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A review of agronomic management strategies for fusarium head blight. (Pre print version)

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STRATEGIES FOR MANAGING FHB IN WESTERN CANADA

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A Review of Literature

July 1, 2011 estimates of crop production show winter, durum and spring wheat to grow on 8,752,200 hectares in Canada, with just over 50% of that being grown in Saskatchewan. {{1386 Anonymous 1998-}} Recent research conducted in crop production revealed that a large portion of these crops was infected with a fungal disease which is known as Fusarium Head Blight (FHB). FHB is considered to be the most important disease of wheat, and, as of 2007, was responsible for over $1 Billion in losses in Canada. The disease is also found on barley and oats. {{1367 Xue, A. 2007}} Extensive research has been, and is being done on this disease. A literature review of major databases (Scopus, Science Direct, Agricola, Bio One Abstracts, ISI Web of Knowledge and more) reveals an extensive list of over 800 scholarly articles on managing this disease.

In Saskatchewan, surveys have shown evidence that F. graminearum, a more aggressive form of Fusarium, is heading west through the Prairie Provinces. F. graminearum is only one of many Fusarium species, however, it is considered the most important one in Canada due to its impact on grain yield and quality, ability to produce different toxins and its abundance in Western Canada. The other 3 species in North America that can cause FHB are F. culmorum, F. avenaceum and F. crookwellense. {{1364 Clear, R. 2010}} Like with other crop diseases, there is yield loss, however, FHB also produces mycotoxins (one of which is deoxynivalenol, or DON) which should not be consumed by livestock or humans. It is believed that infection with the fungi is associated with rainfall during the flowering stage. The infection spreads by wind, but the pathogen is also spread by planting infected seed. Also, Fusarium head blight thrives in hot and wet environments, thus, in a particularly wet season, as it was in 2010 in Saskatchewan, high levels of FHB appeared. (Irrigation Crop Diversification Corporation (ICDC), 2011.)

Some crops are more susceptible to FHB than others. Below is a chart showing the most susceptible to the least.

Figure 1

{{1369 Anonymous 2011}} A list of the Fusarium susceptibility ratings for wheat varieties is available in Appendix A: *Fusarium susceptibility ratings for wheat varieties.*

Saskatchewan Agriculture suggests some agronomic management strategies for FHB. These include: utilizing high quality clean seed; seed treatment; crop rotation; stubble management; and variety selection. However, research must continue in order to make management more effective.

This report reviews up to date research by highlighting modern management of FHB, with a special focus on agronomic management practices suited to Western Canada. These are broken down into: fungicide control research; bio control research; crop residue research; and other emerging strategies. The end of the report highlights major research groups/ conferences focused on FHB.

Fungicide control research

Fungicides are chemicals used to kill/inhibit fungi or fungal spores. Fungicide performance is affected by fungicide type, crop variety, application quality and application timing. (Ouellet & Leger, 2011) Research published in 2011 looked at the economics of using fungicide to control foliar fungal disease in winter wheat. This research took place in the Central Great Plains USA and included eight field trials over two years. The results showed that foliar fungicide application to winter wheat could be profitable when there is moderate to high levels of disease (including FHB), however, net losses could occur in years with low disease severity. (Wegulo, Zwingman, Breathnach, & Baenziger, 2011) This is important for farmers as other management strategies, such as risk forecasting, that may impact crop performance.

Aerial application

Farmers may prefer aerial treatment over ground (the following section) as aerial can be done when fields are wet. Large amounts can be sprayed in a short time period and there are no tracks left on the field like there are from ground application. Traditional methods for aerial fungicide application resulted in poor control of FHB. The most important site of infection of the wheat (grain head) and barley (grain head) needed to be covered by the fungicide. The North Dakota State University has these recommendations:

- Produce a 'large fine' to 'small medium' sized spray drop (300-350 microns).
- Minimum spray operating pressure should be 30 psi.
- Operate smaller and slower aircraft at a height of 8 to 10 feet above the surface, and a heavier aircraft at 10 to 12 feet.
- Apply the fungicide at 5 gallons per acre.
- Mount the spray nozzles so they do not exceed more than 70 percent of the wing span. Nozzles mounted over 65 percent of the wing span are preferred.
- Produce a uniform spray pattern with tapered edges.
- Most aircraft use uniform nozzle spacing except in the center. Nozzles in the centre of the aircraft should have spacing at least double to those mounted on the wings.
- Mount the spray nozzles as low as possible below the wing. This helps discharge spray into air with the least amount of turbulence. Turbulence causes spray drop breakup and spray drift. (Hofman et al., 2007)

Ground Application

North Dakota State University has recommendations for ground application of fungicide:

- Produce a fine to medium sized drop (300-350 microns) with an 80 degree flat fan nozzle.

- Angle all (flat fan) nozzles forward 30-45 degrees down from horizontal. Thirty degrees is preferred over 45 degrees.
- Apply fungicide at 10 gallons per acre for controlling FHB.
- Position angled spray nozzles 8-10 inches above the grain heads.
- Fungicide should be applied to the sides of the grain head. (Halley et al., 2008)

Time of application

The time of application is important. The list below has recommendations on fungicide timing for various crops.

Hard red spring wheat: should be sprayed during early flowering.

Durum wheat: should be sprayed at early flowering and possibly slightly later due to a long window of vulnerability (from early flowering to kernel watery ripe stage).

Spring barley: should be sprayed at early full head emergence and later application may be successful. (US Wheat and Barley Scab Initiative, 2011)

Barley: the ideal time to spray barley is at early, full head emergence. {{1376 Hofman, V. 2000}}

Seed treatment

Fungicidal seed treatments are used to control: soil borne fungal disease organisms (pathogens); fungal pathogens that are surface-borne on the seed; and internally seed-borne fungal pathogens. Farmers are concerned about planting seed infected with Fusarium in areas which have been affected by FHB. Research published in 2010 looked at 12 combinations of fungicidal seed treatments in wheat and barley fields in Saskatchewan. They found that these treatments did not consistently improve the agronomic performance of F. graminearum infected crops as the seed treatment did not significantly affect grain yield directly. Their results indicated that if a F. graminearum infected seed survives germination and emergence, it should develop and produce grain similar to uninfected seeds. (May, Fernandez, & Lafond, 2010) The US Wheat and Barley Scab Initiative (USWBSI) recommends using fungicidal seed treatment, however, it also mentions that this will not rescue poor quality seed or guarantee absence of FHB scab the following year. (US Wheat and Barley Scab Initiative, 2011)

Fungicide Varieties

Strobilurin fungicides were introduced as broad spectrum fungicides in many countries in the 1990's. These fungicides are widely used and are effective against diseases such as STB, powdery mildew and rusts. However, Strobilurin fungicides have been shown to be ineffective against FHB. {{1318 Blandino, Massimo 2009}} In Canada, fungicides are registered with the Pest Management Regulatory Agency (PMRA), under Health Canada. Of all the varieties of fungicides available to producers (triazole, imidazole or triazolinthione active ingredients which inhibit the biosynthesis of ergosterol) have proven to be the most effective against FHB infection and DON contamination. {{1318 Blandino,Massimo 2009}} In 2007, tebuconazole (a triazole) was the only fungicide registered for the control of FHB in Canada. {{1367 Xue, A. 2007}} Although more have been added, current fungicide options are still mainly limited to the triazole family of fungicide. The North Central Regional Committee on Management of Small Grain Diseases (NCERA-184) produces an annual list of fungicide efficacy for control of wheat diseases in the USA. In the chart below, Caramba, Proline, and Prosaro were listed in 2008 as good / very good efficacy against FHB. In the 2011 chart, these three were listed with good efficacy. (NCERA-184, 2011)

The following table lists products currently available for FHB suppression (data derived from the North Central Regional Committee (NCERA-184) of Small Grain Pathologists).

Fungicide[1]	Product names	Rate/A fl oz/A	Head Scab efficacy	Preharvest interval
Metconazole	Caramba	10.0 – 17.0	G[2] (VG)[2,3]	30 days
Propiconazole	Tilt, PropiMax, others	4.0	P[2]	40 days
Prothioconazole	Proline	5.0 – 5.7	G[2] (VG)[2,3]	30 days (32 for barley)
Prothioconazole + Tebuconazole	Prosaro	6.5	VG[2]	30 days
Tebuconazole	Folicur, Embrace, Onset, Orius, Monsoon, TebuStar, Tergol, Toledo, others	4.0	F[2]	30 days

(US Wheat and Barley Scab Initiative, 2011)

Below is a list of the major fungicides used for FHB control available in Canada.

- Prosaro is a mixture of tebuconazole and prothoconazole. This combination was mentioned at the European Fusarium Seminar in 2010. (11th European Fusarium Seminar. 2010). Recently, Prosaro has been launched in Canada by Bayer and is available for the 2011 growing season.
- Proline is also made by Bayer and contains the active ingredient: prothioconazole. It can be used on several crops including flax, lentils, barley, canola and wheat. It is available in Canada as of 2010.
- Caramba and Metconazole Fungicide Technical are triazole fungicides made by BASF that contain metconazole. They can be used on barley, oats, rye, sugarbeets, triticale and wheat. Health Canada granted these fungicides registration in July 2011. The international producer

is Kureha Corp, who supplies the active ingredient metaconazole. Note that V-10116 is also a metconazole and is mentioned below.

- Folicur is also made by Bayer and was the original fungicide registered to protect against FHB. It is registered for use in Canada and contains tebuconazole.
- JAU6476 is a seed treatment containing prothioconazole. As of July 29, 2011, it was proposed for full registration by Health Canada.

Taking a look at the practical application of these fungicides, in 2010 the annual summary from the US Wheat and Barley Scab Initiative stated that several growers in the USA applied fungicides Prosaro, Caramba and Proline to their wheat fields. Some growers reported success at reducing the FHB symptoms, however, others found that, despite using Prosaro and Caramba, they had losses from DON. (Lilleboe, 2010) The Saskatchewan Ministry of Agriculture published a report in 2011, based on a project with industry, which demonstrated efficacy of fungicide application to control FHB. They tested Caramba, Folicur, Proline and Prosaro. Of these, Prosaro, Proline and Folicur demonstrated yield benefit, while Caramba did not. Of the three with positive results, Prosaro had the greatest benefit in all demonstration sites. There was more benefit seen in test sites with durum and soft white wheat than the hard wheat sites. Report concluded that fungicide application was profitable for irrigated Durum and Soft White Wheat producers but producers should examine the economics before applying fungicide to hard wheat. (Irrigation Crop Diversification Corporation (ICDC), 2011.) US Wheat and Barley Scab Initiative (USWBSI) research from 2004 in Minnesota found Folicur, V-10116 6 fl oz and JAU6476 to improve control of FHB, preserve grain yield and quality in hard red spring wheat. (Hollingsworth & Motteberg, 2005)

New Fungicides / not available in Canada

A study conducted in China looked at four modern fungicide effects on winter wheat: JS399-19 and azoxystrobin (a strobilurin) are considered potential fungicides for control of FHB; while tebuconazole and carbendazim are currently widely used for controlling FHB in China. (Zhang, Zhang, Chen, Zhou, & Wang, 2010) The study indicated that FHB disease was low during the tests, however, the fungicides: JS399-19; tebuconazole; and carbendazim; did reduce FHB severity compared to the control. FHB levels in wheat treated with azoxystrobin did not differ from the control. (Zhang et al., 2010) Other research on JS399-19 was done, testing its antifungal properties against twelve pathogens. In these tests, JS399-19 was shown to strongly inhibit growth of Fusarium and authors recommended its use in the field. (Li et al., 2008) JS399-19 is available in China and is a cyanoacrylate, however, it was not found on Health Canada's PMRA website. Carbendazim has been registered with Health Canada as a fungicide to control Dutch elm disease but it does not mention fusarium. The Canadian supplier of Carbendazim is Pilar Agriscience Canada Corp.

Integration

Because there is no fully effective fungicide treatment, it is suggested that fungicide application be integrated with other FHB management tools. (Ouellet & Leger, 2011)

Fungicide with Fertilizer

Recently, the addition of a foliar nitrogen fertilizer to a fungicide application has become widely used as it was found to increase grain yield and quality. {{1362 Gooding,M.J. 2007}} To see if this combination could affect FHB, researchers in Northern Italy evaluated the effect of fungicides and foliar nitrogen fertilizer application on durum wheat. Five combinations of foliar application were compared at each site/ year: untreated; azole fungicide at heading; strobilurin fungicide at stemlongation stage and/or at heading; and addition of a foliar N fertilizer to a fungicide programme. The double treatment with stobilurin application during stem elongation state and azole at heading appeared to be an essential practice and showed advantages including FHB control and reduced DON contamination, as compared to the untreated group. Other foliar treatments at heading, such as strobilurin or foliar N fertilizer application, did not seem to provide any advantage. (Blandino, Pilati, & Reyneri, 2009) The authors indicated that work needs to be done at the beginning of wheat cultivation, such as: avoiding cereal succession; incorporating the previous crop residues; and using a resistant cultivar to aid in reducing FHB. Similar research on the combination of fertilizer and fungicide found that Fusarium severity was lower when no fungicides were applied. Nitrogen fertilization significantly increased FHB severity in 2001, but had no effect in 2002. The dry weather in 2001 explained that the N in the soil was not as distributed. Their research concluded that farmers might choose to use less fungicide to control Fusarium spp. However this should be done together with a moderate reduction in N- fertilization. {{1370 Heier, T. 2005}}

Insecticide and Fungicide

As previously mentioned, there is a link between organisms and plant diseases as organisms that bore into plant tissue make a way for fungal pathogens to enter. Integrated management is based on the knowledge that there are several factors that can impact plant health and that these factors can often affect each other. Field trials in France from 2004-2006 studied the control of Lepidoptera caterpillars by agrochemical treatment and the consequences on Fusarium spp, mycoflora and mycotoxin in maize fields. Treatment included either insecticide or insecticide – fungicide association. The insects were controlled by the agrochemicals. The Fusarium microflora was not reduced, however, Fusarium mycotoxin levels in maize kernels were reduced from the insecticide treatment. The addition of fungicide did not show any reduction in Fusarium mycotoxin levels. (Folcher et al., 2009)

Fungicide with Cultivar

A research in Hungary was presented on resistance and chemical control of FHB in wheat. Presenting scientists indicated that most new cultivars were just as susceptible as before, and that fungicides had low efficacy. However, a new fungicide (prothioconazole) and a better spraying technology was introduced which could reduce DON more effectively. (11th European Fusarium Seminar. 2010) The authors stated that more resistant cultivars would respond better to fungicide. Combining better cultivars with new fungicide and techniques might also provide a better outlook than before.

Biocontrol research

The second management technique current research focuses is biocontrol, or biological management solutions. Globally, traditional pesticide use is on the decline, while bio-pesticide usage has increased annually. (Bailey, Boyetchko, & Laengle, 2010) This is in response to high economic and environmental costs of chemical fungicides. Major pesticide companies such as Bayer, BASF and Monsanto have entered into the biopesticide market. Biopesticides are also registered through Health Canada's PMRA.

Fungus

At the 6th Canadian Workshop on FHB, a presentation from researchers at the University of Saskatchewan outlined utilizing fungi to counteract FHB. The researchers found that optimal biocontrol was seen with fusarium specific mycoparasites while bioprotection depended mostly on plant-specific endophytes of wheat and barley. (Ouellet & Leger, 2011) Researchers in Ontario studied *Clonostachys rosea*, a fungus (fungal strain ACM941) which can fight FHB. Testing against a fungicide (Folicur), they found that this fungus performed better than the fungicide on the FHB in corn, soybean and wheat residues. {{1367 Xue, A. 2007}} Trichoderma sp. was found to reduce FHB severity by up to 25% in one study, however, Folicur preformed better, reducing disease severity by up to 47%. Other, less effective fungi included Epicoccum and Alternaria sp. {{1371 Riungu,G.M. 2008}} In Saskatchewan, Dr. Vladimir Vujanovic has been working on biocontrol of FHB, using a species of fungus native to Saskatchewan, Sphaerodes mycoparasitica. Research is leading to a biopesticide created with this fungus. (Vujanovic & Goh, 2009) (King, 2006) Only one product was registered with Health Canada containing an above mentioned fungus. RootShield Biological Fungicide, Trichoderma harzianum Rifai strain KRL-AG2: this is registered with Health Canada as a biological fungicide which protects against disease causing fungal pathogens, including fusarium in soybeans.

Bacteria

Soil bacteria, such as pseudomonads, can reduce pathogen pressure for plants. This is done by activating plant defense mechanisms and by inhibiting pathogens due to the production of antibiotics. {{1368 Henkes, G.J. 2011}} Recent research showed that Pseudomonas fluorescens CHA0 can prevent diversion of carbon and prevent the reduction of plant biomass in response to F. graminearum infection in barley. The results suggested that activation of plant defenses is a central feature of biocontrol bacteria, and may even surpass the effects of direct pathogen inhibition. {{1368 Henkes, G.J. 2011}} *Pseudomonas fluorescens* Strain A506 and Blightban A506 is a product registered through Health Canada. It contains the technical grade active ingredient *Pseudomonas fluorescens* strain A506, to control fire blight on apples and pears. There was no mention of this being registered to fight FHB.

At the 11th European conference for FHB, Bacon, Hinton, and Snook presented on using Bacillus mojavensis as a biocontrol agent for Fusarium verticillioides. They found that this bacterium had the potential to antagonize Fusarium in maize, reducing its ability to produce toxic fumonisins. (11th European Fusarium Seminar. 2010) Research in 2007 by Bacon and Hinton using Bacillus mojavensis showed that several strains of this bacterium were antagonistic to F. graminearum and F. verticilloides. {{1372 Bacon,C.W. 2007}} Other Bacillus species have also been investigated as possible biocontrol agents. {{1371 Riungu,G.M. 2008}} Pediococcus Pentosaceus, another type of bacteria reviewed at the conference, was found to repress the growth of Fusarium proliferatum and verticillioides. (11th European Fusarium Seminar. 2010)

Vujanovic, of Saskatchewan, researched biological stressors of F. graminearum and F. sporotrichioides: Bacillus amyloliquefaciens and mycoparasitic Acremonium strictum. These biotic antagonists were found to stress the Fusarium and impact its survival. (Goh, Daida, & Vujanovic, 2009) Bacillus amyloliquefaciens was also presented at the National Fusarium Head Blight Forum in 2010 as an option for FHB reduction. Research found that this biological control had better results in the greenhouse than on the field and did not uncover significant reduction of FHB or DON on the field trials. (Crane, Gibson, & Bergstrom, 2010). Despite this research, only one biological fungicide was found on the Health Canada database. Bacillus subtilis strain MBI 600 (Integral Liquid Biological Fungicide) was registered in 2010 by Health Canada as a microbial pest control agent. This strain is used as a seed treatment for disease in canola including Fusarium spp.

Yeast is also being tested as a biocontrol agent. Research found that combining Prosaro with a double yeast treatment significantly decreased DON, when comparing to treatment with Bacillus amyloloquefaciens and Prosaro. (Yuen et al., 2010) Research has shown that, often, biocontrol agents work more effectively in laboratory conditions than in real life. Things such as competition for nutrients, water availability and more, can stress the biocontrol agents. Therefore, work is being done on physiological improvements to biocontrol agents that can improve their effectiveness against Fusarium infection. Some results of this research showed that physiologically modified strains of B. subtilis RC218 and Brevibacillus sp. RC 263 were effective biocontrol agents. {{1379 Palazzini,J.M. 2009}}

OTHER BIO-CONTROL AGENTS

Sometimes, controlling other pests in crops can influence the amount of FHB. It has been found that insect damage of maize is a good predictor of Fusarium mycotoxins contamination. Insects can carry spores of mycotins producing fungi and bring the fungi into the plant. Management of these pests can help control FHB. (Wagacha & Muthomi, 2008)

CROP RESIDUE CONTROL RESEARCH

Crop residue is material left on the ground after the crop has been harvested. These residues can be dangerous in the context of plant disease as contamination of the next year’s crop can occur from residue. Maize is a plant most susceptible to contamination by Fusarium and studying it can potentially contribute to the development of defense strategies for wheat and barley. Spores released from the fungus can settle in the soil and grow on plant residues. This contaminates the next crop grown. (Jouany, 2007) Thus, it was recommended early into the research to perform crop rotation and tillage to reduce FHB. Later on, research revealed that crop rotation depended on which crops were used in rotation, and that minimum tillage instead of plowing actually increased DON (deoxynivalenol, a mycotoxin produced from Fusarium) content in the following wheat crop. (Jouany, 2007) Crop residue research has evolved and became more complicated as FHB levels depend on so many factors.

Previous Crop

Research in 2008 looked at maize residue effects on FHB in wheat. It was found that tillage was not a significant factor but the residues of the previous plant played a major role in Fusarium infection and DON contamination. (Maiorano, Blandino, Reyneri, & Vanara, 2008) Researchers concluded that if wheat is grown after maize, it is, on average, more contaminated than wheat grown after other crops. This is due to the larger amount of residues that maize leaves on the soil. The researchers advised that agricultural practices which can reduce the amount of previous crop debris (such as stalk bailing) or that can move the residues deeper (such as plowing) can be effective agronomic choices where wheat is rotated with maize. (Maiorano et al., 2008)

Over a two year period, a German research group studied DON content in winter wheat looking at environmental, topographic, and management factors (tillage, preceding crop and susceptibility ranking) of wheat cultivars to Fusarium spp. Their model indicated that DON on wheat fields, with maize as the preceding crop, was one order of magnitude higher than wheat grown after oilseed rape. It was also established that plowing significantly reduced DON by more than one order of magnitude. The research showed that humid areas had higher DON content than dry. Also, hilltops showed lower levels of DON. The susceptibility ranking did not have a significant influence on DON. Overall, a combination of climatic, topographic and crop management factors effected DON concentration on winter wheat. (Müller, Brenning, Verch, Koszinski, & Sommer, 2010) The USWBSI website recommended rotation with broad leaf crops such as soybean, sunflower or canola to reduce FHB. In areas where the rate of reside decomposition is high a single year rotation may be enough, however, three years or more may be necessary in other areas(US Wheat and Barley Scab Initiative, 2011).

Previous Herbicide Use

Glyphosate is a broad spectrum systemic herbicide used to kill weeds. It has been established that previous glyphosate use could increase levels of Fusarium populations. {{1374 Kawate,M.K. 1997}} , {{1375 Sanogo,S. 2001}} Looking specifically at the crops grown in Western Canada, a multi-year field study in Saskatchewan showed a relationship between previous glysophate use and increased Fusarium colonization in wheat and barley. {{1231 Fernandez,M.R. 2009}}

Tillage

Tillage buries infested residues and helps to reduce disease carryover. In Saskatchewan, some of the leading research on FHB in wheat and barley has come from Fernandez et al. The researchers asserted that crop residues were an important source of inoculums, and therefore, it was important to understand the ability of Fusarium first, to colonize and survive in different residue types; next, how agronomic practices could effect this. (M. R. Fernandez, Huber, Basnyat, & Zentner, 2008) In their research, residues from farms in Saskatchewan between 2000-2001 were sampled. The authors found that factors affecting Fusarim in residues included: current crop; cropping history; and tillage systems. In 2009 the same research team published an article that included a review on the impact of tillage and glyphosate use on FHB and CRR diseases. The article also took a further look at their previous four year study done in Saskatchewan which indicated that environment was the most important factor in determining FHB development. Also, previous glyphosate use and tillage practice were associated with FHB. (M. R. Fernandez, Basnyat, & Zentner, 2007), (M. R. Fernandez et al., 2007) The earlier research showed that disease was highest in crops under minimum till management, and that previous glyphosate use was consistently associated with higher FHB levels. (M. R. Fernandez et al., 2009) However, it was difficult for the researchers to separate the effects from the reduced tillage and glyphosate usage, as they are both consistently associated with one another. The researchers believe that understanding these management processes on their own would greatly aid in managing FHB. In the four year study, the mean FHB index in wheat was highest in minimum till and lowest under zero till. Previous glyphosate application, nested within tillage systems, was the only agronomic factor significantly associated with higher FHB levels. Similar results were found in barley, with minimum till and previous glyphosate usage, resulting in higher levels of FHB. (M. P. Fernandez, Zentner, DePauw, Gehl, & Stevenson, 2007)

In the discussion, the authors indicated agreement between their results and previous studies which showed higher levels of FHB with minimum till as compared to zero till or conventional till management. They noted that some studies indicated that tillage had no effect on FHB {{1336 Teich, A.H. 1984}}. The association of previous glyphosate applications with FHB development suggested that lower disease levels seen with zero till were not related to glyphosate but to factors intrinsic to the zero till, as it does not disturb the residues. (M. R. Fernandez et al., 2009) The group's results regarding glyphosate use and FHB levels also agree with several other research studies undertaken, although their research was the first to focus on grains. Overall, this report stated that "growing susceptible crops under minimum-till management in fields, where glyphosate has been previously applied, resulted in the most damage in years conductive to disease development" (M. R. Fernandez et al., 2009)

Soil Microbial Antagonists (biocontrol)

Fusarium survival on crop residues is affected by soil microbial antagonists. Perez et al. studied the incorporation of green manures which have been shown to increase the density and diversity in soil, particularly pathogen-inhibitory bacteria and fungi. Their research looked at streptomycete (bacteria) populations, which increase in soil as a response to green manures, and their negative effect on the survival of Fusarium. Results suggested that green manures could enhance populations of indigenous soil microorganisms, antagonistic to the survival of F. graminearum in wheat residue. {{1381 Perez,Carlos 2008}}

Other emerging strategies

Cultivar Use

Research into cultivars to control FHB has been going on since 1990. {{1365 Schmale, D.G. 2010}} Although this report does not go into detail regarding genetic research and FHB, many farmers are being careful when choosing more resistant cultivars for their crops to manage FHB. An in depth review of current literature, as of 2006, stated: "Careful choice of cultivar is currently the most effective agronomic method to decrease DON contamination levels in wheat followed by ploughing, avoiding maize as pre-crop and applying triazole fungicides at wheat anthesis." (Beyer, Klix, Klink, & Verreet, 2006) Therefore, it is important to mention some of the newest cultivars coming onto the market which farmers may be able to use. Research in breeding for resistance is a worldwide activity as researchers in the USA are doing genetic research and breeding of cultivars from China to produce more resistant soft red winter wheat for the Midwestern USA. (Kang et al., 2011) To date, many initial sources of resistance were derived from the Chinese wheat cultivar Sumai 3, and were not well adapted to most regions in North America. {{1365 Schmale, D.G. 2010}}

In 2010, the US Wheat and Barley Scab Initiative review of 2010 mentioned several states using cultivars which were developed as part of this initiative to reduce FHB. In Ohio, farmers were successful planting resistant varieties such as Malabar, a new variety coming out of OSU's wheat breeding program funded through USWBSI. Other resistant varieties were Truman and Bess, which are from the University of Missouri program. (Lilleboe, 2010) A list of resistant varieties for each crop can be found on USWBSI's ScabSmart website (www.scabsmart.org/). In Maryland, a new resistant soft red winter wheat germplasm, MD01W233–06–1, was developed. (Costa et al., 2010)

In Canada there are two durum wheat breeding programs located at the Semiarid Prairie Agricultural Research Centre of Agriculture and Agri-Food Canada in Swift Current and the Crop Development Centre at the University of Saskatchewan. Durum varieties such as Brigade, Eurostar, Enterprise, DT801 and CDC Verona have come out of these programs. Brigade, Eurostar and CDC Verona seed should be available in 2011; Enterprise for 2012 and DT801 should be available to plant in 2013. {{1387 King, C. 2010}} In Saskatchewan, breeder Ron DePauw has come out with a new spring wheat variety called Carberry through his research with Ag Canada's Semiarid Prairie Agriculture Research Centre. This variety has been found to improve resistance to Fusarium. De Pauw noted that it was not fully resistant, but it was an improvement. This seed should be available to plant in 2012. (DePauw, Knox, McCaig, Clarke, & Clarke, 2011) Researchers presenting at the 11th European Fusarium Seminar indicated that for barley two-row cultivars in general are more resistant to DON accumulation than six-row cultivars. The problem for farmers is that two-row has lower yields than six row. The researchers believed the cultivar Leader could make up for this with its high yields. (11th European Fusarium Seminar. 2010) Leader is a two row spring feed barley cultivar developed by the Eastern Canada Barley Breeding Group, Agriculture and Agri-Food Canada. It has a high yield and moderate resistance to DON and performs well in Eastern Canada. {{1388 Choo,T M. 2009}}

Fertilizer Research

Fertilizers can alter the rate of residue decomposition, act on the rate of plant growth, and change the soil structure and microbial activity. There have been conflicting studies regarding Nitrogen fertilizer and FHB. In the late 80's research was done to show that Nitrogen supply resulted in increased incidence of FHB in grain. (Jouany, 2007), (Teich, 1989) One study revealed that when wheat and barley were grown with an initial application of 70 kg of nitrogen per hectare, plants which received an additional 50 kg of nitrogen per hectare during Zadocs' growth stages 30 and 45 showed higher levels of FHB than those without any additional application. (Martin, Macleod, & Caldwell, 1991) On the other hand, wheat grown in fields with 90 kg of Nitrogen per hectare or less showed higher levels of FHB than those with more Nitrogen. (Teich & Nelson, 1984) Research from 2010 done on FHB in barley studied the control of Nitrogen fertilization as a possible way to minimize FHB in barley. This research showed an increase in Fusarium infection in barley with low N. (Yang et al., 2010) It was also reported that wheat grown in clay loam or sandy loam soil without N fertilization had more FHB than with 100 kg of nitrogen per hectare. (Subedi, Ma, & Xue, 2006) Research on maize, however, showed that application of 100 kg per hectare of ammonium nitrate decreased disease severity and levels of DON. All of these conflicting results prove the need for more research on Nitrogen fertilization and FHB. As mentioned previously, research looking at the combination of fertilizer with fungicide application resulted in recommendations of reducing N fertilization in order to reduce FHB. {{1370 Heier, T. 2005}}

Organic Farming practices

A review article in 2007 stated that there was 'no clear answer' when looking at Organic farming and FHB. Conflicting research on the topic created the need for more studies in the future. (Jouany, 2007) Ongoing research, that focused on Saskatchewan practices of farming, looked at three different input levels: high - with tillage, fertilizer and pesticides; reduced [RED] - with conservation tillage, targeted fertilizer and weed control; and organic [ORG] - with tillage and N-fixing legumes. The study also used three levels of cropping diversity: low diversity - with wheat and summer fallow or legume green manure fallow; diversified - using annual grain crops; and diversified - using annual grain crops and perennial forages. Results indicated that ORG management helped reduce populations of Fusarium pathogens in the Canadian Prairies. The authors noted that to their knowledge there was no studies in North America examining root and crown rot of wheat grown in organic, compared with nonorganic management systems, despite a growing interest and involvement in organic farming in the area. (M. R. Fernandez et al., 2011) An earlier study looked at similar cropping systems: conventional; integrated; direct drilling; and organic. Results showed that climate appeared to play the key role in mycotoxin contamination; however, in years with severe disease cropping the role of the disease was most important. The direct drilling system resulted in the highest levels of contamination, especially in years of severe disease. The other systems could not be ranked as there was no consistent pattern. {{1377 Champeil,A. 2004}}

Climate Change and Agronomical Management

Research has shown that environment greatly affects FHB and that F. greminearum thrives in hot, wet climates. One management technique recommended by the USWBSI is to stagger planting dates so that environmental periods of Fusarium infection will not impact all crops, as not all crops will be in the most susceptible stage. (US Wheat and Barley Scab Initiative, 2011) Emerging research is looking at how climate change can impact FHB and how this can impact management of the disease. Climate change has a direct impact on FHB, however, the severity of the disease is likely to increase. Indirect effects of climate changes, such as increased cropping of grain maize, are a potent source of inoculums of Fusarium. (West et al.) Another article in press reviewed mycotoxin effects from climate change. Warmer weather, heat waves, greater precipitation and drought were found to have various impacts on mycotoxins in food. The authors demonstrated that F. graminearum had a higher temperature optimum, making it a threat with worsening climate change. (Paterson & Lima,) Other research confirmed this idea, stating that cold regions may become liable to temperate problems, including Fusarium toxins in the future. (Paterson & Lima, 2010)

Integrated Management

Integrated management of FHB uses multiple strategies for maximum management of the disease. In the past decade, FHB management has focused more and more on the use of multiple techniques. By combining management techniques which reduce FHB, producers may be able to manage this disease. Researchers in Illinois have been emphasizing to growers the importance of integrated management for FHB. This includes the use of fungicides and using more resistant varieties. (Lilleboe, 2010) Multi-state research studies in the US have been examining the use of two or more strategies to manage the disease. Primary strategies include: integrating host resistance; crop rotation; and fungicide use. These integrated strategies have proven to be reliable and results will be presented in a new effort called Scab Smart. (Ouellet & Leger, 2011) The Government of Saskatchewan, Ministry of Agriculture advises producers to combat FHB with an integrated approach using: crop rotation, irrigation scheduling and fungicide application. (Cranston, 2010)

Several presentations at the Canadian Workshop on FHB mentioned utilizing their methods as part of an integrated management technique. It is important to remember that environmental factors still have the greatest influence over the FHB levels. Research coming out of Argentina analyzed the effects of different tillage on FHB as well as other agronomic practices such as nitrogen fertilization and the influence of environmental conditions. Their results suggested that favourable weather conditions were more important than tillage and fertilizer treatments. The recommendation made by the researchers was to integrate all of the available strategies to decrease FHB. (Lori, Sisterna, Sarandon, Rizzo, & Chidichimo, 2009) Researchers have emphasized the importance of integrating biocontrol with other management techniques stating that, when used alone, only a small amount of biocontrol programs succeed. Therefore, it should be combined with chemical, cultural, genetic or other methods of an integrated pest management strategy. {{1380 Gurr,G.M. 2010}}

Risk forecasting / modeling

Disease forecasting and risk models can aid farmers as they can plan crops around increased threats of FHB, since, as indicated above, the environment plays an important role in FHB. Research from 2010 showed that temperature alone did not seem to correlate with FHB, but moisture or wetness plus temperature were correlated with FHB intensity. Therefore, FHB intensity depends, in part, on environmental conditions during a short, critical time period of FHB development. {{1361 Kriss, A.B. 2010}} Planning around these conditions then, can aid in planting and production. Around the world, computer based FHB risk models, based on weather models (temperature, rainfall, and moisture level), have been created. {{1363 Prandini,A. 2009}} Researchers from the University of Guelph presented an integrated management kit which included a forecast of risk called DONcast (http://www.weatherinnovations.com/doncast.cfm). It informed producers of fungicide spraying opportunities, marketing decisions, registrations of fungicides, new application technologies, and new research on genetic resistance. (11th European Fusarium Seminar. 2010) The Minnesota Association of Wheat Growers also has a scab epidemic risk model available for public use (http://mawg.cropdisease.com/). North Dakota State University has a Small Grain Disease Forecasting Model and a Barley DON Model (http://www.ag.ndsu.nodak.edu/cropdisease/). Such models are for producers in North Dakota, western Minnesota and eastern Montana. The largest resource for growers in the USA is the US Wheat and Barley Scab Initiative's *fusarium head blight risk assessment tool.* (http://www.wheatscab.psu.edu/riskTool_2011.html) This tool also provides alerts which gives growers advanced notice of potential outbreaks and the risk of scab in the area. Alerts can be sent as cell phone or email alerts, making it extremely useful for farmers.

Other Resources: Major research initiatives/ workshops/ conferences

Major research initiatives have come out of the pressing need for FHB research and funding. These initiatives have come forward with some of the leading research in FHB, and span over the world, helping researchers connect and research with other experts.

US Wheat and Barley Scab Initiative (USWBSI) (www.scabusa.org/)

The USWBSI is one of the largest research initiatives and is based in the USA. The yearly review published by the initiative is a rich summary of what worked and did not work for farmers. The USWBSI offers several tools, such as a risk forecasting and alarm tool, and a quick guide for managing FHB called Scab Smart (www.scabsmart.org/). There is also the National Fusarium Head Blight Forum which is an annual conference organized by USWBSI providing a major source of new information and research.

European Fusarium Seminar

In Europe, an annual seminar focused on Fusarium has run for 11 years where scientists from around the world participate. Some of the major topics covered in 2010 included: breeding for resistance; fusarium plant diseases in the food chain; genetic research into fusarium; forecasting models; chemical control; integrated management; and fungicide use. (11th European Fusarium Seminar. 2010)

Canadian Workshop on Fusarium Head Blight

This annual workshop brings together researchers to share and educate about the modern techniques for reducing Fusarium Head Blight. Research studies presented during such workshops provide useful resources for local farmers.

Useful Websites

APS Net : Fusarium head blight
http://www.apsnet.org/edcenter/intropp/lessons/fungi/ascomycetes/Pages/Fusarium.aspx

Top Crop Manaer – could fusarium head blight become an even more serious problem?
http://www.topcropmanager.com/content/view/1454/132/

Canadian Grain Commission – fusarium head blight in western Canada
http://www.grainscanada.gc.ca/str-rst/fusarium/fhbwc-foc-eng.htm

Health Canada – Pesticides and Pest Management Reports and Publications http://www.hc-sc.gc.ca/cps-spc/pubs/pest/index-eng.php

Government of Alberta – Fusarium Head Blight in Barely and Wheat
http://www1.agric.gov.ab.ca/$department/deptdocs.nsf/all/agdex92#how

Government of Saskatchewan – Fusarium Head Blight
http://www.agriculture.gov.sk.ca/Default.aspx?DN=24a3bb18-a096-4bcd-889c-b1e2c94a03e9

Government of Manitoba – Dealing with Fusiarum Head Blight
https://www.gov.mb.ca/agriculture/crops/diseases/fac12s01.html

Canadian Grain Commission – Fusarium Head Blight in Western Canada
http://www.grainscanada.gc.ca/str-rst/fusarium/fhbwc-foc-eng.htm

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