr. Mary Burrows, Montana State University, www.bugwood.org

Fungal leafspots affect grain yield by reducing the photosynthetic area of the plant, and are considered the "common cold" of small grains. In arid regions these diseases do not significantly decrease yield. And while they can decrease test weight, which may lower the price to the producer, they do not reduce end-use baking quality. Organic farmers may choose simply to live with these diseases and the accompanying yield loss, a decision that does not require further management (Grey, 2009).

> **Further Resources**
>
> **Fungal Leaf Spot Diseases of Wheat: Tan spot, *Stagonospora nodorum* blotch and *Septoria tritici* blotch.** NDSU Extension circular PP-1249. 2009. M. McMullen and T. Adhikari. *www.ag.ndsu.edu/pubs/plantsci/pests/pp1249w.htm*

Blotch

The blotch diseases are fungal leaf diseases similar to Tan Spot and Septoria, but they affect only barley. There are three blotch diseases to be aware of: Net Blotch, Spot Blotch, and the Spot Form of Net Blotch. Temperatures of 68° to 77°F and 100% relative humidity are ideal for spore production (Schwartz et al., 2009a). Spores are spread by wind and rain, with barley residue serving as the main source of infection for subsequent crops.

Organic control practices to prevent Net Blotch:

- Use resistant cultivars.
- Bury crop residue and destroy volunteers.
- Use balanced applications of nitrogen and phosphorus. Heavy nitrogen applications create conditions favorable to outbreaks of this disease.
- Follow a crop rotation that includes at least two years of non-susceptible hosts. Barley should not follow barley, particularly if disease levels were high the previous year.
- If barley must be grown in two successive years, use a susceptible cultivar the first year and a resistant type the second.
- Use pathogen-free seed if possible (Skoglund, 2010).

Scald

Like the blotch diseases, scald is a fungal leaf disease that mainly affects barley. Some resistant barley cultivars are available. Crop rotation and plowing under diseased barley residue seem to be the best methods of control for situations with high infestation (Maloy and Inglis, 1993).

Rust

There are three rust diseases of wheat in the United States: leaf (or brown) rust, stem (or black) rust, and stripe (or yellow) rust. These rusts have a long history in the cultivation of wheat and have been managed with the development of resistant varieties. However, according to North Dakota State University researchers, "The leaf rust pathogen is dynamic, and races are constantly changing. Varieties formerly considered resistant can become susceptible if new rust races develop. Resistance levels are updated each year for varieties" (McMullen et al., 2008a). For this reason, it's best to check variety resistance ratings each year before planting.

Rust spore infection is promoted by long periods of dew on the foliage. Therefore, high-humidity environments are more often affected by these diseases. Elemental sulfur or copper can be used to protect the flag leaf prior to infection or an anticipated rain, and as a last-ditch effort to reduce the impact of rust. However, surface protectants require multiple applications to be effective. Use of elemental sulfur in a wettable powder form is recommended. Elemental sulfur can also reduce powdery mildew (Grey, 2009).

Damping Off

Damping off can be caused by many different fungal pathogens that live in the soil. These include Pythium, Fusarium, and Rhizoctonia. Damping off causes seedling death and results in bare patches in the field. Wet, cool soil often provides ideal conditions for the development of damping-off pathogens. Delayed planting can help to avoid this situation (Schwartz et al., 2009b). Cultural controls for damping off: "Plant high quality seed in a firm, well-prepared seedbed at optimum pH, soil temperature, and fertility level for rapid germination and growth. Avoid compaction, poorly drained fields, and excess irrigation that can favor damping-off pathogens" (Schwartz et al., 2009b).

Rhizoctonia is often associated with continuous cereal production in no-till systems. Because tillage breaks up the underground fungal growth, this pathogen is not expected to be a problem in an organic system if crop rotation and later planting dates are used to allow the soil to warm before planting (Burrows, 2010).

The beneficial bacteria *Bacillus subtilis* is a biological agent registered for control of Fusarium, Pythium, and Rhizoctonia. *Bacillus subtilis* is sold under the trade name of Kodiak® and is approved for organic crop production (Schwartz et al., 2009b). Kodiak is applied as a seed treatment prior to planting. As with any input, always check with your organic certifier prior to application to ensure approval. For Kodiak label information, see the ATTRA Ecological Pest Management Database at *www.attra.ncat.org/attra-pub/biorationals*.

Fungal Root Diseases

Common fungal root diseases of small grains include Fusarium crown rot, common root rot, and take-all. While resistant varieties are available for Fusarium and common root rot, no wheat or barley varieties are resistant to take-all. Oats, corn, and broadleaf plants are resistant to take-all, however (Van Voast, 2009).

Organic management practices for prevention of these diseases:

- Plant varieties adapted to your geographic area.
- Use crop rotation.
- Plant into a firm, mellow seedbed. (Loose seedbeds promote disease.)
- Control weeds in summer-fallow land. (Weeds deplete soil moisture, and that predisposes plant roots to infection in the fall.)
- Always plant good-quality seed. (Bin-run seed is higher risk.)
- Plant at the recommended date for your geographic area. (Early planting or extended, warm fall weather promotes disease.)(Watkins and Burrows, 2009)

Fusarium Head Blight

Fusarium head blight (FHB), also known as scab, is a fungal disease that survives on the residue of wheat, barley, and corn. For this reason, rotation to a broadleaf crop can reduce the fungal inoculum and help to ensure it does not affect a subsequent crop. If FHB is a problem in your area, avoid planting adjacent to a field with wheat, barley, or corn residue (McMullen et al., 2008b).

A key diagnostic symptom of FHB is partial bleaching of the head, producing small, powdery white kernels called tombstones. If you find these kernels in harvested grain, or suspect you have FHB, make sure you have the grain tested for deoxynivalenol (DON). **If the test result is above the threshold of 1 ppm, do not sell the grain for human consumption.** Grain that tests above 5 ppm is not recommended as feed for non-ruminants or pregnant cows. FHB produces the DON vomitoxin, and it can cause illness if consumed.

Recent efforts by public and private breeding programs in variety development have proven effective in management of FHB in wheat (Burrows and Grey, 2008). Varieties with moderate resistance can limit crop failure. However, no resistance is available in barley varieties.

Further Resources

The **Wheat Fusarium Head Blight Prediction Center** is a joint effort of several universities to predict the incidence of Fusarium head blight.
www.wheatscab.psu.edu/index.html

Ergot

With the revival of cereal rye in organic systems as both a cash grain and a cover crop, ergot may become a greater problem. Ergot is a fungal disease that infects the flowers of cereal crops and produces ergot sclerotia in the heads. The ergot body becomes a contaminant of the harvested grain and spreads to new fields in seed. While the crop yield reduction can be from 5 to 10%, the main concern with ergot is the danger it poses to human and livestock health. The ergot fungus produces mycotoxins that cause miscarriage, convulsions, and in extreme cases, death.

Note: If you are growing cereal rye anywhere in your rotation, it is important that you have a clear, written contract with your buyer that documents their standards for ergot. If ergot is detected, some buyers may refuse to take the grain or severely dock the price. Make sure you understand your buyer's standards before planting this crop.

Because rye is an open-pollinated crop, it is more susceptible to ergot infection. However, "triticale, wheat, durum, barley, oat, quack grass, crested wheat grass, brome grass, foxtail, rye grass, orchard grass, timothy, wild rye, and other grasses serve as ergot hosts" (McMullen and Stoltenow, 2002).

Dr. Mary Burrows of Montana State University notes that ergot can also be a problem in grassy hay crops. One Montana farmer had a field in alfalfa for seven years, and then planted a crop of hay barley that experienced a significant ergot infestation.

Grain crops are susceptible to ergot infection at the flowering stage. Cool, wet weather that lengthens flowering will increase the possibility of an infection. The "honeydew" that forms on the heads contains spores of the fungus. This attracts insects that further spread the spores among the grain flowers.

To minimize ergot infestations, there are several techniques organic farmers can use.

- Rotate cereals and grasses with non-susceptible crops for one year or longer. The ergot sclerotia, or dark bodies, can survive in the soil for more than three years. Thereafter, summer fallow or crop rotation to a non-cereal crop for at least one year will help reduce ergot.
- Deep-plow fields that have a severe ergot infestation to bury the sclerotia. The ergot sclerotia are less likely to survive if buried more than 1 inch deep.
- Plant only ergot-free seed or Certified seed to avoid introducing or re-introducing the fungus into the crop.
- Eradicate or prevent wild grasses from setting seed in fields, rocklands, headlands, ditches, and fence rows. Mow wild and escaped grasses and pastures, or graze pastures before they flower, to prevent ergot infections.
- Resistant commercial varieties of wheat, barley, rye, and cultivated grasses are not available. However, some resistance differences among varieties may occur, and those with long flowering periods may be more frequently infected. Generally, grain crops that experience a long, cool period during flowering are highly susceptible. Avoid irrigation prior to and during the flowering period of grasses (McMullen and Stoltenow, 2002; Burrows, 2010).

Steve Zwinger at the North Dakota State University Experiment Station in Carrington reports they do have some minimal ergot in their organic grains. However, it has not been a problem for them and has always been under the allowed tolerances.

Further Resources

For more information on ergot, including its role in history, see The American Phytopathological Society website.
www.apsnet.org/education/lessonsPlantPath/ergot/default.htm

Smut and Bunt

Special thanks to Dr. Blair Goates, a smut and bunt expert at the USDA-ARS facility in Aberdeen, Idaho, for sharing information for this section.

Smuts and bunts are both soil-borne and seed-borne fungi that can severely damage yields. These diseases are of particular concern for organic grain farmers in the United States, since very few varieties have been bred with resistance. However, there are excellent dwarf bunt-resistant varieties available that are adapted to the winter wheat dryland farming areas of southern Idaho and northern Utah, and also a few soft white wheat varieties adapted to the Palouse region. The introduction of conventional seed-treatment fungicides has made the development of resistant varieties a low priority in breeding programs in the United States. In contrast, Canada and Europe both still breed some grain varieties with tolerance to these diseases.

External Spores

The smut and bunt diseases can basically be broken into two groups. In the first group, fungal spores occur on the exterior of the seed coat. This group includes common bunt of wheat, covered smut in barley, and loose smut in oats. These spores on the coating of the grain infect the plant after seeding but before emergence. **These diseases can be quite serious: common bunt can wipe out 60% to 70% of a crop.**

However, because these spores are on the exterior of the seed, some organic treatments show promise. Organic producers in Europe have had success with a product called "Tillecur." This is a commercially available treatment based on a formulation of mustard powder. Likewise, large-scale equipment used to treat seed with steam jets is also used in Europe. As of this writing (2010), no such treatment is available in the United States.

A beneficial fungus, *Muscodor albus*, has shown some promise in research trials. *M. albus* is an "endophytic fungus first isolated and described from the non-native cinnamon tree (*Cinnamomum zeylanicum*) in Honduras by Gary Strobel" at Montana State University (Biocontrol News and Information, 2008). When used as a fumigant, this fungus kills common bunt spores (Goates and Mercier, 2009). As of this writing, however, there is no commercial source of this product for seed treatments.

The beneficial bacteria *Bacillus subtilis* is a possible organic seed treatment for these diseases. *Bacillus subtilis* can be used to control storage fungi such as *Penicillium* and *Aspergillus* (Grey, 2009). *Bacillus subtilis* is sold under the trade name Kodiak and is approved for organic crop production. For Kodiak label information, see the ATTRA Biorationals database at *www.attra.ncat.org/attra-pub/biorationals.*

For producers with small amounts of seed, washing may be an option. Wash seed in hot water and then dry before planting. Or, wash with a dilute solution of bleach in hot water for even greater efficacy. Take care with any heat treatment of seed because excessive temperatures can kill the seed and decrease the germination rate.

In 1888, the Danish seedsman J.L Jensen proposed the following standards for hot water treatment of seeds. "Basically, this process involved soaking the seed for 110 minutes in water held at 118.4°F (48°C), or 95 minutes at 120.2°F (49°C)" (Mathre et al., 2006).

Trial and error may be needed if using the hot-water-wash method, as no recent standards are available for grains. Run a test batch of 100 kernels in various treatments and then test the germination of the seeds after the treatment.

While not specific to grain seeds, guidelines for using hot water wash for vegetable seeds are available from Ohio State University Extension, **Hot Water and Chlorine Treatment of Vegetable Seeds to Eradicate Bacterial Plant Pathogens**, Miller and Ivey, HYG-3085-05, *http://ohioline.osu.edu/hyg-fact/3000/3085.html*

Internal Spores

In the second group of smut and bunt diseases, the fungi are carried within the seed as dormant hyphae and not as spores on the seed surface. The most common disease in this category is loose smut of wheat and barley. Spores of these fungi infect the grain kernel at flowering. The fungus then moves into the embryo of the seed, and the infected seed cannot be distinguished from a healthy seed prior to planting. After planting, the fungus resumes its life cycle and maintains itself in the growing point of the plant, eventually infecting the developing grain head and converting it to a mass of spores (Cook and Veseth, 1991). For this type of disease, there are few organic options. Since the disease is inside the seed coat, an external treatment such as washing is ineffective.

Loose Smut on wheat. Photo: Donald Groth, Louisiana State University AgCenter, www.bugwood.org

The consolation is that this disease will not destroy an entire crop. A 15% yield loss would be considered unusually high for this disease, with 1% to 2% yield loss more common. Likewise, loose smut has little impact on end-use quality. If this disease appears, however, it is important that an organic farmer not save seed, but purchase seed from disease-free fields for the following crop year. Because loose smut is carried within the seed, identification of infection can be determined only by laboratory analysis. Even "[c]ertified seed is not guaranteed to be free of loose smut or other seed borne diseases" (Lipps, no date).

Smuts and bunts can cause severe crop loss. While some grain varieties in the United States have limited resistance to these diseases, this is due mainly to their flowering habit and less to breeding efforts. Organic seed treatments options are few, with field sanitation and crop rotation being the best practices to prevent infection. More research is needed in the area of successful organic small grain seed treatments for prevention of these diseases.

Further Resources

Organic Seed Treatments and Coatings. 2010. E. Gatch. *www.extension.org/article/18952*

Organic Seed-treatment as a Substitute for Chemical Seed-treatment to Control Common Bunt of Wheat. 2000. M. El-Naimi, H. Toubia-Rahme, and O. F. Mamluk. European Journal of Plant Pathology. 106:433-437.

Viral Diseases

Barley Yellow Dwarf Virus

Several grain diseases are viral and are carried by insects such as aphids and mites. One of these viral diseases is barley yellow dwarf (BYD), caused by Barley yellow dwarf virus (BYDV). Barley yellow dwarf is a misleading name, because it also can infect wheat, oats, rye, corn, sorghum, and more than 100 species of grasses (Montana State University Extension, 1998). BYDV is spread by more than 20 species of aphids. The aphids ingest the virus when feeding on infected plants and transmit the disease to subsequent plants while feeding on them (Wegulo, 2008).

Barley Yellow Dwarf Virus. Photo: Keith Weller, USDA-ARS, www.bugwood.org

Varieties resistant to BYDV are available. BYDV is most active in Washington, Oregon, and Idaho. In this region, it is crucial that organic growers plant barley varieties with resistance to BYDV.

Some Great Plains breeding programs have developed plant resistance in certain varieties. However, in Montana and North Dakota, BYDV is not a major concern in winter wheat since that crop is planted after a frost, which significantly reduces aphid populations. If trying to manage for BYDV in winter wheat, make sure to delay planting until cool fall nights arrive, generally after Labor Day, since aphids have little cold tolerance (Grey, 2009). Likewise, the northern states have a lesser problem with BYDV in spring-seeded wheat and barley since both crops are advanced in their growth stages before aphids migrate north.

Further Resources

For more information on management of Barley yellow dwarf virus, see:

Washington State University Bulletin
http://pnw-ag.wsu.edu/smallgrains/barley%20yellow%20dwarf.html

PennState Field Crop Disease Facts
http://extension.psu.edu/small-grains/documents/barley-yellow-dwarf.pdf

American Phytopathological Society
www.apsnet.org/edcenter/intropp/lessons/viruses/Pages/BarleyYelDwarf.aspx

Wheat Streak Mosaic Virus

Another serious viral disease is wheat streak mosaic, which is transmitted by the wheat curl mite, a tiny insect that is barely visible with the use of a hand lens. This disease is a bigger problem for the northern states than Barley yellow dwarf (McMullen, 2002). While wheat is the primary target of the mite, it will also feed on corn, barley, oats, and various native and weedy grasses. To date, there is no evidence that the mite transmits the virus to rye.

A main organic management strategy to break the life cycle of the wheat curl mite is to eliminate any "green bridges" near your grain fields. Green plant material serves as a host for the mite and the virus. While grassy weeds can serve this function, the real reservoir comes from in-field volunteer grains. Tillage will eliminate this threat. A long period of "brown out" in August, with no volunteer grain or early-seeded wheat, will reduce mite populations. For this reason, make sure that winter wheat seeding is late enough to discourage hosting the mite (McMullen, 2002).

Providing habitat for mite predators such as spiders and carabid beetles can also help prevent spread of the disease. Create a mulch of plant residue, such as a strip of mowed grass around the grain field, to create a habitat for these beneficials.

Further Resources on Spider Predation

Spider predation in agroecosystems: Can spiders effectively control pest populations? 2003. D. Maloney, F.A. Drummond, and R. Alford. University of Maine. Technical Bulletin 190. *www.umaine.edu/mafes/elec_pubs/techbulletins/tb190.pdf*

Further Resources

High Plains IPM website
http://wiki.bugwood.org/HPIPM:Main_Page

American Phytopathological Society
www.apsnet.org

Compendium of Wheat Diseases and Pests, Third Edition. 2010. APS Press.

Wheat Health Management. R.J. Cook and R.J. Veseth. 1991. APS Press.

North Carolina Organic Grain Project, Wheat and Small Grain Disease Management
www.organicgrains.ncsu.edu/pestmanagement/wheatdiseases.htm

Resource Guide for Organic Insect and Disease Management, Cornell University.
http://web.pppmb.cals.cornell.edu/resourceguide/index.php

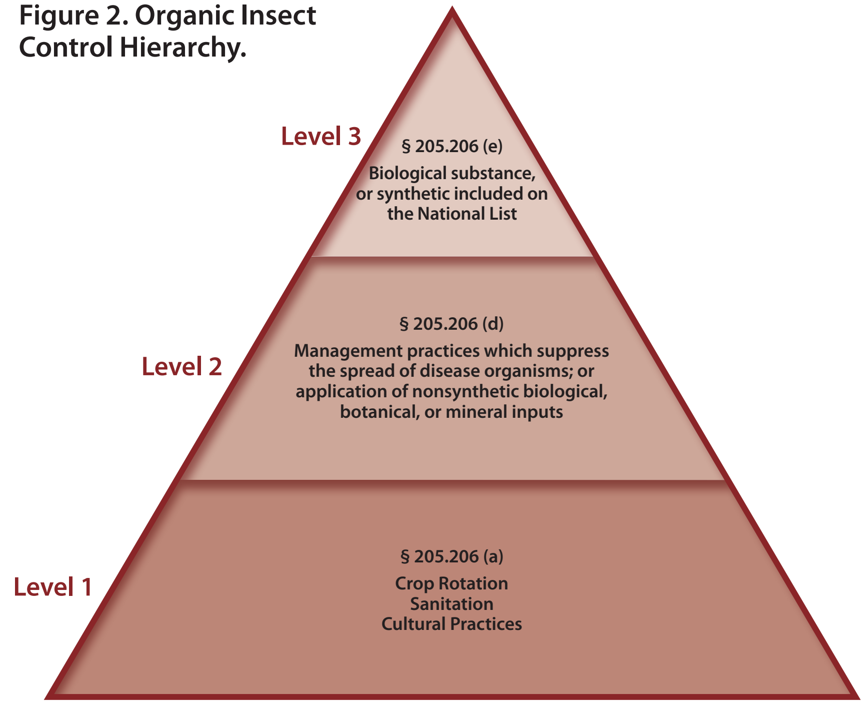
In-crop Insects

Management of insects within a growing crop can be a challenge since bugs can move from one spot to the next. However, there are some strategies to minimize in-crop insect damage. Similar to organic weed and disease management, organic insect management is based on the National Organic Program guidelines for pest management, section § 205.206. The foundational principles of cultural practices, rotation, and sanitation come first. Next are the second-tier strategies of predators, traps, and lures. And finally, biological and allowed synthetic substances can be used, provided the first two steps in the hierarchy are in place.

Cultural Practices

As with other organic pest-control strategies, prevention is more effective than cure. *Resistant varieties* can often help manage problem insects. For example, farmers are now able to reduce wheat stem sawfly damage by selecting resistant

Figure 2. Organic Insect Control Hierarchy.



varieties. Solid-stem varieties work the best, and local experiment stations should have records of varieties with the greatest resistance. However, these solid-stem varieties are primarily semi-dwarf, and semi-dwarf varieties may not be as competitive with weeds in an organic system. A farmer will need to select a variety based on his or her primary pest problem. If a diverse rotation is in place and wheat stem sawfly pressure is minimal, it may be more important to select a variety with quick, early growth to suppress weeds, rather than selecting a semi-dwarf variety with wheat stem sawfly resistance.

Diverse *crop rotation* can also help to break the insect cycle. Organic farmers tend to have fewer sawfly problems in general because of their crop rotation practices and the biodiversity inherent in organic production systems. Rotation to a less-preferred crop may also help to break the life cycle of cutworms and wireworms. Organic farmers also can benefit from surrounding monocultures that lure the key pests away. On the other hand, a neighboring monoculture may also be the source for recurrence of an insect pest problem.

To use *trap crops*, plant something on the border of your grain field that bugs like to eat and that stays green longer than the crop for harvest. After attracting the bugs into the trap crop, till it into the ground. Most bugs will not survive tillage. This practice can work well to manage edge-effect pests like the wheat stem sawfly that clearly prefer certain cultivars over others. Local experiment stations will be able to provide information on varieties and preferences of this pest (Morrill et al., 2002).

Specific In-crop Insect Pests

Grasshoppers

One of the oldest insect pests of grain crops is the grasshopper. This insect can be difficult to control with organic methods, because it can move from a control area to a non-control area and vice-versa. There has been some limited success with the use of *Nosema locustae*, a parasitic fungus that is combined with wheat bran bait for field use. Often, the results of Nosema are seen over several years of use, with mixed results when used on large areas (Cunningham and Sampson, 1996). Several brand names of Nosema are available and information about them can be found in the ATTRA Biorationals database (*www.attra.ncat.org/attra-pub/biorationals*).

Pest scouting is an essential part of using Nosema successfully. The most effective time to use it is when the grasshoppers are young (third instar stage). Usually, when you notice a large infestation, it is too late to use biological controls. Make sure you are watching for grasshoppers before they become a problem.

Mowing around grain fields may also help control grasshoppers. The shorter plants limit their food supply and make them more vulnerable to predators. The larger the field, the wider the mowed strip will need to be (Planet Natural, 2009).

Chickens are voracious grasshopper eaters, and on smaller acreages chickens may be an effective means of grasshopper control. However, chickens do require adequate water, housing, and protection from predators. Mobile chicken coops, sometimes called "chicken tractors," provide protection and shelter, and also allow for easy movement to different parts of a field.

Further Resources

CARMA stands for **Case-based Range Management Advisor**. It is a computer-based tool to help assess the economics of managing grasshopper infestations in rangeland. *www.sidney.ars.usda.gov/grasshopper/Support/Carma.htm*

USDA-APHIS Plant Protection and Quarantine offers several resources for grasshopper management, including an IPM handbook and an annual grasshopper hazard map for the western United States. *www.aphis.usda.gov/plant_health/plant_pest_info/grasshopper/index.shtml*

Russian Wheat Aphid

Another major in-crop insect pest for small grains is the Russian wheat aphid (RWA). The Russian wheat aphid affects grain by injecting a toxin that damages the plant, typically resulting in a white stripe running down the leaf blade. Several resistant varieties have been developed and are used extensively in Colorado, Kansas, and Texas, where warm temperatures allow for greater RWA survival. Most grain in Montana and North Dakota does not have this resistance. These states escape serious aphid infestation because their cold northern climates delay aphid migration, although climate change may affect this. University of California IPM Pest Management Guidelines point out, "Wheat and barley are the most susceptible; rye and triticale, while susceptible, are usually less damaged; and oats appear to sustain little or no injury. Russian wheat aphid does not attack corn, sorghum, or rice" (Summers et al., 2009). A diverse crop rotation can help minimize Russian wheat aphid damage across an entire farm.

Russian Wheat Aphid. Photo: Frank Peairs, Colorado State University, www.bugwood.org

Another management strategy for this pest is to control volunteer wheat and barley. According to the HighPlains IPM website, "Volunteers are the most important source of infestation for the new crop in the fall. Try to have a three-week volunteer-free period prior to emergence of fall seedlings." Winter grains should be planted as late as possible in Colorado, Nebraska, and Wyoming. Spring grains should be planted as early as possible (Peairs et al., 2010).

In addition, a healthy, stress-free crop is more likely to survive an aphid infestation. Make sure the field's nutrient levels are sufficient to produce a healthy stand (Peairs et al., 2010).

Wheat Stem Sawfly

The wheat stem sawfly has been a major in-crop pest in the Northern Great Plains since the early 1900s. Since then, various species of this insect have become a worldwide problem. The female sawfly lays one to two eggs per plant stem and can lay as many as 30 to 50 eggs in a season. After the eggs hatch, the larvae live inside the plant, causing damage by trapping nutrients and preventing grain heads from gaining weight.

Plant breeders have introduced solid-stemmed wheat varieties. While this has reduced the sawfly problem, it hasn't solved it completely. Even the most solid varieties can still experience some sawfly damage.

Dr. David Weaver, professor of entomology at Montana State University, gives the following principles for non-chemical management of wheat stem sawfly (2011):

- Leave the grain stalks as high as possible during harvest. Ideally, leave 1/3 of the stem height. This will conserve the naturally occurring Braconid parasitoid wasps that provide a control for the sawfly.
- Grow trap crops to protect hollow-stem spring wheat varieties. Winter wheat or a solid-stem spring wheat will work. Plant the trap crop between last year's wheat crop, which will be the source of new insects, and this year's wheat crop.
- Use a forage winter wheat variety as a trap crop. Hay the crop at the end of the sawfly flight period.
- Plant the most-solid-stem varieties. Check with a local Extension agent for this information.
- Include spring wheat crops in the rotation to increase parasitoid numbers.
- Grow non-host cereals or other alternate crops. Oats and smooth brome are examples of alternate non-host crops for sawfly. Sawfly cannot survive in oats, making it an excellent choice for crop rotation.

Integrating livestock into the system could provide an acceptable level of sawfly control. Dr. Pat Hatfield, livestock specialist at Montana State University, has achieved good sawfly control by using sheep to graze wheat stubble (Goosey et al., 2005). Sheep and goats were turned into summer fallow fields and consumed the sawfly larvae that live in the grain stubble. Consult with a livestock specialist for stocking rates and dates if considering this technique.

Stored-grain Insects

Insects are not only a problem while the crop is growing; they are also a concern during grain storage. The most common grain-storage insects are secondary insects that attack cracked and broken kernels in the grain bin, or kernels that are in poor condition or otherwise damaged (Canadian Grain Commission, 2009). These secondary pests include the rusty grain beetle, the hairy fungus beetle, the red flour beetle, and the foreign grain beetle.

The most damaging storage pests are insects that can chew directly into the grain. In the Northern Great Plains, these include the lesser grain borer and the rice and maize weevils. Of all of these pests, the only one that regularly overwinters in the North is the rusty grain beetle.

Further Resources

Stored Grain Pest Management. 2002. P. Sullivan. ATTRA.
www.attra.ncat.org/attra-pub/storedgrain.html

Storage Temperature

Special thanks to Dr. Paul Flinn, USDA-ARS Center for Grain and Animal Health Research, Manhattan, Kansas, for providing much of the information on storage temperature, sanitation, and beneficial insects.

The best technique for controlling insect pests is to control the storage temperature of the grain. The cooler the temperature, the less active the insects and the less likely they are to reproduce. Insect activity as it relates to temperature is given in the following table.

Table 1. Insect Activity at Various Temperature Ranges.

Temperature	Insect Activity
86°F (30°C)	Optimal temperature for insect activity
77°F (25°C)	Reproductive rate is cut in half
68°F (20°C)	Insects stop developing
50 – 59°F (10 – 15°C)	Activity stops

(Flinn, 2009)

Grain bins. Photo: Susan Tallman, NCAT

Cooling grain to below 68°F (20°C) minimizes insect activity. The usual way to do this is to run fans at night when the outside air is coolest. Install a thermostat on the fan, so that it does not operate in the daytime and circulate hotter air into the bin. Set the fan thermostat to 77°F (25°C). When the outdoor temperature drops to this level at night, the fan will start and the grain will begin to cool. It may take several weeks to cool the grain to 77°F. Then in September, cool the grain down to 68°F (20°C) as the nights cool off even more. Finally, cool the grain down to 59°F (15°C) and let it stay there the rest of the time it's in storage. It is very important to cool grain down as soon as possible so that the insects have less time to develop under warm, favorable conditions. These specific temperature points can vary in a colder environment that has later harvests, but the concept remains the same.

Some farmers do not use fans during a rain, fearing that this would increase humidity in the bins. However, as cool outside air is warmed by the grain, the relative humidity of the air decreases. Running the cooling fans during a rain event will not increase humidity in the bin if the outside temperature is less than 77°F (25°C).

Likewise, some farmers worry that running fans will dry out the grain and thus decrease its test weight. This is only a concern if the fans run both day and night and pull in high-temperature daytime air. If the fans run only when the air temperature is less than 77°F, loss of test weight (grain moisture) should not be a problem.

How long grain can be stored will depend on the location. In colder states such as Montana and North Dakota, grain can be stored for two to three years with no insect or mold problems if the grain is carefully monitored for changes in temperature and insect numbers. Farmers in warmer states such as Kansas and Oklahoma usually store grain over only one winter to avoid insect and mold problems. This issue of storage time affects a farmer's marketing plan, since some specialty organic grains can take more than a year after harvest to sell.

Further Resources

Questions and Answers about Aeration Controllers. Kansas State University Extension bulletin. *www.ksre.ksu.edu/library/grsci2/mf2090.pdf*

Sanitation

When placing organic grain in bins, make sure they have been thoroughly cleaned and that all cracks have been sealed. Also, never put new grain on top of old grain. Use smaller bins to reduce the risk of spreading insect or mold problems. The standard 3,000- to 5,000-bushel bins should be small enough, but avoid using the large 50,000-bushel bins. Air does not circulate well in these bins, and small infestations soon become very large problems. One infestation can ruin an entire crop if it's all in the same bin.

Beneficial Insects

In one research study, Hymenoptera wasps proved successful predators of the lesser grain borer and functioned well at the cooler temperatures so important to slow the activity of the pest insects (Flinn, 1998). In fact, these beneficial wasps provided a very high level of borer suppression (99%) at 25°C.

Bear in mind that some of these parasitic wasps occur naturally in stored grain. Any organic insecticide meant to control pests, such as diatomaceous earth, will also kill the beneficial

A parasitoid wasp for storage insects (Anisopteromalus Calandre). Photo: Dr. Paul Flinn, USDA-ARS

wasps. However, aeration to cool the grain will not kill the parasitic wasps but will help them to control the pests more effectively. A farmer must weigh the pros and cons of using controls, and establish a threshold tolerance for pests.

Further Resources

As of this writing, very few companies in the United States produce beneficial insects for stored grain insect control. One is **Biofac Crop Care** in Mathis, Texas. Contact them at their website *www.biofac.com*, or toll-free at 1-800-233-4914.

Diatomaceous Earth

Special thanks to Dr. David Weaver, Montana State University, for providing information on Diatomaceous earth.

Diatomaceous earth (DE) can be used to control storage insects. DE works by clinging to insects and adsorbing their protective surface-wax, allowing moisture to escape, and drying them to death. It works better at higher temperatures because then insects are more active. DE may be a good option in warmer regions, where cooler nights do not arrive until several weeks after harvest. DE also works better in dry conditions, since it loses activity when it contacts water. A state with a hot, dry climate, such as Arizona, might be an ideal place to use DE.

DE is made of fossilized marine diatoms and is composed primarily of silicon dioxide with some calcium. There are different kinds of DE—freshwater and saltwater—with different characteristics. For a complete listing of various trade names of DE, check the ATTRA Biorationals database at *www.attra.ncat.org/attra-pub/biorationals/*.

Use Certified Organic DE

When using DE, be aware that not all products are certified for organic use. Some DE products may contain fillers or additives that are not allowed under organic standards. Make sure you document which DE product you use, and verify that it is allowed in organic production. Contact your certifier if you have any questions.

The activity of DE varies with insect species. It doesn't work very well on the red flour beetle, but other insects are quite vulnerable to it. Experts are not sure why the effectiveness differs by insect species.

DE may affect grain quality by decreasing the test weight. Also, it slows down the flow of grain in handling systems. It is easily digestible by humans and will not affect the end-use quality of the grain for baking purposes. In a lab analysis of flour, DE would show up as ash content.

The particle size of DE is similar to talcum powder. Take care when using it, and wear a respirator to limit inhalation. DE does disperse in handling and can be blown out of the grain when it is loaded from the bin, if desired.

There are two recommended ways to use DE in storage: the incorporation method and the sandwich method.

Incorporation Method

Of the two methods, incorporation is most effective. To use this method, mix DE into the entire bulk of the grain stored. This may not be necessary, or desirable, if the expected insect pressure does not warrant such heavy use.

The best way to mix in the DE is to apply a layer on top of the grain in the truck, prior to loading in the bin. Cut it in with a shovel before unloading, then auger the grain into the bin. Mix in the exact recommended amount of DE for the number of bushels in the truck. To determine the rate of application, check the listing on the packaging.

Another alternative is to stand at the auger and throw in a bit of DE every so often. This is less accurate and can lead to patchy application, especially if the person doing the job becomes distracted.

Sandwich Method

The sandwich method can cut costs and will affect the test weight less than the incorporation method. In this method, add DE to the first load of grain into the bin at the recommended rate. For the middle loads, do not add any DE. For the last two loads, add DE again at the recommended rate. Then add 6 inches of DE at the top of the bin.

DE can also be used in an empty bin to get rid of residual bugs. Use the bin dryer to blow it around. Or use a special applicator to apply DE directly to the bin surface.

Spinosad

A final product that has gained some interest for grain storage is spinosad. One formulation of spinosad is the by-product of bacterial fermentation and is allowed for use in organic systems. It has proven effective in managing insects in stored grain (Bhadriraju, 2009). As of this writing, however, Spinosad is not labeled in the United States to control stored grain pests, as some countries will not accept spinosad-treated grain under international Codex tolerances. The manufacturer is waiting for trade negotiations to be completed before labeling the product as acceptable for use on stored grain.

The 2010 Organic Materials Review Institute (OMRI) Generic Materials List shows spinosad is an allowed nonsynthetic with restrictions. It can be used as a pest lure, repellent, or trap, and as an insecticide if the criteria of the pest management rule are met. Since there is some gray area on the of use of spinosad in stored grain, it is best to check with your organic certifier before using.

However, spinosad is accepted to treat in-crop insect pests. To date, most use of spinosad is in vegetable systems. An Ohio State University Extension publication gives information on recommended application of spinosad for control of armyworm and cereal leaf beetle at *www.entomology.osu.edu/ag/images/Small_Grains.pdf.*

There are several formulations of spinosad on the market; some are organic and some are not. Make sure you choose the correct one for application in an organic system. For more information, see the ATTRA Biorationals database at *www.attra.ncat.org/attra-pub/biorationals/*.

Conclusion

When managing diseases and insects in an organic system, prevention is truly the best strategy. Many of the foundational practices of organic production, especially crop rotation, help to minimize pest pressure and promote biological diversity that suppresses pests. A farmer must stay ahead of outbreaks by implementing a long, diverse rotation, practicing vigilant monitoring, selecting resistant varieties, and being attentive to management strategies.

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