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Economic Impact of USWBSI's Scab Initiative to Reduce FHB

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Economic Impact of USWBSI's Scab Initiative to Reduce FHB[1]

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Project Report Outline

Abstract

Fusarium Head Blight (FHB) has led to major economic losses for wheat and barley producers. Deoxynivalenol (DON) is a mycotoxin associated with FHB. Grain products and feed grain contaminated with DON (commonly known as vomitoxin) are subject to FDA advisory limits and as a result, end-users place restrictions on their use. This has led to steep price discounts, as well as higher risks for producers and grain merchandisers. Varietal research has led to the development of varieties that are resistant to moderately resistant to FHB. Also, studies indicate combinations of genetic resistance, fungicides, and some management practices (combine settings, tillage practices, etc.) can be used to decrease losses due to FHB. These approaches were developed beginning in 1997, with the introduction of the United States Wheat and Barley Scab Initiative (USWBSI). However, the detailed economic impact of the initiative (combined genetic resistance, fungicide uses, and some management practices) are yet to be estimated.

The purpose of this study was to estimate the economic impact of reducing FHB on cereal producers, traders and handlers, and processors. To do so we developed a number of economic models, analyzed extensive data, and conducted surveys of wheat flour millers, barley maltsters, and grain handlers. Taken together these procedures allow us to make an assessment of 1) the cost to these industries of FHB; 2) the impact of mitigating strategies on yields and DON levels; 3) the marketing practices of the supply chain; 4) the impact of the Scab Initiative on reducing yield losses; 5) the return on investment of the Scab Initiative; and 6) the secondary impact of the initiative.

In general, the results indicate some important findings regarding the Scab Initiative can be deduced from this study. One is that the DON problem has improved. However, it has not been eliminated and remains a temporally and spatially sporadic problem. Second, while there are a number of risk mitigation tools, and all of these prospectively have impacts of reducing the impact of DON, two are particularly important. One is fungicide use, which has increased from virtually nil in the 1990s' to being applied to 70-80% of the cereals planted. This is substantial, and at a high cost, but, also is effective though not perfect. The second is the development and adoption of resistant varieties. The statistical analysis reported here documents the importance of these, though the effect varies across classes.

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[1] Funding source for this project was the USDA/ARS SCAB Initiative, and titled Economic Impact of USWBI's Impact on Reducing FHB.

[2] Authorship is shared

This study estimates the return on investment to the research expenditures of the Scab Initiative which has spent $76 million over its life, including in-kind contributions. For both wheat and barley, the NPV of net savings from reduced production loss ranges from $5.3 - 5.4 billion over the period 1993-2014. For every $1 invested, plus in-kind and fungicide costs, there are $71 in benefits. This is significant and compares very favorably to other studies on agriculture research. The return on investment for expenditures on the Scab Initiative (including in-kind costs) was approximately 34%, which is substantial**.**

DON has a devastating impact on producers and the supply chain. It imposes substantial costs throughout the marketing system and increases risk to all participants. The returns and net savings from funding the Scab Initiative have been substantial and have contributed to reducing the impacts of the disease. There are a number of further challenges and several technologies are showing further prospects toward mitigating these problems.

1. Introduction

Fusarium has major implications for the entire industry. It raises costs and risks for growers, inducing them to use more costly management practices and/or shifting to other crops. It reduces the quantity produced, raises prices, and increases premiums for non-fusarium wheat and malting barley, meaning higher costs, risks, and more complicated logistics for domestic processors and importers, and finally, it raises the breeding cost. All of these effects would be exacerbated by recent CODEX proposals to measure and limit fusarium on raw materials instead of products.[3]

FHB impacts also have resulted in growers shifting production to less risky crops/crop rotations. While changes in cropping patterns have been influenced by many factors (Government Farm Program changes, rise of importance of ethanol and increased demand for corn, soybeans, and canola, increased profitability of alternative crops, etc.), the increased risk of FHB is an important factor. Ali and Vocke (2009) indicate that the concern of the impact of fusarium head blight has affected planting decisions by farmers since the 1990s. The degree of incidence may be increasing due to larger corn plantings and a switch toward minimum or reduced tillage practices, which increases the host presence for fusarium head blight development when environmental conditions are favorable. Similarly, much of the durum and malting barley production has shifted out of eastern, central, and northeastern counties in North Dakota in to more westerly counties in North Dakota and eastern Montana.

Objectives

This project comprises five objectives:

1) Estimate the economic value of crop losses suffered by wheat and barley producers without (1993 to 1996) and with (1997 to 2013) fungicide uses and some management practices;

2) End-use value of reduced scab will be derived. A focused survey of millers and maltsters will be conducted to illicit benefits of the initiative for end-users;

3) Estimate the economic value of crop losses suffered by U.S. wheat producers without (1993 to 1996) and with (1997 to 2013) moderate FHB resistant wheat varieties developed by universities funded by the initiative. This would include impacts of fungicide use and management practices from objective one. The economic value of crop loss from both time periods will be used to estimate the benefits of the USWBSI;

[3] This is discussed in U.S. Industry Response to CCCF on Agenda Item 7, DON, (2014) which considered imposing maximum limits on DON in raw corn, wheat and barley for international trade.

4) Estimate the secondary economic impact of losses attributable to FHB with and without the initiative. The value of the USWBSI goes beyond production to other sectors in the economy (agribusiness industry, input supplies, trade, etc.). This will enable policy makers, industry representatives, and those in academia to evaluate the comprehensive economic value of the USWBSI for Hard Red Spring Wheat (HRS) only; and,

5) Use an internal rate of return, a modified internal rate of return (MIRR), and the aggregate rate of return approach to assess the return to investment on funding spent by the USWBSI.

Organization

The report is organized as a comprehensive research report. First, related and previous studies are reviewed. The second section contains background material and some related analysis. Then, we proceed to present the results of each of the objectives. The first objective analyzes and shows the impact of relevant technical relationships and variables of DON on wheat and barley, and the impacts of DON on wheat yields. These relationships are then used in an analysis of risk and returns for growers to evaluate how the incidence of DON impacts growers returns and risk.

The following section provides a summary from a survey of end-users that provides a description of how DON impacts their strategies, operations, and costs (Objective 3).[4] The estimates are provided for the cost of testing, discounting, etc. The last three sections present the results for Objectives 2, 4, and 5. These include estimates of the economic value of crops loss through time, due to DON, and, also the direct and indirect impact of these crop losses. Then estimates of several measures of returns to the Scab Initiative are derived. The final section provides a comprehensive summary and implications. Finally, a number of tables of data and results are shown in the appendix and referenced from the text.

[4] We reorganized this presentation to more logically present the results: First we present the impacts of DON on costs and operations, and then the impacts of DON on the value of yield loss, secondary impacts, and returns to the SCAB initiative.

2. Previous and Related Studies

Earlier studies by Johnson et al. (2003) and Nganje et al. (2004), estimated the value of economic losses due to FHB. Johnson et al. 2003 estimated production and price effects for HRS, Durum, and SRW wheat from 1993 to 1997. They estimated the relationship for yield as a function of rainfall, temperature, and trend. These forecast yields and actual yields were utilized along with expert opinions to adjust losses contained in actual yields (difference between forecast yields and actual yields) to the proportion of losses attributable to FHB to determine yields without FHB. An acreage adjustment was included to compensate for higher acreage abandonment in FHB outbreaks. Price effects were evaluated as the production shortfall impact on market prices and effect of crop quality premiums and discounts. The economic impact of production losses ranged from 134 mil. bu in 1993 to a low of 62 mil. bu in 1996. Price effects due to production shortfalls resulted in higher prices than what would have occurred without FHB outbreaks. Combining the two effects reduced the total impact of FHB. The largest production effect occurred in 1993, however when considering both price and production effects, the largest loss occurred for all classes in 1995, largely due to the large negative price effects on Soft Red Winter Wheat (SRW). For HRS, the year with the largest losses were $245 million in 1994.

Nganje et al. (2004) updated results from Johnson et al. (2003), to cover the years 1998-2000 and expanded the analysis to include malting barley. Nganje et al. (2004) used generated losses to estimate direct and secondary yield losses, which were then utilized within an input-output model of the economy to project direct and secondary economic impacts on the larger economy. Direct economic losses were estimated at $870 million from 1998 to 2000. The combined direct and secondary losses totaled $2.7 billion with 55% of losses accrued in North Dakota and Minnesota.

More recent estimates of outbreaks have tended to focus on yield losses and extent of coverage of FHB outbreaks. Cowger and Sutton (2005) estimated the impact of the 2003 SRW outbreak. They interviewed researchers, extension specialists, extension agents, millers, and growers in the southeastern US for opinions on 2003 infestations. Lilleboe (2010, 2011, 2016) summarized the effects of FHB in 2010 and 2011 across states/crops for the U.S. McMullen et al. (2012) summarized studies since 1991 on the economic estimates of FHB outbreaks and the degree and location of FHB outbreaks by class of wheat.

Hollingsworth et al. (2008) examined the economics of growing Moderately Susceptible (MS) vs Moderately Resistant (MR) cultivars with the application of fungicides at different stages and different levels of FHB infestation. They evaluated the effects of different varieties, fungicide application combinations, and applied a direct cost comparison for Net Revenue, with discounts for levels of DON and market prices obtained in the post-harvest period. They indicate about an 8% net revenue disadvantage for MR cultivars vs. MS cultivars although not statistically significant in one of the two years. McMullen et al. (2012) reviewed the effectiveness of fungicide and agronomic management practices (changing combine settings, cleaning grain post-harvest, etc.) and noted that while these can be effective in decreasing levels of DON in grain, they can become quickly uneconomic depending on the price of wheat, premiums/discounts, cost of application, etc.

Recent studies indicate combinations of genetic resistance, fungicides, and some management practices (combine settings, tillage practices, etc.) can be used to decrease losses due to FHB (Wiersma, 2016, Salgado et al., 2014, Hollingsworth et al., 2008). The most effective of these is genetic, however limited genetic resistance has been incorporated into wheat/durum/barley varieties (McMullen, et al. 2012). In addition, the effects of genetic resistance and fungicide application tend to be additive (Salgado et al., 2014, Willyerd et al., 2012, McMullen et al., 2012, Hollingsworth et al., 2008).

Other studies on wheat stem rust estimated losses and projected appropriate funding levels based on the value of losses (Beddow, et al., 2013 and Pardey et al., 2013). They estimated yield distributions for two periods, one with rust, and one when rust resistant varieties were prevalent. They used georeferenced area and yield data in combination with weather data within CLIMEX to model rust population dynamics and plant susceptibility. These were simulated and applied to the period from 1960-2009 to estimate annual losses. These losses were then utilized to project appropriate funding levels for rust research using a modified internal rate of return (MIRR) method (Beddow, et al., 2013 and Pardey et al., 2013). Leslie and Logrieco (forthcoming) has a chapter devoted to yield loss estimation and estimation of susceptibility for mycotoxins in grain.

Prandini et al. (2009) reviewed predictive models for FHB and DON in wheat. This included computer models for Argentina, Belgium, Canada, Italy, the U.S., and Europe based on weather variables including temperature, rainfall, and moisture level. They indicate that the relationship between FHB and DON in other countries are intermediate between U.S. winter wheat and U.S. spring wheat, with U.S. spring wheat having the strongest relationship between FHB and DON and U.S. winter wheat the weakest. These computer models have been implemented in several U.S. states and regionally at www.wheatscab.psu.edu (USWBSI, 2014).

The economic benefit of scab management practices depends on several key variables. Statistical estimates of the relationship between these variables provide an indication about these economic benefits. Using uniform treatment data observed between 1998 and 2007, Paul et al. (2010) explicitly models the relationship between six fungicide treatments, including a control; FHB intensity, as measured by percentage of diseased spikelets; and test weight effects for soft winter and spring wheat varieties. No statistically significant difference was observed across the test weight of all wheat types for any of the six fungicide trials. Nevertheless, a variety of statistically significant reductions in lost yield were observed for all five fungicides relative to the control. Using data observed between 1995 and 2007, Madden and Paul (2009) show a statistical relationship between yield and FHB intensity, with a mean 4.10 MT/ha yield for hard red spring wheat when the disease is not present and a reduction of 0.038 MT/ha for each unit increase in the presence of FHB. The mean yield is 0.85 MT/ha greater in soft-red winter wheat, but no difference in the rate of yield reduction were observed across wheat types. Salgado et al. (2014) find a negative relationship between FHB index and yield. Other studies, including Paul et al. (2005, 2006), Paul et al. (2007) show statistically significant correlations between FHB index and DON content.

Finally, it is important for the Scab Initiative to acknowledge the longer-term prospective impact of the proposed CODEX Alimentarius (International Food Regulations) regulations regarding DON. Currently U.S. domestic regulations, and many other countries, have varying limits on raw and processed grains. CODEX is considering a proposal that would change these to more restrictive levels. If adopted, this would have a drastic impact on the entire wheat value chain, as could be imagined. Bianchini, et al. (2015) provide a detailed discussion of the evolution of DON in the supply chain, as well as the prospective impact of these regulations on the U.S. wheat industry. Certainly, costs would escalate, there would be reduced exports, expanded use of wheat as feed within North America, increased testing, and segregation costs; and, these are notwithstanding the inevitability of further switching away from wheat by growers in any of the regions that have vulnerability and risk to excessive DON levels.

3. Background and Related Analysis

Evolution of Scab[5]

DON was identified in wheat and barley in 1973 and described as vomitoxin. Since then it has evolved and has become very important throughout the wheat and barley sectors in the United States, and in many other countries.[6] This has impacted the entire supply chain including inputs, farm production practices, marketing, and handling, in addition to processing and distribution. Taken together it has increased risk and cost throughout the marketing system.

Concurrent with the emergence of DON was the impact on the production of cereals within North America. While there were other factors impacting these shifts, it is important that areas planted to wheat in the United States decreased from 70 to 50 million acres and that for HRS wheat decreased from 10 million acres to 6 million acres between the mid-1990s to current. And in 2017, it is expected that wheat plantings will fall to their lowest level in over 50 years, at 49 million acres (AgResource, 2016) in 2016, and the recent USDA Baseline has wheat falling to 48.5 million acres in 2017 forward.

These issues are important to the industry due to the cost and risk, but also due to the reduced production particularly in traditional regions. It also affects the processing sector having the impact of increasing risk and cost for wheat, and for testing etc., changing procurement regions, etc. Indeed, the advent of DON has impacted the food market, the feed market, the petfood market, the marketability of crops offshore, and Oreos (Levine 2015).

Scab Severity

A number of studies and labs provide measures of the distribution of DON in the North American and offshore crop. Two have recently summarized the changes.

Bianchini et al. (2015) provide a summary of the DON data. Their results were from 42,100 samples in the United States market system, and they reported data from 2003-2014. The average DON levels were typically less than .67 and in many years were less than .35 (mg/kg). Only in 2014 was the DON level greater at .85 mg/kg. However, the variability was large and in some years, the deviations approached 2 mg/kg. In further detail, they reported that 1.7% of hard wheat samples showed DON > 2 mg/kg; while >30% of soft wheat had levels exceeding 2 mg/kg.[7]

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[5] Bianchini, et al. 2015 provide a recent detailed discussion of the evolution of DON in the cereals sector.

[6] Vomitoxin is not only a problem in wheat and barley, but also in corn. Of interest, the 2016 corn crop in the United States apparently has vomitoxin and the Andersons are testing every delivery of corn at its ethanol plant in central Indiana (Thomson Reuters, 2016 and 2017; ProAg 2016a).

[7] 1 PPM is equivalent to 1 mg/kg.

In addition, U.S. Wheat Associates regularly publishes data on DON in wheat, which varies by class (2004-2015). This data comes from varying labs throughout the United States and typically are a result of composite samples and testing. While this provides an indication of DON over time, it is limited in that it masks inter-sample variability in DON levels. These are shown in Tables 3.1-3.3.

The data for HRS show that the average level of DON varies across origins, and was fairly large in the mid-2000s. Since then, there has been a notable decline in the DON level, and in recent years including 2016 with the exception of a few origins, it was nil for North Dakota (U.S. Hard Red Spring Wheat Regional Quality Report 2016) vs 0.2 ppm in 2015. For SRW the results showed an increase due to spikes in 2009 and for selected states in 2013-2015. High DON levels were indicated in Arkansas, Missouri, Illinois, Ohio, Kentucky, and Maryland during the 2013-2015 period, and Ohio, Kentucky, and Missouri in 2009.

For durum, the levels are minimal in Montana, but select regions in North Dakota have shown levels near or above maximum limits from 2011 to 2015. These include northwestern North Dakota (A) in 2014, Northcentral North Dakota in 2011, 2013-2015, and Northeast North Dakota in 2011. In 2016 there was a sharp increase in DON levels in the North Dakota crop (U.S. Durum Wheat Regional Quality Report 2016) at 1.5 ppm, vs 1.2 in 2015.[8]

[8] This has sparked concern following the 2016 crop harvest with headlines such as: "Time to Drop Durum? Vomitoxin, Price Discounts Are Huge Concerns "(ProAg 2016b).

Table 3.1. HRS: DON Levels from Composite Samples, by Region and Year, 2004-2015.

State	Region	2004	2005	2006	2007	2008	2009	2010	2011	2012	2013	2014	2015	Average
East	<13.5**	1.3	2.2	0.0	0.0	0.0	0.7	0.0	0.7	0	0.5	0.5	0.0	0.5
East	13.5-14.5**	1.0	2.5	0.0	0.0	0.0	0.5	0.0	1.2	0	0.9	0.0	0.0	0.5
East	>14.5**	1.2	2.8	0.0	0.0	0.0	0.5	0.0	1.1	0	0.7	0.0	0.0	0.5
West	<13.5**	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.3	0.0	0.0	0.0	0.0
West	13.5-14.5**	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.2	0.4	0.7	0.0	0.0	0.1
West	>14.5**	0.0	0.0	0.0	0.0	0.0	0.0	0.0	1.0	0	0.0	0.0	0.0	0.1
ND	A	0.0	2.0	0.0	0.0	0.0	0.0	0.0	1.6	1.2	1.2	1.1	0.4	0.6
ND	B	1.3	2.0	0.0	0.0	0.0	0.0	0.0	1.9	0.7	0.7	0.0	0.0	0.5
ND	C	1.0	2.0	0.0	0.0	0.0	0.0	0.0	1.2	0	0.0	0.0	0.0	0.3
ND	D	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0	0.0	0.0	0.0	0.0
ND	E	1.8	1.0	0.0	0.0	0.0	0.0	0.0	1.0	0	0.7	0.4	0.6	0.5
ND	F	1.0	3.0	0.0	0.0	0.0	1.0	0.0	1.8	0	0.8	0.2	0.2	0.7
MT	A	0.0	*	0.0	0.0	0.0	0.0	0.0	0.0	0	0.0	0.0	0.0	0.0
MT	B	0.0	*	0.0	0.0	0.0	0.0	0.0	0.0	0	0.0	0.0	0.0	0.0
MT	C	0.0	*	0.0	0.0	0.0	0.0	0.0	0.0	0	1.2	0.0	0.0	0.1
MT	D	0.0	*	0.0	0.0	0.0	0.0	0.0	0.0	0	0.0	0.0	0.0	0.0
MT	E	*	*	*	*	*	0.0	0.0	0.1	0	0.0	0.0	0.0	0.0
SD	A	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.4	0	0.0	0.0	0.0	0.0
SD	B	0.5	1.0	0.0	0.0	0.0	0.6	0.0	1.6	0	0.5	0.7	0.0	0.4
SD	C	1.0	1.0	0.0	0.0	0.0	1.4	0.0	0.6	0	1.0	1.7	0.0	0.6
MN	A	1.2	3.0	0.0	0.0	0.0	0.0	0.0	0.6	0	0.0	0.0	0.0	0.4
MN	B	1.1	2.0	0.0	0.0	0.0	1.3	0.0	1.0	0	1.0	1.5	0.0	0.7
PNW	A	*	*	*	*	*	*	*	0.0	0.3	0.0	0.0	0.0	0.1
PNW	B	*	*	*	*	*	*	*	*	*	0.7	0.0	0.0	0.2
	4 State Average	0.6	1.4	0.0	0.0	0.0	0.3	0.0	0.7	0.1	0.4	0.3	0.1	0.3

Source: U.S. Wheat Associates, Various.
*Missing

Table 3.2. Durum: DON Levels from Composite Samples, by Region and Year, 2011-2016.

State	Region	2011	2012	2013	2014	2015	2016	Average
Montana	A	0.25	0.25	0.25	0.25	0.25	0.25	0.25
Montana	B	0.25	0.25	0.28	0.25	0.25	0.25	0.26
North Dakota	A	1.15	1.61	1.39	3.50	1.20	1.30	1.69
North Dakota	B	2.83	1.66	2.63	3.00	2.90	1.80	2.47
North Dakota	C	3.03	1.66	1.00	1.00	1.10	4.50	2.05
North Dakota	D	0.95	0.25	0.76	1.80	0.30	0.25	0.72
Two State Average		1.41	0.95	1.05	1.63	1.00	1.39	1.21

Source: U.S. Wheat Associates, Various.

Table 3.3. SRW: DON Levels from Composite Samples by State and Year, 2006-2016.

	2006	2007	2008	2009	2010	2011	2012	2013	2014	2015	2016	Average
Arkansas	0.00	0.10	0.50	1.40	0.50	0.30	0.10	0.30	1.10	2.60	0.50	0.67
Missouri	0.10	0.50	1.00	2.40	2.10	0.80	0.40	0.80	1.70	4.00	0.50	1.30
Illinois	0.50	1.60	0.70	3.20	1.70	0.70	0.50	0.80	5.20	2.30	0.90	1.65
Indiana	1.20	0.20	0.50	2.70	2.70	2.30	0.20	2.70	2.90	3.30	0.50	1.75
Ohio	1.20	0.20		1.00	4.40	2.40	0.20	1.00	0.70	2.70	0.30	1.41
Kentucky	1.10	0.20	0.40	3.50	2.00	1.20	0.30	2.70	3.50	0.60	0.20	1.43
North Carolina	0.00	0.10	0.30	0.40	0.10	0.20	0.20	1.30	0.30	0.50	1.20	0.42
Virginia	0.30	0.30	0.70	1.80	0.20	0.20	0.80	2.50	0.60	0.80	0.90	0.83
Maryland	0.90	0.10	1.00	4.00	0.90	1.40	0.70	4.10	1.10	0.70	1.20	1.46
9 State Avg	0.59	0.37	0.64	2.27	1.62	1.06	0.38	1.80	1.90	1.94	0.69	1.26

Source: U.S. Wheat Associates, Various.

Breeding and Scab

Breeding for reduced DON became a high priority following the 1993 epidemic. This entails disease screening and testing of advanced breeding lines and cultivars. This all escalated following 1993.[9] By the early 2000s HRS cultivars were released for wheat and barley with improved FHB and reduced DON. The observed level of DON was reduced by 50% compared to susceptible checks. This was led by the HRS varieties, which over time were adopted for the vast majority of the planting areas.

Figure 3.1 shows the adoption of varieties by susceptibility in the case of HRS. These data show the reduced plantings of Very Susceptible (VS) and Susceptible (S) varieties over time. Planting is now dominated by Marginally Resistant (MR) and Moderate (M) varieties, capturing about 70% of the plantings. There was a change in the reporting of these categories in the data in the mid-2000's, which explains the decrease in MR plantings.

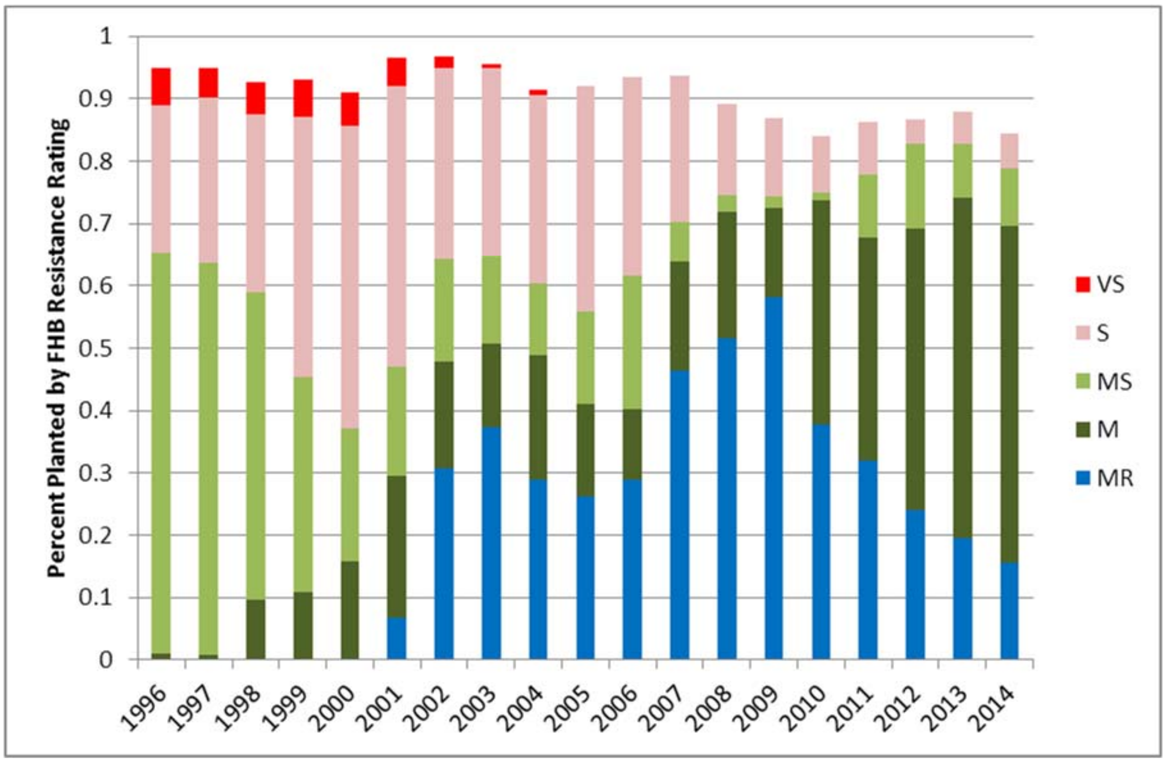

Figure 3.1. HRS Variety Adoption by FHB Resistance Rating, 1996-2014.

For other classes including SRW, Hard Red Winter Wheat (HRW) and Durum, the development and adoption of MR varieties lagged. There is no scab resistance in

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[9] As discussed in Bianchini, et al. 2015 p. 40, and extracted from Rudd, J., Horsley, R., McKendrey, A. and Elias, E. 2000. "Host plant resistance genes for Fusarium head blight: Sources, mechanisms, and utility in conventional breeding systems," Crop *Sci*. 41:620-627, 2001.

current Durum varieties. The best available scab resistance in Kansas is Everest, which has been the number one variety of acres planted for several years with more than 60% of the acres in southeastern Kansas where the risk of scab is higher. Everest began to grow in popularity around 2010. The relative yield dropped off in the last few years and its yield performance has declined relative to other varieties in the last two years. Zenda will be the next variety with scab resistance adapted for Kansas. Other replacement varieties appear to be more susceptible.[10] The first scab resistance variety available in SRW was Ernie that became available in about 2005. Ernie was released before then but it was MR at best.[11]

Conventional breeding and alternatives are being explored to further improve scab resistance. Dahl, Wilson, and Johnson (2004) and Dahl, Wilson, and Nganje (2004) illustrated the tradeoffs and values of fusarium resistant varieties in breeding programs. In addition, Flagg (2008) estimated the value of a fusarium resistant wheat at over $115 million at the time of regulatory submission, which far exceeded that of a herbicide tolerant trait. Earlier, Syngenta had been working on a GM fusarium resistant wheat but postponed the project in 2007 "due to public concern over biotechnology" (ISAAA, 2016). More recently, KBS and apparently others (GMO Compass 2016) have been working on a GM transformation of a fusarium resistant wheat.[12] It is anticipated that fusarium may be addressed using newly developed gene-editing technologies (e.g., CRISPR, TALEN, and Zink-Fingers).

Finally, Demaree (2016) described an important breakthrough at Kansas State University in overcoming scab problems in wheat. The breakthrough was the cloning of the resistance gene. Specifically, (citing Gill), "We have identified the DNA and protein

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[10] Further discussion on this matter with breeders familiar with development, release, and planting indicated the following: For SRW, the industry became aware of SCAB in 2003 and scab resistant varieties were rated and released for planting commencing in 2005 and 2006. For HRW, Everest (KS 2009) was popular and had 12% of the Kansas acres in 2016, and is expected to drop off and be replaced with Zenda in 2016. The other varieties like Hitch and Art have only intermediate levels of resistance. Hitch was released about 2007 and Art around 2009. Neither of these varieties have held many acres in Kansas because of other disease problems and lower yield in many trials.

For South Dakota, the most popular MR varieties were Redfield (SD 2013), Overland (NE 2007), and Lyman (SD 2008) at 14, 7, and 7% respectively. In Nebraska, Overland (NE 2007) captured 20% of the acreage and was also planted in South and North Dakota. The HRS MR varieties were derived from a Chinese Sumai 3, a Chinese wheat. Most of the other wheat varieties were developed from other sources, or native resistance. It has taken years (more than a decade) of selection to bring this resistance into varieties that are competitive yielding varieties with desirable quality and other agronomic parameters. (Personal communication with Erick DeWolf (KSU).

[11] Personal communication with David VanSanford.

[12] Specifically, *GMO Compass* indicated: "Genetic engineering opens the door to new strategies for managing Fusarium and other fungal diseases. Scientists are currently developing genetic approaches to conferring resistance to fungal diseases and are testing their effectiveness on wheat. Field trials are underway in many countries, including countries in Europe, to find out if experimental GM wheat plants are actually resistant to fungal infection and thereby produce grains won't be laden with dangerous mycotoxins."

sequence, and we are getting some idea of how this gene provides resistance to the wheat plant for controlling the disease. The cloning of this gene is the key to unlock quicker progress for control of this disease."

Regulations Regarding Scab and Wheat

DON has been subject to regulations to assure safe food and feed. In 1993, the FDA revised earlier regulations to provide clarity and implemented it as an advisory level, which applies to finished wheat products. The restriction is applied to finished wheat products (e.g., flour, bran, and germ) used for human consumption. The purpose of an advisory level is to provide guidance to the industry and is believed to provide an adequate margin of safety.[13]

The reason the regulation is applied to products, as opposed to the raw grains, is that the DON level can be reduced through the manufacturing process. Similar regulations apply to grains used in feed and the limit varies across species.

These are advisory levels and provide guidance to the industry. The market place through contract specifications also establishes limits, which are influenced by these advisory limits, and are reflected in contracts and contract forms. For example, most buyers specify a 2 ppm limit on raw grains (shown below) with the notion that through processing, the DON on raw grains would be reduced to 1 ppm. However, in some products, e.g., whole grain flour, buyers often specify tighter limits (e.g., 1 ppm) the reason for this is that processing does not reduce the DON levels in these products.

Finally, CODEX[14] proposed limits on DON in 2014. The proposal recommended maximum limits on DON in cereal grains and would be applied to unprocessed wheat and barley. Though these would not apply directly to U.S. domestic processors, it would impact them.[15] However, it is unclear where and how these would be applied. Current maximum limits in the United States are applied on semi-processed grain. Some countries would like it applied to raw grains, which could detect infested grain prior to entering primary elevators. The latter would be more costly and restrictive.

Export Limits and Marketing Practices

Importers of cereals at least from North America also have tools and mechanisms available for controlling DON content. In concept, these are similar to those of domestic mills and primarily include contract limits for DON content. However, additionally these can include targeting locations, ports, and suppliers that have the

[13] NGFA (2011) provides a detailed explanation of the implementation of these regulations.

[14] CODEX (Codex Alimentarius Commission) was established by the UN FAO and World Health Organization for setting international food standards, guidelines and codes of practice that contributes to the safety, quality and fairness of food trade.

[15] Bianchini, et al. (2015) discuss the prospective implications of this regulations on the North American processing sectors.

ability to reduce DON content in years when it is problematic. This is already a current and effective practice and has the effect of targeting origins, testing, and segregating, and inducing cleaning at both country and export elevators prior to shipping. The effect of these would be to increase the intensity of cleaning and targeting of origins for the grain prior to exporting.

This is most commonly accomplished by targeting origins, and segregating, cleaning, and blending at the country elevator and at the export elevator (Johnson, et al. 2001) prior to shipment, ultimately to meet specification limits made by importers. For illustration, Table 3.4 shows a list of importing countries and their contract limits on DON in the case of wheat from the United States. Of course, the effect of these are the cost of testing, potential rejections, and are impacted by the available supply of DON free wheat.

It is important that a number of these specifications are effectively tighter than those applied at the U.S. domestic milling industry. First, the international limits as indicated are on the raw grain, as opposed to the finished product as in the U.S. industry. Second, some of these, notably the EU as well as some other large buyers have limits in the 1 to 1.25 level, which on raw grains is substantially tighter than applied in the U.S. Industry.

Table 3.4. International DON Limits by Country

Country	DON Limit (ppm)	Country	DON Limit (ppm)
Bolivia	2	Israel*	1
Canada*	2.0(under review)	Japan*	1.1
Brazil	2	Jamaica	2
Chile	2	Jordan	2
China*	1	Malaysia	2
Colombia	1.25;	Mexico	2
	2 in contracts	Nicaragua	2
Costa Rica	2	Norway*	1
DR	2	Nigeria	2, as needed
Ecuador	2	Pakistan	2
Egypt*	1.25;	Panama	2
	2 in some contracts	Peru	2
El Salvador	2	Philippines	2
EU*	1.25 common wheat; 1.75 durum	Russia*	0.7
	1.75 Durum	Singapore	2
Guatemala	2	South Korea*	1
Haiti	2	Taiwan	2
Honduras	2	Thailand	2
Indonesia	2	Trinidad-Tobago	2
India*	1	Vietnam	2
Iraq	2	Venezuela	2

*Government Regulation
Source: U.S. Wheat Associates.

Market (futures) Regulations and Treatment of Scab

Both the futures and cash markets (discussed below) have an impact on the supply and disposition of cereals having potential scab damage.

The futures market has had varying regulations on DON or vomitoxin over time. The Minneapolis Grain Exchange (MGEX) has always had a specification limit on HRS wheat with vomitoxin. That is stated as not specific, but is acceptable for food consumption. Specifically, *Rule 2040:* indicates

> "Wheat declared unfit for human consumption under Federal Food, Drug and Cosmetic Act is not deliverable on a Minneapolis Futures Contract."

Thus, any wheat that is deliverable must conform to the FDA regulations, which allows flexibility over time. This was the prevailing reference for the MGEX futures until May 2013. At that time, Resolution 803 was made regarding vomitoxin, which indicated: [16]

[16] Source: http://www.mgex.com/documents/MGEXDeferredRules1-19-12.pdf

Effective with the May 2013 contract month, all warehouse receipts issued for delivery against Hard Red Spring Wheat ("HRSW") futures contracts shall be marked with a deoxynivalenol ("vomitoxin") limit expressed in tenths as either (i) 2.0 parts per million or (ii) 3.0 parts per million. Warehouse receipts marked as 2.0 parts per million or 3.0 parts per million shall represent a maximum vomitoxin level. Further, warehouse receipts marked as 2.0 parts per million shall be delivered at contract price, while receipts marked as 3.0 parts per million vomitoxin shall be delivered at a 20 cents per bushel discount.

The CBOT (Chicago Board of Trade) treatment of vomitoxin also has changed over time. Prior to 1999 there was no limit on DON. As early as 1996 there was concern that the CBOT wheat futures could be a dumping ground for wheat with high vomitoxin. Simply buyers of wheat with high vomitoxin would sell futures, make delivery, and in the process liquidate their positions through delivery. The impact of this was to distort the pricing structure for wheat, ultimately prospectively forcing CBOT values to feed equivalence. This is important, as the CBOT is the reference price for all SRW and a derivative for all other classes.

In response, the CBOT initiated a series of changes, which are summarized in Table 3.5. In the deliberations leading to these changes, there were a number of important views. Most important was that there was "support eliminating delivery of 4 ppm vomitoxin wheat arguing that the export and milling markets typically specify a maximum of 2 ppm vomitoxin, and then 4 ppm designation on CBOT wheat makes it a feed wheat contract and constrains participation in the delivery market."[17]

[17] As indicated in a letter dated Sept 5, 2008 to the Office of the Secretariat CFTC regarding implementation of changes to the CBOT wheat futures contract.

Table 3.5. Evolution of CBOT Changes to Vomitoxin in Wheat Futures

Contract Dates	Discount
pre-September 1999	No DON-related discounts
September 1999 – July 2006	Maximum 5ppm (specification added to require 2 cents/bu max. to endorse receipts)
September 2006 – July 2009	Maximum 4ppm (no set price to endorse receipts, WN6-WU6 spread at about 6 cents/bu discount 5ppm to 4ppm)
September 2009 – July 2011	Par Maximum 3ppm, 12 cents/bu discount at Maximum 4ppm
September 2011 – July 2012	Par Maximum 2ppm, 12 cents/bu for 3ppm and 24 cents/bu for 4ppm
September 2013	Par Maximum 2ppm, 20 cents/bu discount for 3ppm.

Prior to the September 2011 contract month, wheat with a vomitoxin level of 3 ppm was deliverable at par and at 4 ppm with a discount of 12 cents/bu. These changes were added to a previous change on September 1, 2009 requiring shipping certificates to be marked with either 3 or 4 ppm vomitoxin (CBOT 08-138). They kept the par specification for vomitoxin at 2 ppm and discounted 3 ppm to 20 cents/bu. They also determined that wheat with 4 ppm vomitoxin would no longer be deliverable. These amendments were made effective with the September 2013 contract month. (CBOT 11-329).

Market (Cash) Discounts

In addition to the discounts implied in futures contracts and limits posed by buyers, discounts for excessive DON in cash markets are particularly important. To validate and document these practices, we conducted an informal interview of a number of country elevators, and a survey of intermediate/export traders (see Appendix A). These results are summarized in this section.

Discounts in the cash market are very important and are ultimately the mechanisms that convey signals to growers and input suppliers regarding the value of reduced or excessive DON. They also provide the mechanisms to allocate the distribution of wheat within and between market channels, and between the domestic and export markets. The survey provided a number of generalizations including:

- Discounts in the cash market for DON vary through time and across market participants in the supply chain. However, there is limited public information on these discounts over time;

- While in practice, these discounts change in time, they do not seem to have changed substantially. Rather, it is more common that the quantity to which the discounts apply varies;

- Discounts tend to be larger and more variable at the country elevator level; smaller at the level of intermediate traders and discounts at mills vary depending if it is an origin or destination mill (see discussion below).

  The likely reason for this is largely that the greatest amount of inter-sample variability is at the country elevator level. As grain moves through the market place, buyers impose limits, and suppliers segregate/blend as appropriate to conform to these quantitative limits.

- There is very limited information that is public and can document these observations through time.

Testing, Strategies, and Discounts across the Supply Chain

Below are representative cash market discounts for DON at the country elevator level and for intermediate traders (discounts at mills are discussed in a section below).[18]

Cash discounts and limits for excessive DON for a representative country elevator in North Dakota are shown in Table 3.6. Typically, and in recent years, the specification at which nil discount is applied is 2 ppm, though during 2011 the specification differed. Discounts would apply for levels greater than this and in recent years are from 5 to 10c/b per ½ ppm. For excessively large levels of DON, larger discounts or limits may apply.

[18] This analysis ignores the impacts of SCAB on importers and exporters. It is important, as this problem evolves, that 1) EU standards are tighter than in the US; 2) buyers make specifications to conform, but 3) traditionally rely on origin testing which uses different tests and averaging; 4) at discharge, EU importers use specific EU sampling methods and test with the HPLC method; and as a result 5) there is periodic excessive DON in shipments when received in the EU, due in part to using different tests, and sublot averaging protocols.

To resolve this, the Federal Grain Inspection Service (FGIS) submitted a pre-approval request to the EU Commission for them to accept DON tests at origin. However, this was rejected. FGIS uses the Elisa quick test method for DON and routinely tests 0.2 ppm above HPLC. However, the EU does not view this method as reliable.

The impacts are huge and result in wheat being disallowed to enter the food channels. These are important problems and are referenced, recognizing these problems are beyond the scope of this study.

Table 3.6. Representative Cash Market Discounts in HRS at Country Elevator[19]

Crop Year	Specification limit (allowed) without discounts	Discount
2011	1	5c per ½ ppm; >5.1=60c
2012	2	0-2.6 ppm=0; >2.6 10c
2013	2	5c/ ½ ppm over 2;
2014	2	10c/ ½ ppm
2016	2	5c/ ½ ppm for 2.1 to 4 ppm; 10c/ ½ ppm >4.1 ppm

A survey of intermediate traders representing buyers for resale to export markets or domestic mills was conducted. By far the dominant specification/treatment was:

- 2 ppm allowed without discounts;
- Shipments with greater than 2 ppm would be discounted typically at 10c/ per ½ ppm.

For SRW and HRW the more common values were the same as above. However, the discounts ranged from:

- 5c/ per 1 ppm, and 20c if DON>3 ppm.

Another trader shared the following discount schedule for 2015 SRW:

2.1 - 3.0 ppm -0.50
3.1 - 4.0 ppm -0.70
4.1 - 5.0 ppm -0.90
5.1 - 6.0 ppm -1.25
6.1 - 7.0 ppm -2.00
7.1 - 10.0ppm -2.75

Finally, the respondents (intermediate traders) described their procurement and typical testing protocols. These can be generalized as:

- Procurement strategies involved simply applying specification limits and discounts in purchase specifications. In addition, blending was used if/as necessary. Typically, buyers would rarely reject shipments, but instead apply discounts, segregate it, and find a way to blend it in later shipments.

- One shipper indicated that if DON>5 ppm they would reject the shipment; and another indicated they would not reject unless DON>10 ppm.

[19] Similar questions were asked of durum; but, all traders indicated these were difficult to document and track.

- There was only limited use of targeting or excluding origins.
  Generally, traders indicated that now DON was manageable.

- Specification limits: Virtually all buyers use a specification of 2 ppm without discounts. The reason for this is that mills would typically reject if DON>2 ppm. Also, exporters or terminal markets would discount or reject if DON>2 ppm.

- Discounts in HRS were the same as those above; but they indicated the country might have greater discounts than intermediate traders. One trader indicated their current discount at 10c/ ½ ppm over 2 ppm.

- Testing in HRS varies from year to year, typically testing early to assess concerns and adjusting later. Estimates of testing costs range from $15 to $20 or as high as $30/test. Elisa was the most common test.

- Testing protocols were to routinely test 1 test per 5 rail cars (i.e. a composite sample from 5 rail cars) at $15/test;

- Testing in SRW: Results indicated 1 test per rail car or truck, typically at $5/test; and tests were only conducted if early season shipments from an elevator or region had DON values exceeded 2 ppm

Lastly, traders were of the perception that the reason for improved DON was 1) increased use of fungicide; 2) adoption of MR varieties; and 3) making adjustments in the harvester, though the former was of greater importance.

Distribution of Market Discounts

To illustrate the quantitative dimensions of discounts on the aggregate market, we developed a stochastic simulation model for the HRS area. There are two important sources of uncertainty. One is the level of DON in a region or shipment. The other is the level of discounts that would apply. This section develops a methodology and data that are used to estimate the impact of reduced DON on discounts applied in the wheat marketing system.

Stochastic simulation was used to quantify the level of the value of discounts and its distribution. The base case DON levels were for each year. The base case specification limits and discounts were defined to reflect a broader case as typified in the table above. These were:

- Specification limits which were allowed without discounts: 1, 2, or 2.5 ppm and distributed randomly;

- Discounts were -10 c/bu per .5 ppm DON exceeding acceptable levels.

Sensitivities were then conducted.

Two cases are shown for HRS. The distribution for the average from 2004-2015 (Red) is shown, as well as that for the 2015 crop year (Figure 3.2). As illustrated, the distribution for 2004-2015 shifted leftward to reflect the trend in region B's reduced DON over time. The mean decreased from .50 to .28 and the share of the crop with >2 ppm is small. Discounts would apply to those samples with > 2 ppm. The probability of DON > 2 is: 2.4% for 2004-2015 and 1.3% for 2015. The probabilities also vary by region: from nil to .09. The best regions were ND D, Mt, SD A and the worst cases were ND A, B, F, SD C Mn B (Figure 3.3).

Results of the simulations are shown below. Important points of these are:

- In the base case (Figure 3.4), the aggregate value of DON discounts in HRS=$1.9 m/yr. The cumulative probability distribution (CDF) shows a large proportion of time, no discounts are applied (about 75%). There is a wide range of discounts: 0 to $11.1 million with a probability of 90%;

- For 2015, the level of DON in the crop was improved relative to the previous average. The result indicates the aggregate value of DON discounts in HRS was $1.6 million;

- In a simulation of the CODEX proposal (discussed above) the results indicate the aggregate value of DON discounts would increase to $4.6 million

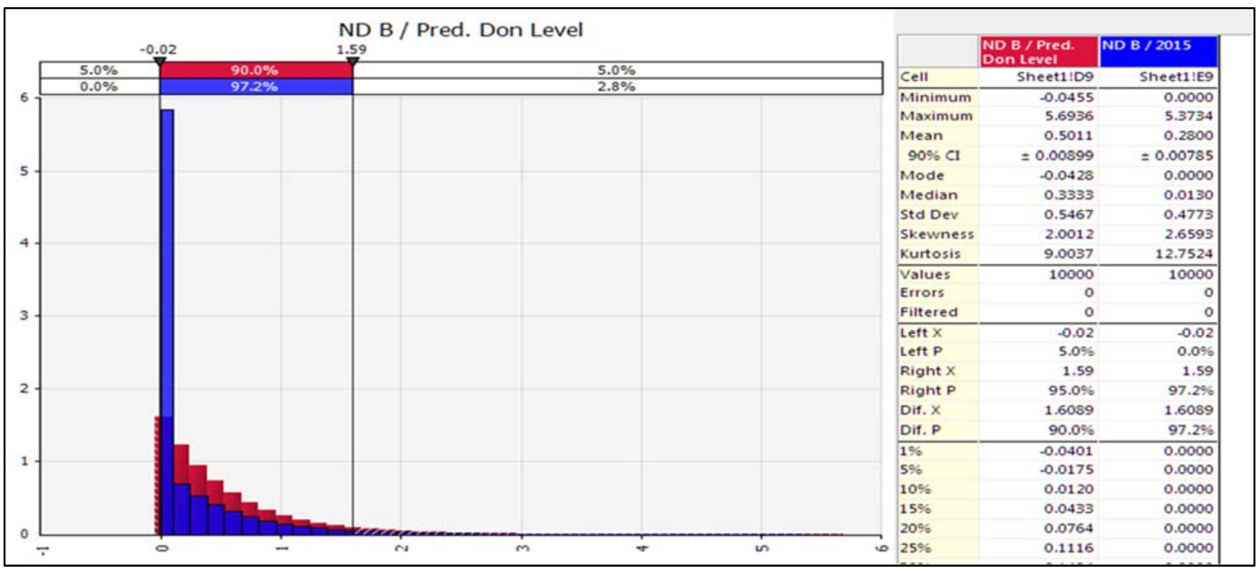

Figure 3.2. Simulated Distribution of DON Discounts, 2004-2015 and 2015.

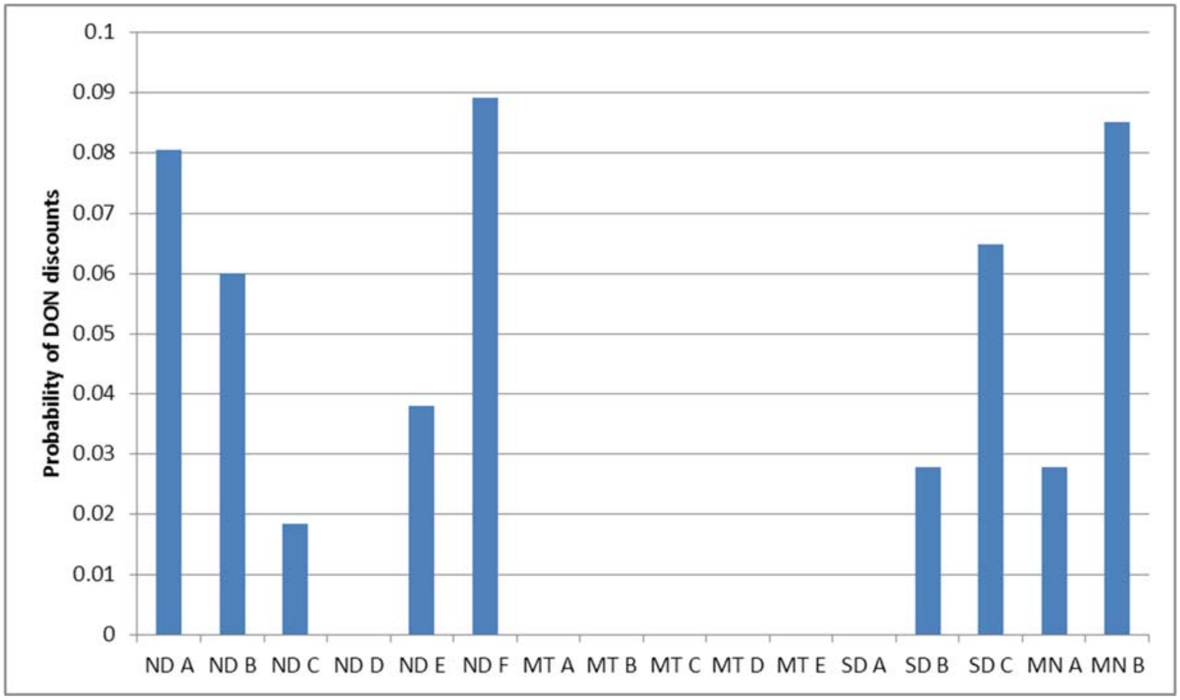

Figure 3.3. Probability of HRS DON Discounts Being Applied, by Region/State.

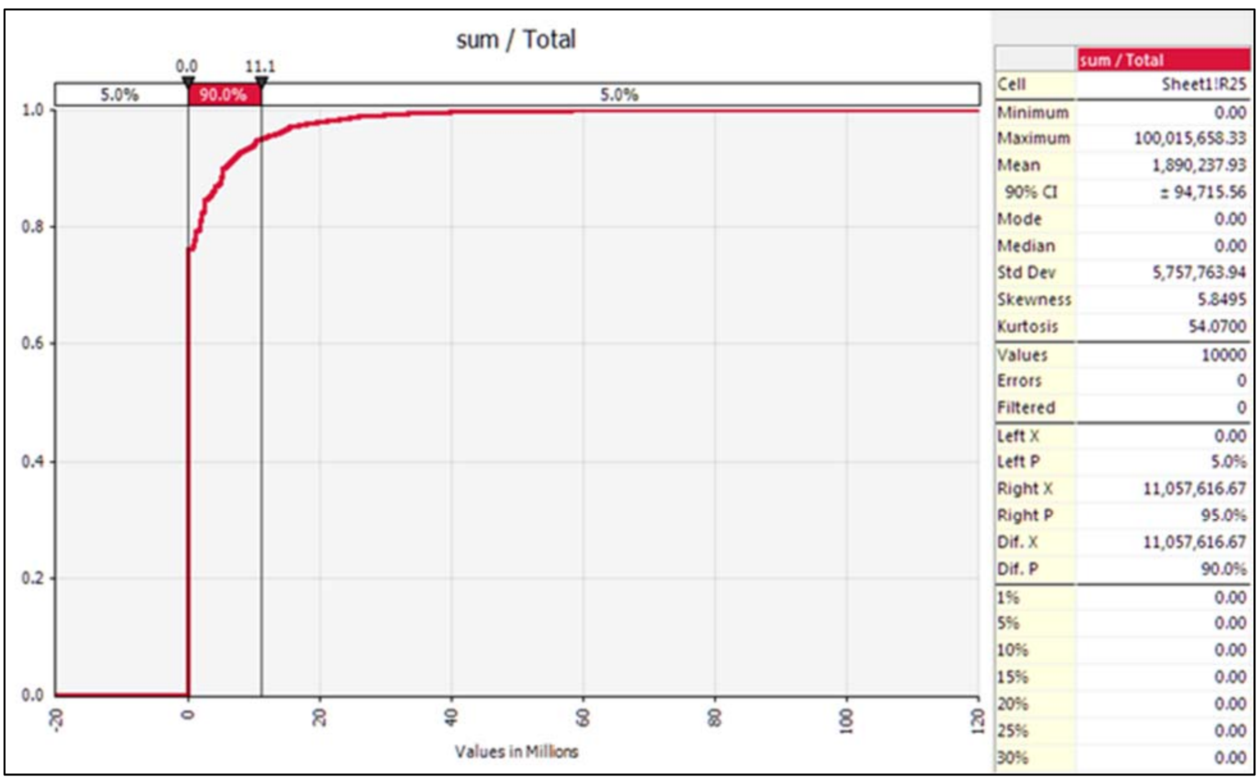

Figure 3.4. Simulated Cumulative Distribution Function for HRS Scab Discounts.

The probability of excessive DON in SRW was much higher than for HRS (Figure 3.5). The highest probability of discounts occurred in Kentucky, followed by Indiana, Ohio, Illinois, Maryland, and Missouri. Low probability states included Arkansas, Virginia, and North Carolina.

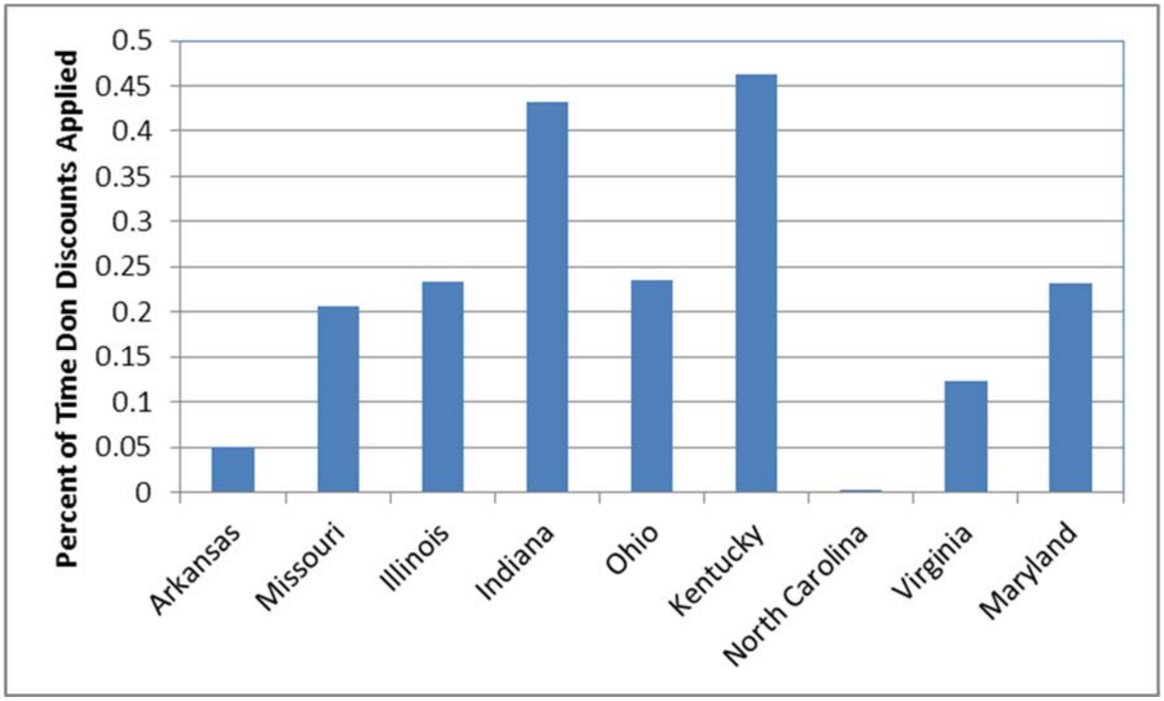

Figure 3.5. Probability of DON Discounts Being Applied for SRW States, 2006-2015.

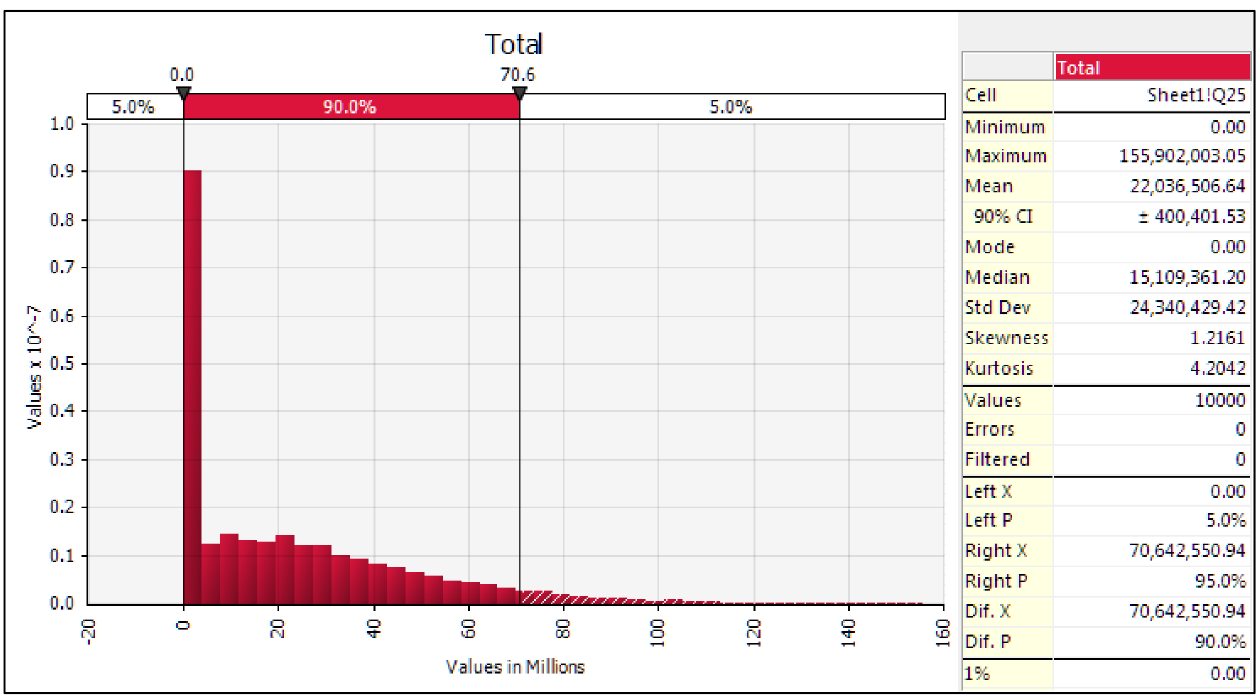

Figure 3.6. Simulated Cumulative Distribution Function for SRW Scab Discounts.

- For SRW (Figure 3.6), the aggregate value of DON discounts in SRW=$22 million/yr. The CDF shows that for a large proportion of time, no discounts applied (about 90%). There is a wide range of potential discounts.

- Sensitivities were conducted for HRS and SRW for DON discounts in 2016. Discounts for HRS were $0.05/per 0.5 ppm for HRS from 2 ppm to 4 ppm and $0.10/per 0.5 ppm above 4 ppm. Discounts for SRW were $0.05 per ppm from 2 to 4 ppm.

  In this case, the simulated costs for DON discounts for HRS were $455,488 and for SRW were $3.1 million for 2016.

Potential reasons for higher discounts in SRW include higher production of SRW and a greater probability of DON exceeding specifications in any one year.

Scab Mitigation Tools

Other authors have described the tools used and adopted by the industry to mitigate the risks of DON. Early on, Aakre et al. (2005) defined the essential tools for growers to include: crop rotation, tillage practices, resistant varieties resistance, and fungicide applications.

These risk mitigation tools were also described recently in Bianchini et al. (2015). These include what was defined as:

1) Variety selection and best management practices;
2) Toxin prediction (fungicide application and increased sampling);
3) Disease forecasting;
4) Source management cleaning
5) Processor specifications and
6) Surveillance.

The specifications of this array of tools includes several downstream mechanisms. Taken together, these have had the impact of reducing the incidence and risk associated with DON within the marketing system and amongst supply chain participants.

Fungicide Use in Wheat

The section above provided a quantitate review of the adoption of MR varieties, which has gone a long way toward mitigating risks in the marketing system.

The increased use of fungicide is very important and has contributed to a reduced incidence of DON. The figures below (Figures 3.7-3.10) were created from data obtained from USDA-NASS (2016) and illustrate the use of fungicide in this sector. The important points from these data indicate:

- Fungicide use has increased in each class of wheat, notably since about the mid-2000s, and varies across states;

- That for HRS increased from near nil in the early 2000s to now at about 40 to 75% of the area planted, with the greatest use in Minnesota and North Dakota;

- For winter wheat, fungicide use has increased from virtually nil in the early 2000s to now ranging between 40-60% of the area planted. States with the greatest use of fungicide include Idaho, Illinois, Missouri, Oregon, South Dakota, and Washington;

- Durum use of fungicide increased sharply after the 2006 crop year, and now is 70+% in North Dakota; and

- For barley in North Dakota, the use of fungicide increased from about 10% in 2003 to nearly 50% in 2011. Other major producing states are in the area of 30%.

Finally, the growth in use of fungicide as a management tool may be driven "as much by other diseases as it was by FHB" as suggested by Wiersma (2016).

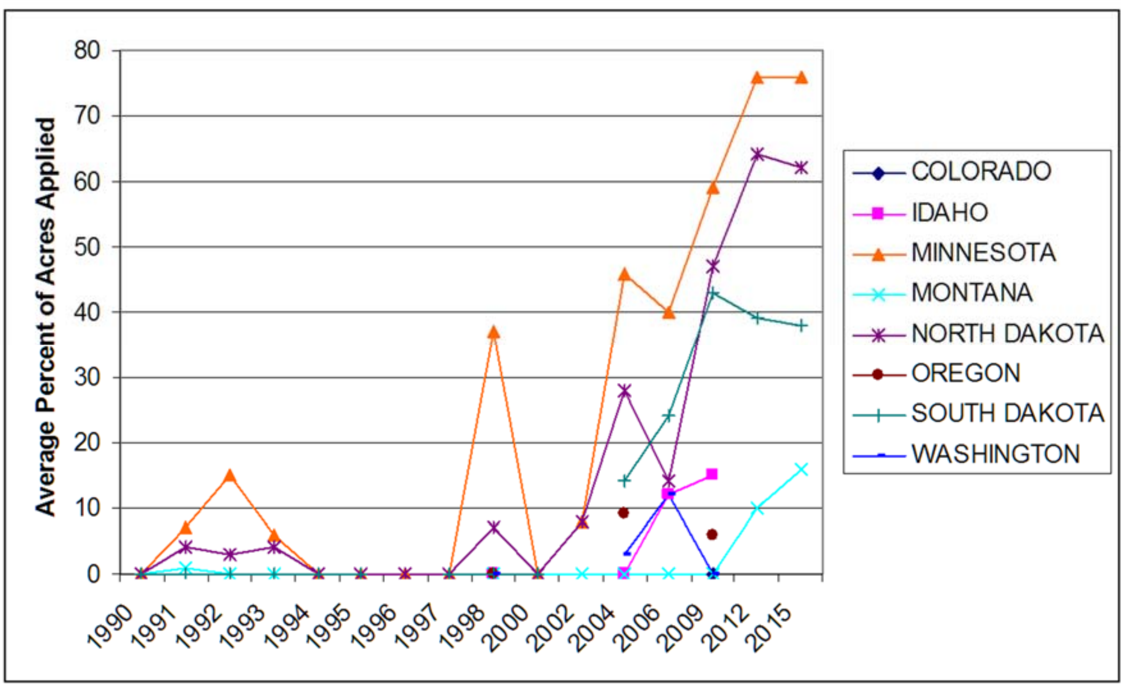

Figure 3.7. HRS Use of Fungicides by State, 1990-2015.

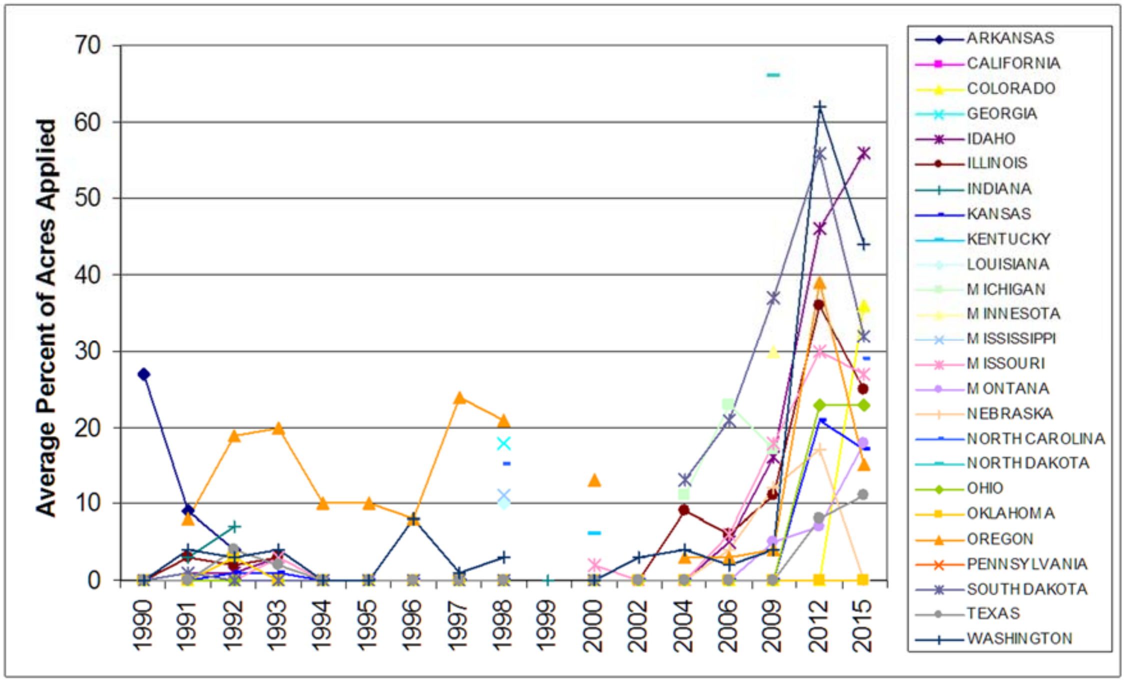

Figure 3.8. Winter Wheat Use of Fungicides by State, 1990-2015.

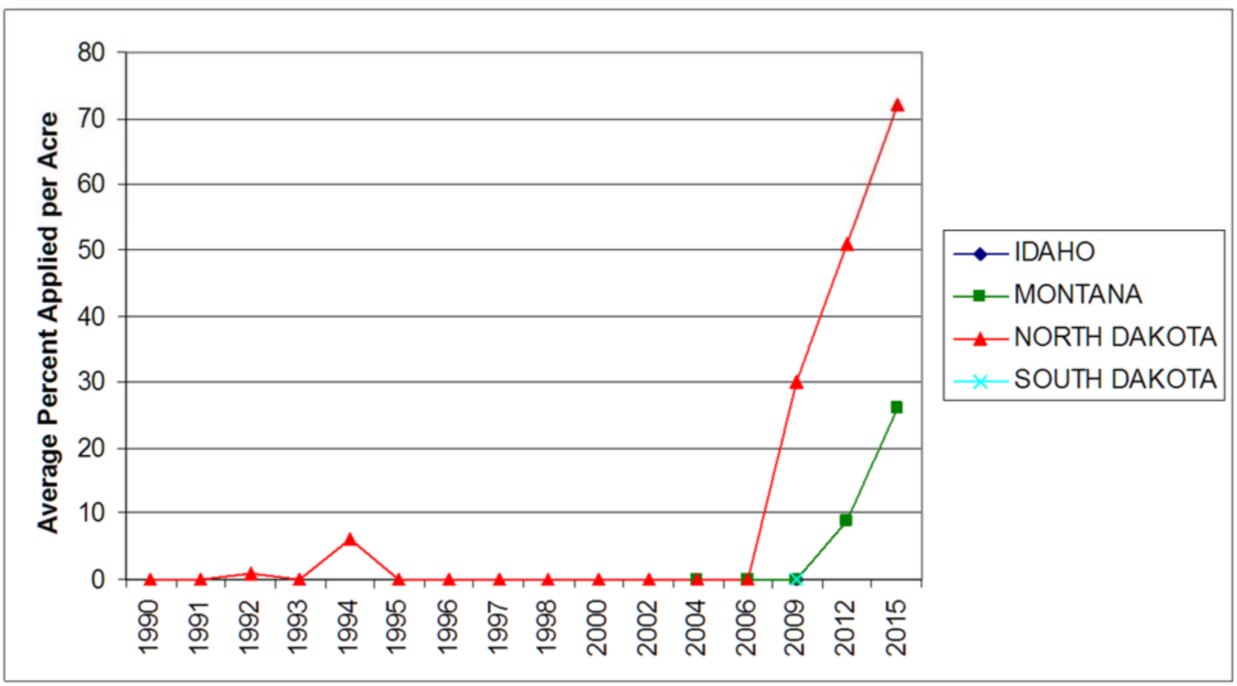

Figure 3.9. Durum Wheat Use of Fungicides by State, 1990-2015.

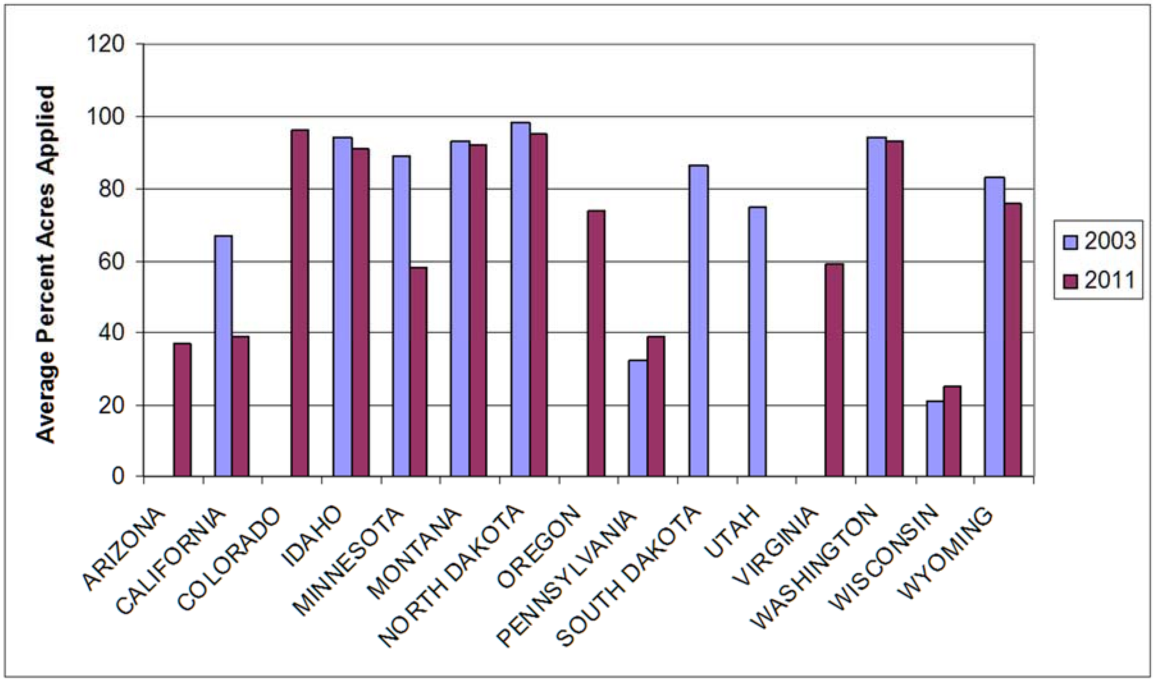

Figure 3.10. Barley Use of Fungicides by State, 2003 and 2011.

4. Impacts of Mitigation Strategies on Yield and DON[20]

Objective 1 of this study seeks to evaluate how management tools and technologies impact the level of wheat yield and DON in wheat and barley. The first section below provides a detailed statistical analysis of these relationships. Then, in the section that follows, this is used to evaluate how these relationships impact returns and risk for growers of these crops.

Using a statistical measure of the rate of scab management technique adoption and dissemination of scab management research results, we measure the value of foregone, suboptimal, scab management practices that could have been adopted but for extension of scab research results to the public. Data for this will come from the recently completed NASS survey conducted by NCSU (Christina Cowger and colleagues). Additional data will be taken from Paul et al. (various dates) as appropriate.

The results will be used to simulate performance of varieties and management techniques that are very susceptible, susceptible, moderate resistant, and resistant varieties with/without fungicide application vs. other crops (corn, soybeans, and barley). New fungicides, application technologies, and management practices are particularly important for durum and barley since resistant FHB varieties are yet to be developed.

Scab reduces returns to farmers of wheat and barley through reduced yield and reduced grain quality. Farmers use management techniques to reduce yield loss and mitigate penalties for relatively high levels of DON. This study uses data assembled from multiple sources to estimate the relationship among wheat yield (bu/ac) and grain quality (DON ppm) in wheat and barley, scab presence, and use of scab management techniques.

Management techniques include 1) growing moderately resistant varieties, 2) applying a recommended fungicide with scab as the primary target at heading or flowering, 3) rotating crops so that growing wheat rarely or never follows another small grain or corn crop, and 4) growing varieties that head at different times. A selection of other independent variables used by Haidukowski et al. (2005) is adopted to estimate the relationship between yield and DON in wheat, or DON in barley, and scab presence, as well as additional information on scab management techniques. Evaluating these statistical relationships under selected levels of scab presence and scab management decisions facilitates an estimate of foregone yield and quality (DON) loss, when scab management techniques are used.

Analytical Overview

Econometric models were specified to examine the relationships and factors that impact wheat yields, and DON levels in wheat and barley.

[20] Research reported in this section was led by Dr. McKee.

The data is from field trials and covers the period 2007-2010 for wheat and 2008-2015 for barley.[21] Data is included for HRS, HRW, SRW, Soft White Winter Wheat (SWWW), and malting barley and is from a broad geographical area including IL, IN, LA, MD, MO, ND, NY, SD, OH, and VA. There are 1698 observations with non-missing values of DON, and 2382 for barley. Data for each includes: yield, DON, variety (cultivar), resistance, fungicide use, severity, scab incidence, disease pressure, wheat class, location, and year and management techniques. Tables 4.1 and 4.2 categorize each variety for resistance. The data were pooled across classes and regions and the values of DON and yield are standardized.

Data on management techniques are taken from Cowger.[22] These variables are combined with the field trial data and used to evaluate their impact on yield and DON. Producers decide whether to adopt any of the four scab management practices including: 1) growing moderately resistant varieties, 2) applying a recommended fungicide with scab as the primary target at heading or flowering, 3) rotating crops so that growing wheat rarely or never follows another small grain or corn crop, and 4) growing varieties that head at different times. These data are combined with field trial outcomes from any combination of any of the four management practices and assumed to hold in any commercial production condition using the same combination of scab management techniques.

Three models are specified. These include:

- Wheat yield=*f* (variety (resistance), disease pressure, fungicide, incidence, severity, DON, location, year, class);

- Wheat DON=*f* (fungicide, resistance (variety), incidence, class, severity, location, year); and

- Barley DON=*f* (variety (resistance), disease, fungicide, resistance, incidence, severity, location, year).

The variables and data are explained fully in Appendix B.

In addition to these general specifications, we evaluated a number of interaction effects. Most important is the interactions among: variety and fungicide, etc. The models are estimated using ordinary least squares of pooled data. Statistical tests were evaluated about the appropriateness of each variable, their interactions and how they impact the dependent variable.

[21] Appendix B contains a detailed description of the data and the model specification and estimation procedures.

[22] The data from Cowger was the original data from a survey (personal communication).

Table 4.1. Wheat Variety, Class, and Resistance. Field Trials, Years 2007-2010, Various Locations.

VARIETY	CLASS	RESIST ANCE	VARIETY	CLASS	RESIST ANCE	VARIETY	CLASS	RESIST ANCE
2137	HRWW	VS	Excel5530	SRWW	MR	NuDakota	HRWW	MS
25R47	SRWW	S	Expedition	HRWW	MS	Oklee	HRSW	MS
AC_9511	SRWW	MR	Falcon	HRWW	S	Overland	HRWW	MR
AC_BRANSON	SRWW	MS	Faller	HRSW	MR	P2137	HRWW	S
ACCIPITER	HRWW	S	Freyr	HRSW	MS	P25R47	SRWW	S
ADA	HRSW	MS	GA6E8	SRWW	MS	P25R54	SRWW	MS
AGI101	SRWW	MS	Glenn	HRSW	MR	P25R56	SRWW	S
ALICE	HRWW	MS	Goodstreak	HRWW	MS	P25R62	SRWW	MS
ALSEN	HRSW	MR	Granger	HRSW	MS	P25R78	SRWW	S
ART	HRWW	MR	Granite	HRSW	MS	P26R15	SRWW	MS
BANTON	HRSW	MS	Harding	HRWW	MS	P26R61	SRWW	S
BESS	SRWW	MR	Harry	HRWW	MR	Paul	HRWW	MS
BIGRED	HRSW	MS	Hawken	HRWW	S	Peregrine	HRWW	MS
BOOMER	HRWW	MS	Hopewell	SRWW	MS	Pro220	SRWW	MS
BRICK	HRSW	MS	Howard	HRSW	MS	Radiant	HRWW	MS
BRIGGS	HRSW	MS	INW0412	SRWW	MR	Ransom	HRWW	MS
BUTEO	HRWW	S	INW0801	SRWW	MS	Reeder	HRSW	S
BW5170	SRWW	MR	Jagalene	HRWW	S	Richland	SWWW	S
BW5530	SRWW	MR	Jensen	SWWW	MR	Roane	SRWW	MS
CARTER	HRWW	MR	Jensen	SWWW	MR	Roughrider	HRWW	MS
CHESAPEAKE	SRWW	MS	Jerry	HRWW	MR	Rush	HRSW	MS
COKER9155	SRWW	MR	JTOWN	SRWW	S	Sampson	HRSW	VS
COOPER	SRWW	S	Kaskaskia	SRWW	MS	SD96240-3-1	HRWW	MS
CUMBERLAND	SRWW	S	Knudson	HRSW	MS	SD98W175-1	HRWW	MS
D8443	SRWW	MR	LA841	SRWW	MS	SS8641	SRWW	S
DARREL	HRWW	MS	Lolo	HRSW	MS	SteeleND	HRSW	MS
DARRELL	HRWW	S	Lyman	HRWW	S	Striker	HRWW	S
DECADE	HRWW	S	Mace	HRWW	S	Traverse	HRSW	MR
ELKHART	SRWW	S	McCormick	SRWW	MS	Trooper	HRSW	S
EXCEL5170	SRWW	MR	Millenium	HRWW	S	Truman	SRWW	MR
						Ulen	HRSW	MS
						Wendy	HRWW	MS
						Wesley	HRWW	S
						Yellowstone	HRWW	S

VS = Very susceptible
S = Susceptible
MS = moderately susceptible
MR = moderately resistant
R = Resistant

Table 4.2. Barley Variety and Resistance. Field Trials, Years 2008-2015, Various Locations.

Variety	Resistance
2ND25276	S
AC Metcalf	MS
CDC Meredith	MS
CDC Mindon	MR
Celebration	S
Conlon	MS
Eslick	S
Excel	MS
FEG65-02	MR
Innovation	MS
Lacey	S
Legacy	MS
M122	MS
Merit	S
ND Genesis	MS
ND20448	MS
ND22421	S
ND26036	S
Pinnacle	MS
Quest	MR
Rasmusson	S
Rawson	S
Robust	S
Scarlet	MR
Stellar-ND	MS
Tradition	S

S = Susceptible
MS = moderately susceptible
MR = moderately resistant

Statistical Results

Wheat yield

Estimated coefficients for Equation 1 appear in Appendix Table B1.[23] These show a statistically significant relationship between varieties, severity, incidence, DON, wheat class, location, year, management techniques, and wheat yield. The R-square for the estimated equation is 0.71.

Several variety dummy variables are statistically significant, with mixed signs. These marginally increase or decrease wheat yield in the presence of scab, relative to

[23] Statistical results are shown in Appendix B; and in this section the marginal effects are interpreted.

the intercept. The absence of a significant coefficient for a given variety only implies that its marginal effect on yield is not different from the average of the observed varieties. The estimated yield of two varieties, Excel5530 and Wesley, is affected by the presence of medium disease pressure. This suggests unique production properties exist among varieties developed by the Initiative that depend distinctly from other varieties, such as the other thirteen with significant estimated coefficients in Equation 1, or the other varieties from this sample pooled into the intercept.

Fungicide use alone, as a scab management technique, increases yield (see Figure 4.1). Fungicide use, combined with planting selected wheat varieties, also has a significant effect on yield, as observed by the estimated coefficients on three dummy variables (Exc5170, P26R15, and Richland). This is an explicit, complementary relationship between variety and fungicide use. Two varieties (Bess, P25R47) are observed to have a significant three-way effect: variety, fungicide, and disease pressure.

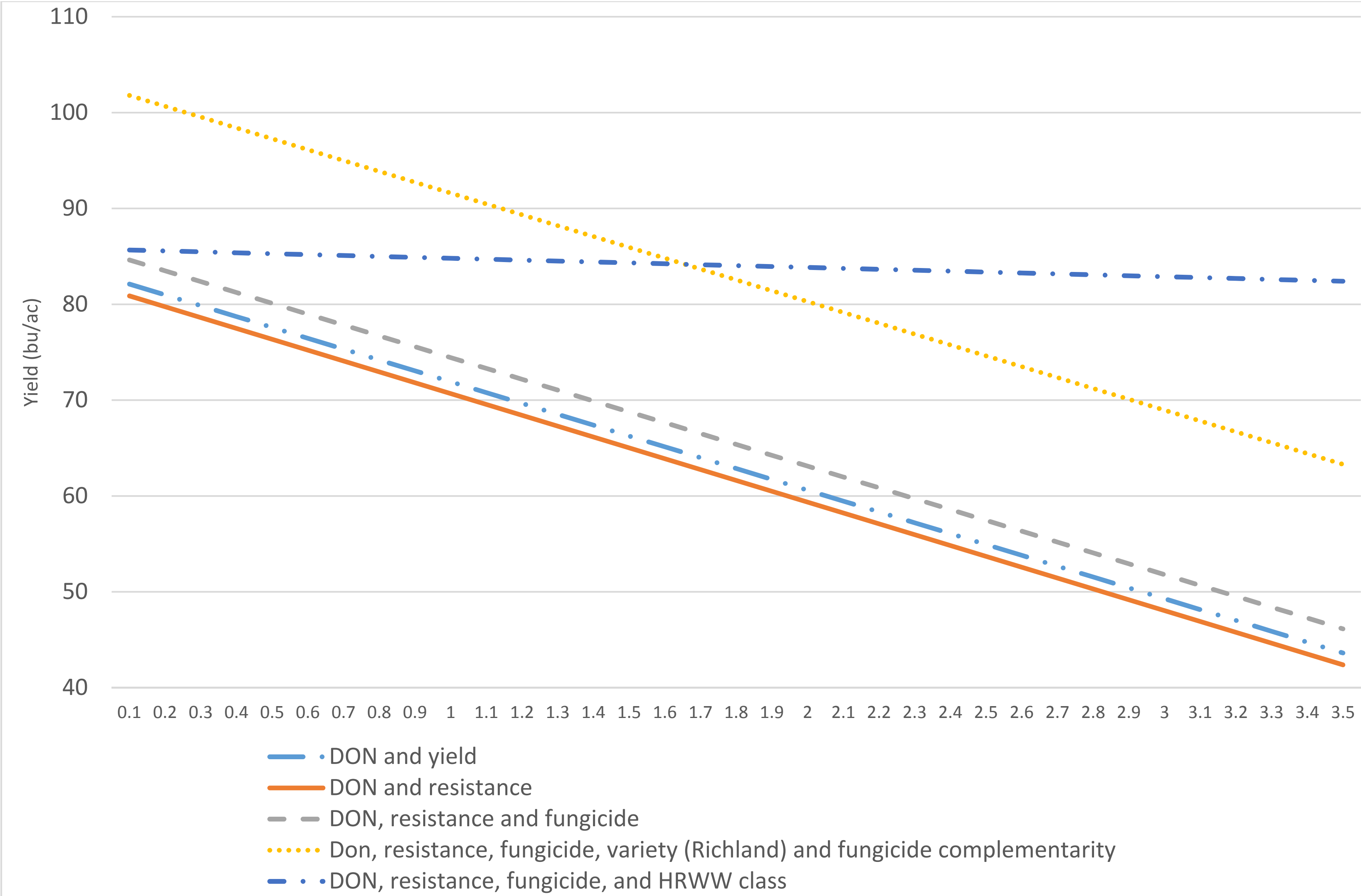

Figure 4.1. Illustration of Marginal Tradeoffs between Wheat Yield (bu/ac), DON (PPM), Scab Resistance, Fungicide Application, and the Complementary Effects of Fungicide and Variety (e.g. Richland).

The dummy variable *Resistance* has a significant, albeit negative, marginal effect on wheat yield (see Table 4.1 for description of variety resistance). This indicates that variety selection for scab resistance alone does not, on the margin, increase yield within this sample of varieties developed during the life of the Initiative. However, there is a complementary relationship between variety and fungicide as noted above, i.e., the effect of variety depends on use of fungicide. The yield effect is the foregone yield loss from reduced incidence, reduced severity, or resistance combined with a variety. For instance, Wegulo et al. (2011) showed that, although scab index is reduced in moderately resistant varieties as compared with susceptible ones, yield is negatively correlated with index. In contrast, of the twenty significant estimated coefficients involving a variety in Table 4.1, seventeen are classified as other than susceptible. Some level of resistance appears to be required in order for a significant marginal yield effect to be present, even if it is not always a positive one. In six of these cases the marginal yield effect of variety, with some level of resistance, is positive. Hence, integrating scab resistance in the variety with fungicide application can be effective for wheat yield management.

The dummy variable *Incidence* is statistically related to wheat yield in combination with wheat class. The estimated coefficient of the variable *Incidence* without respect to wheat class is statistically insignificant in Equation 1. Scab incidence is observed to have a significant and negative marginal effect on HRWW yield and a positive and significant marginal effect on SRWW yield. The estimated coefficient of the variable *Severity* is statistically significant and negative when considered across all wheat classes. A separate interaction term estimated for the interaction of scab severity with the HRSW class is also negative and statistically significant.

Finally, the presence of DON also has a significant, negative effect on wheat yield (see Figure 4.1), regardless of class. The negative effect is less in the case of HRWW varieties (see Figure 4.1). Hence, there is a marginal tradeoff between DON levels and wheat yield in all classes of wheat; it is only when management practices reduce incidence or severity this effect is overcome on net. Also, this yield tradeoff is ameliorated when fungicide applications are made or a variety is planted with positive complementarity between variety and fungicide applications (see Appendix Table B2).

Location, year, and wheat class also have a unique relationship with wheat yield in the presence of scab. Of the nineteen observed locations, eleven have a statistically significant estimated coefficient. Of these, Bradford, Carbondale, “IN”, Princeton, and “WYE” had greater wheat yield relative to evaluating Equation 1 with the intercept alone. Hence not all yields across locations fare equally well in the presence of scab, and most locations have a statistically significant effect on wheat yield, relative to the intercept. Of the four observed years (2007-2010), all three years included in the model (2008-2010) had a statistically different effect on wheat yield. The effect was positive in 2008 and 2009.

Marginal Effects on Wheat Yields

The statistical results indicate there is an economic value from scab management practices developed within the USBWI for wheat production during the sample period. A selected combination of management techniques results in increased yields, relative to evaluating Equation 1 at the intercept alone, of 1.0, 1.1, 7.5, 16.1, and 7.0 bu/ac respectively. If an average farm is 500 acres, and average grain price is $4.00, then revenues are increased between $2000 and $32,000 per farm, else equal.

These can be further explained using marginal effects, defined as how the dependent variable changes with respect to a change in the independent variable and recognizing any interdependencies. Table 4.3 shows a marginal effect of the estimated coefficient of Equation 1 on wheat yield. Thirteen significant coefficients for wheat varieties are observed. Of these, eleven have a negative marginal effect on wheat yield, relative to the intercept (see Table 4.1 for description of variety resistance). The estimated wheat yield, based on the intercept (absent management, disease, changes in incidence or severity, and other factors), is 83.24 bu/ac. Yield from variety P25R47 can be estimated by calculating the sum of the intercept and the associated dummy variable, resulting in an estimate of 93.14 bu/ac, a marginal effect of about 10 bu/ac. The use of variety P2137 has an estimated yield of 65.25 bu/ac, a marginal effect of about -18 bu/ac. Hence, some varieties have a unique yield relationship in the presence of scab and most yield poorer in the presence of scab relative to the average of the observed varieties in the observed sample.

Table 4.3 also contains an estimated marginal effect on wheat yield for the interaction terms that include a wheat variety and disease pressure. The estimated yield calculated by evaluating the intercept and the dummy variable of variety Excel5530 results in an estimate of 95.41 bu/ac under medium disease pressure, a marginal effect of about 12 bu/ac relative to the intercept.

The use of fungicide has a marginally positive and significant increase in wheat yield. The size of this marginal effect can be calculated from the intercept and the estimated coefficient of *Fungicide*, resulting in an estimated marginal yield change of 3.76 bu/ac when fungicide is used. Importantly, the marginal effect of fungicide is affected by the wheat variety planted, as measured by the interaction terms for variety and the *Fungicide* variable. For example, yield from the use of variety P26R15 with fungicide can be estimated by calculating the sum of the intercept, the estimated *Fungicide* variable coefficient, and the interaction term for *Fungicide* and P26R15, resulting in a marginal yield increase of 7.29 bu/ac relative to the yield from the intercept alone. Similarly, the use of variety Exc5170 with fungicide results in a marginal yield decrease of 8.48 bu/ac. Thus, fungicide applications have a net greater or smaller effect on these wheat varieties, and Richland, as compared to all others.

Table 4.3 also shows estimated coefficients for how the marginal yield effect of fungicide to selected wheat varieties is affected by disease pressure. The use of fungicide, under high disease pressure conditions, estimated yield from the variety Bess is 10.76 bu/ac smaller than evaluating the estimated intercept alone (see Table 4.3).

The estimated coefficient can be used to calculate the marginal change in wheat yield by scab resistance alone. Evaluating Equation 1 by using the intercept and the estimated coefficient of *Resistance* indicates use of a very susceptible variety, for example, marginally reduces wheat yield 1.24 bu/ac; similarly, the use of a moderately resistant variety marginally decreases wheat yields 4.96 bu/ac.[24]

Table 4.3 provides a measure of the marginal effect of changes in scab incidence and severity on wheat yield. All else equal, planting HRWW causes a one-unit increase in the arcsine of incidence to decrease yield 18.13 bu/ac. Similarly planting SRWW will cause a one-unit increase in the arcsine of incidence to increase yield 4.00 bu/ac. The marginal decrease in yield due to the interaction of scab severity in HRSW class wheat varieties can be estimated by calculating the yield from the sum of the intercept, and a severity of 1.0. The estimated marginal decrease in HRSW class wheat varieties from a one-unit increase in scab severity is 31.51 bu/ac.

The estimated coefficient for Equation 1 can be evaluated to calculate the marginal change in wheat DON by scab resistance alone. For HRW and SRW wheat classes, increasing the variety resistance from S to MS, or MS to MR, etc., is the estimated coefficient with the largest marginal change on DON. Evaluating Equation 1 by using the intercept and the estimated coefficient of *Resistance* indicates the use of a very susceptible variety, for example, marginally reduces DON 0.15 PPM; similarly, the use of a moderately resistant variety marginally decreases wheat DON 0.30 PPM.

Wheat DON

*(E*quation 2) *Estimated* coefficients of Equation 2 appear in Appendix Table B2. These show statistically significant relationships between variety resistance, severity, incidence, wheat class, location, year, management techniques, and DON levels (PPM) in wheat. The R-square is 0.56.

Several variety dummy variables are statistically significant, with mixed signs. These marginally change DON in wheat, relative to the intercept. The absence of a significant coefficient for a given variable only implies that its marginal effect on DON is not different from the average. The intercept is interpreted as an HRS variety planted in 2007, with a fungicide application and observed levels of scab incidence greater than 0.

Fungicide use when applied to varieties of various wheat classes, statistically reduces DON in wheat, as observed by the estimated coefficients on three dummy variables (HRW_fungicide appl., SRW_fungicide appl., SWW_fungicide appl.; HRS is the baseline case in the intercept). This is an explicit, complementary relationship between wheat class and fungicide use.

The dummy variable for relative *Incidence* is statistically significant for the middle 50% of observed levels of scab incidence. An observation of scab incidence between 10.00 and 50.00 PPM (in this sample) has significantly less DON than the combination

[24] Other PI's from the Scab Initiative indicated the literature shows that yields can increase or decrease in the presences of resistance. Other factors affect yield and the role of resistance on yield is not clear.

of high and low incidence observations (the high relative concentration variables was dropped from the model) when wheat class is not considered.

The interaction-term dummy variable *Incidence* is statistically related to DON in wheat in combination with wheat class. The estimated coefficient of the variable *Incidence* without respect to wheat class is statistically insignificant in Equation 2, likely due to collinearity with the wheat class interaction terms. Scab incidence has a significant and positive marginal effect on DON in all classes. Of the three estimated in the model, a marginal change of incidence in SRW varieties has the largest increase in DON, and HRS the smallest.

The dummy variable *Resistance* has a significant, negative, marginal effect on DON in wheat. This indicates that variety selection for resistance alone decreases DON, within this sample of varieties developed during the life of the Initiative. The effect of resistance on DON is direct and increases as the subjective degree of resistance increases, regardless of other conditions. Some level of resistance appears to be required in order for a significant marginal DON reduction effect to be present. Hence, integrating scab resistance in the variety with fungicide applications are effective for wheat quality management.

The estimated coefficient of the variable *Severity* is statistically significant and positive when considered across all wheat classes. Hence, a marginal increase in scab severity increases DON in wheat.

Location, year, and wheat class also have a unique relationship with wheat DON in the presence of scab. Of the nineteen observed locations, ten have a statistically significant estimated coefficient. Of these, one location had increased DON relative to the intercept in Equation 2. Hence, not all DON levels across locations increase at the same rate in the presence of scab, and several locations have a statistically lower level of DON relative to the average. Of the four observed years (2007-2010), all three years included in the model (2008-2010) had a statistically different effect on DON in wheat. The effect was positive in 2008, 2009, and 2010, each with greater DON levels than in 2007; 2010 was the year most like 2007.

Table 4.3. Marginal Wheat Yield Effects from Variety, Fungicide, and other Explanatory Variables.

Variable	Parameter estimate	Total yield: Intercept and coefficient only	Marginal yield effect relative to intercept (bu/ac)	Scab resistance category
Intercept	0.84	83.24	0.00	MS
Cultivar: Alice	-0.51	73.40	-9.85	MR
Cultivar: Bess	-0.24	78.67	-4.57	MS
Cultivar: Brick	-0.61	71.38	-11.87	MR
Cultivar: Coker9155	-0.51	73.33	-9.91	S
Cultivar: Elkhart	-0.42	75.07	-8.18	MS
Cultivar: INW0801	-0.35	76.48	-6.77	MS
Cultivar: Kaskaskia	0.14	85.92	2.68	MS
Cultivar: McCormick	-0.37	76.11	-7.13	S
Cultivar: P2137	-0.93	65.25	-17.99	S
Cultivar: P25R47	0.51	93.14	9.89	MS
Cultivar: P26R15	-0.39	75.68	-7.56	MS
Cultivar: Roane	-0.28	77.83	-5.42	S
Cultivar: SS8641	-0.47	74.20	-9.05	MR
Cultivar(Excel5530) x Med disease pres.	0.63	95.41	12.16	S
Cultivar(Wesley) x Med disease pres.	0.87	100.11	16.86	MR
Cultivar(Exc5170) x fungicide applic.	-0.44	74.76	-8.48	MS
Cultivar(P26R15) x fungicide applic.	0.37	90.53	7.28	S
Cultivar(Richland) x fungicide applic.	0.88	100.41	17.16	MR
Cultivar(Bess) x fungicide applic. X high disease pres.	-0.55	72.48	-10.76	S
Cultivar(P25R47) x fungicide applic. X high disease pres.	-0.24	78.63	-4.62	MS
Fungicide applic.	0.19	87.00	3.76	
Resistance (resistance level reported by USBWI)	-0.06	82.00	-1.24	
Arcsine (severity)	-0.04	82.45	-0.80	
Ln(DON)	-0.58	71.92	-11.32	
Arcsine(severity) x Class1(HRSW)	-1.62	51.74	-31.50	
Arcsine(incidence) x Class2(HRWW)	-0.93	65.12	-18.12	
Ln(DON) x Class2(HRWW)	0.53	93.60	10.36	
Arcsine(incidence) x Class3(SRWW)	0.21	87.25	4.00	
Location:Beltsville	-0.68	70.11	-13.14	
Location:Bradford	0.22	87.60	4.36	
Location:Brookings	-0.99	63.95	-19.29	
Location:Barbondale	0.31	89.34	6.10	
Location:DIX	-1.05	62.89	-20.36	
Location:Forman	-1.00	63.77	-19.47	
Location:IN	0.53	93.56	10.32	
Location:Monmouth	-0.45	74.42	-8.82	
Location:Princeton	1.27	107.91	24.66	
Location:Urbana	-1.50	54.03	-29.22	
Location:WYE	0.26	88.32	5.08	
Year:2008	0.19	86.86	3.62	
Year:2009	0.46	92.24	9.00	
Year:2010	-0.38	75.83	-7.41	

Marginal Effects of DON in Wheat

The estimated results of Equation 2 indicate there is an economic value from scab management practices developed within the USBWI for wheat production during the sample period. Selected combinations of management techniques result in reduced DON, relative to evaluating Equation 1 at the intercept alone. Reductions in DON reduce the likelihood penalties will be assessed when grain is purchased. The value of this reduced likelihood is the return from use of management techniques.

Table 4.4 shows marginal effects of the estimated coefficients of Equation 2 on DON levels in wheat. Significant coefficients for the complementary effects of class on fungicide applications and on scab incidence, as they relate to DON levels in wheat, were obtained. Of these, all three fungicide cross terms indicate a negative marginal effect on DON levels in wheat, relative to the intercept, when fungicide is applied. For example, the estimated level of DON in wheat, based on the intercept (absent management, disease, changes in incidence or severity, and other factors), is 1.27 PPM. Estimated DON levels in the HRW wheat class after a fungicide application can be estimated by calculating the sum of the intercept and the associated dummy variable, resulting in an estimate of 1.13 PPM (assuming 0 incidence and 0 severity), a marginal effect of about 0.14 PPM. Hence, some classes have a unique DON management relationship in the presence of scab. The marginal effect of a fungicide application in SRW is smaller than for HRW and greater for SWW than HRW.

Table 4.4 also contains an estimated marginal effect for dummy variables that includes any wheat variety and relative disease pressure. For example, the estimated DON calculated by evaluating the intercept and the dummy variable of incidence observations in the middle 50% of the data results in an estimate of 1.23 PPM, a marginal effect of about 0.04 PPM relative to the intercept.

Table 4.4. Marginal Wheat DON Effects from Variety, Fungicide, and other Explanatory Variables.

Variable	Parameter Estimate	Total DON: Intercept and coefficient only	Marginal DON effect relative to intercept (PPM)
Intercept	-0.27	1.27	0.00
Middle 50% of observed incidence	-0.06	1.23	-0.04
HRW_fungicide appl.	-0.22	1.13	-0.14
SRW_fungicide appl.	-0.12	1.20	-0.08
SWW_fungicide appl.	-1.14	0.54	-0.73
HRW_incidence	0.22	1.42	0.14
SRW_incidence	0.69	1.72	0.44
SWW_incidence	1.27	2.09	0.82
Resistance	-0.23	1.12	-0.15
Severity	0.02	1.28	0.01
Location: Beltsville	0.23	1.42	0.15
Location: Bradford	-0.70	0.82	-0.45
Location: Brookings	-0.27	1.10	-0.18
Location: Carbondale	-1.74	0.15	-1.12
Location: DIX	-0.98	0.64	-0.63
Location: Forman	-0.24	1.12	-0.15
Location: IN	-0.26	1.10	-0.17
Location: Monmouth	-0.58	0.90	-0.37
Location: Urbana	-0.56	0.91	-0.36
Location: Wooster	-1.08	0.58	-0.69
Year:2008	1.27	2.09	0.82
Year:2009	0.56	1.64	0.36
Year:2010	0.39	1.52	0.25

Barley Quality (DON)

Estimated coefficients of Equation 3 are in Appendix Table B3. These show the statistically significant relationship between barley varieties, severity, incidence, location, year, management techniques, and DON levels in barley. The R^2 is 0.52.

For dummy variables of selected barley varieties, which were statistically significant, all estimated variety coefficients are positive, indicating some varieties have a significantly greater level of DON, all else equal, compared to the pooled varieties in the intercept. The interaction terms indicate complementarity of plant variety and disease pressure are also sometimes statistically significant, indicating that in some cases there is a statistically different level of DON in these varieties relative to the value of all varieties observed in this sample observed in the intercept of Equation 3. Ten varieties have greater DON levels under conditions of moderate disease pressure, all else equal. In the case of one variety, observed under high disease pressure, smaller levels of DON are observed.

Interaction terms indicate complementarity of fungicide and variety and are statistically significant. This means that some observed varieties have a statistically different level of DON, by virtue of using fungicide on the observed variety, then the average of all observed varieties. In the case of five varieties, there is a significant relationship between DON and use of fungicide with the variety. In three of the five cases the incremental effect is negative: applying a fungicide on these varieties has a net negative effect on DON levels. In the case of the variety Pinnacle the estimated coefficient is among the largest observed in the model. An additional seven interaction terms are statistically significant which detect the complementarity of variety, fungicide application, and disease pressure. The estimated effect in all cases is negative under conditions of medium disease pressure. Twelve of twenty-five variety and fungicide application trials were observed to have a negative incremental effect on DON. The absence of a significant coefficient for a given variety only implies that its marginal effect on DON levels is not different from the average of the observed varieties, all of which were observed in 2008 or later.

The effect of *Fungicide* on estimated DON levels is positive and significant. Its value indicates that relative to the average, fungicide use at heading increases DON by 0.28 PPM. These results should be interpreted carefully: the effect of fungicide applications is complementary with barley varieties. Twelve barley varieties have significant estimated interaction coefficients with fungicide applications (see Appendix Table B3). Eleven of these have a negative marginal effect on DON levels in barley. When combined with the intercept and the estimated *Fungicide* coefficient, DON is net reduced when fungicides are applied on ten barley varieties (Excel, Lacey, Quest, ACMetcalf, M122, ND20448, Rawson, Robust, Scarlet, and Tradition). Fungicide use is an economically viable scab management technique in that DON levels are reduced in barley when applied to particular varieties. To the extent incidence or severity are reduced by fungicide applications this effect is increased.

The variable *Resistance* is also positive and significant, indicating adoption of a resistant variety marginally increases DON by 0.28 PPM relative to the intercept. For purposes of comparison, this is equal to about 75% of the marginal effect of a fungicide application. As with the *Fungicide* variable, this should be interpreted with caution. Of the ten barley varieties with complementarity with fungicide use, six are not susceptible varieties. Variety FEG65-02, moderately resistant when used with fungicide, has the largest negative effect on DON for the fungicide-variety interaction terms, and variety. Scarlet, a moderately resistant variety has the third largest negative effect on DON under conditions of fungicide use with medium disease pressure. Resistance seems to have the largest, negative effect on DON in combination with variety, fungicide, perhaps, when under medium disease pressure.

The continuous variables *Incidence* and *Severity* both are positive and statistically significant. The estimated *Incidence* coefficient indicates a one-unit increase in the arcsine of average scab incidence increases arcsine DON by 0.42 PPM. This implies that a smaller increase in incidence, of perhaps arcsine 0.10, would increase DON in barley by 0.04 relative to the average. A one-unit increase in arcsine scab *severity* increases DON by 0.36 PPM relative to the average, a smaller effect than estimated by *Incidence*.

The relationship of *Incidence* and DON depends on the level of DON in a complex way. Both a slope term and a dummy variable to capture this relationship, indicating a change in the relationship between DON levels and scab incidence at arcsine *Incidence* values between 0.9 and 1.2, which was observed to have a greater effect on DON.

Time and location effects were also observed. Fargo, St Paul, and Volga had statistically greater DON than the mean. Finally, the years 2009, 2010, and 2011 had statistically greater DON than other sample years.

The dummy variable *Resistance* is significant in this model (see Appendix Table B3 for a description of barley variety resistance). Consistent with Wegulo et al. (2011), an increase in resistance has a positive marginal effect on DON levels in barley. This indicates that it is the combination of fungicide efficacy and resistance that reduce DON level, not the scab resistance in the variety alone. There are twelve varieties whose coefficients are significant in the presence of a fungicide application, with eleven having a positive coefficient: a fungicide application on these barley varieties has a negative marginal effect on DON level. Of the eleven varieties, four are susceptible. This indicates that it typically requires some level of resistance in order for the fungicide application to produce the complementary effect with the variety to have a negative marginal effect on DON. Integrating scab resistance in the variety with fungicide application can be effective for DON management.

Marginal Effects of DON in Barley

The estimated results of Equation 3 indicate there is an economic value from scab management practices developed within the USBWI for barley production. This value is found in the complementarity of varieties and either fungicide application or disease pressure. For example, producing a crop of the variety Excel (a moderately susceptible variety) in Langdon, in 2010, with average incidence and severity, generates an estimated level of DON of 1.02. Given the positive intercept effect of fungicide applications or resistant varieties alone, using these management tools increases the estimated level of DON to 1.38. However, several barley varieties have reduced DON depending on disease pressure and fungicide use. For example, using variety Conlon under medium disease pressure reduces estimated DON to 0.84. Using variety ND Genesis under high disease pressure reduces estimated DON to 0.88. Using variety FEG65-02 with fungicide reduces estimated DON to 0.84. Using variety ND20448, with fungicide, under medium disease pressure reduces estimated DON to 0.87.

Table 4.5 shows marginal effects of the estimated coefficients of Equation 3 on DON levels in barley. Nineteen significant coefficients for barley varieties were observed. Of these, seventeen have a positive marginal effect on DON levels in barley, relative to the intercept. For instance, the estimated DON level in barley, based on evaluating Equation 3 at the intercept (absent management, disease, changes in incidence or severity, and other factors), is -0.15 PPM, essentially 0 PPM and must be considered a benchmark in light of considering the incidence and severity—causes of DON—as equal to zero. DON levels when variety FEG65-02 is observed, can be estimated by calculating the sum of the intercept and the associated dummy variable, resulting in an estimate of 0.16 PPM, a marginal effect of about 0.31 PPM. Use of the variety Celebration has an estimated DON of 0.04 PPM, a marginal effect of 0.19 PPM. Hence, some varieties have a unique DON relationship in the presence of scab and most observed varieties with these relationships have greater DON poorer in the presence of scab relative to the average of the observed varieties in the observed sample.

Table 4.5 contains estimated marginal effects for interaction terms that include a barley variety and disease pressure. For example, the estimated DON calculated by evaluating the intercept and the dummy variable of variety ND Genesis results in a marginal effect of -0.23 PPM relative to the intercept.

Application of a fungicide, as observed by the coefficient on the variable *Fungicide*, has a marginally positive and significant increase in DON level. Most observed varieties, however, have a complementary effect with a fungicide application and must be considered when evaluating the marginal effect of fungicide use. The size of this marginal effect can be calculated by evaluating Equation 2 with the intercept, the estimated coefficient of *Fungicide*, and the interaction terms for variety and the *Fungicide* variable. For example, the marginal change in DON from use of the variety Conlon with fungicide is 0.03 PPM relative to the intercept alone; similarly, use of variety FEG65-02 with fungicide results in a marginal DON decrease of 0.51 PPM. Thus, fungicide applications have a net greater or smaller effect on these, and other, varieties. Table 4.5 shows estimated coefficients for how the marginal effect of deciding to apply fungicide to selected barley varieties is affected by disease pressure. For example, use of fungicide, under medium disease pressure conditions, on Scarlett marginally reduces estimated DON by 0.10 PPM relative to the estimated DON from the intercept alone.

The estimated coefficients for Equation 3 can be evaluated to calculate the marginal change in DON levels in barley by scab resistance alone. Evaluating Equation 3 by using the intercept and the estimated coefficient of *Resistance* indicates the use of a very susceptible variety, for example, marginally increases DON 0.11 PPM. Note again however, that the varieties with complementary (variety, fungicide, and disease pressure) relationships that reduce DON on the margin typically have a resistance category other than "susceptible", indicating some level of resistance is needed in order for a negative marginal effect on DON to be present.

Table 4.5 also provides a measure of the marginal effect of changes in scab incidence and severity on DON levels in barley. All else equal, a decrease in one unit of arcsine of incidence will result in a marginal decrease DON by 0.18 PPM; a one-unit decrease in arcsine of severity will result in a marginal decrease in DON by 0.06 PPM. In addition, a decrease in incidence levels results in a marginal reduction in DON of 0.25 PPM.

Table 4.5. Marginal Barley DON Levels from Variety, Fungicide, and other Explanatory Variables.

Variable	Parameter estimate	Total DON: Intercept and coefficient only	Marginal DON effect relative to intercept (PPM)	Scab resistance category
Intercept	-1.33	-0.15	0.00	
Cultivar: ACMetcalf	0.11	-0.10	0.05	MS
Cultivar: Celebration	0.45	0.04	0.19	S
Cultivar: Conlon	0.20	-0.07	0.09	MS
Cultivar: Eslick	0.40	0.02	0.17	S
Cultivar: FEG65-02	0.71	0.15	0.31	MR
Cultivar: Innovation	0.43	0.03	0.19	MS
Cultivar: Rasmusson	0.34	-0.01	0.15	S
Cultivar: Rawson	0.23	-0.06	0.10	S
Cultivar: Robust	0.23	-0.05	0.10	S
Cultivar: Tradition	0.19	-0.07	0.08	S
Cultivar(Excel) x Med disease pres.	0.34	-0.01	0.15	MS
Cultivar(Lacey) x Med disease pres.	0.68	0.14	0.29	MS
Cultivar(M122) x Med disease pres.	0.46	0.05	0.20	MS
Cultivar(Merit) x Med disease pres.	0.20	-0.07	0.09	S
Cultivar(ND Genesis) x Med disease pres.	-0.53	-0.38	-0.23	MS
Cultivar(ND20448) x Med disease pres.	0.70	0.15	0.30	MS
Cultivar(Pinnacle) x Med disease pres.	0.22	-0.06	0.10	MS
Cultivar(Quest) x Med disease pres.	0.18	-0.08	0.08	MR
Cultivar(Robust) x Med disease pres.	0.36	0.00	0.16	S
Cultivar(Tradition) x Med disease pres.	0.21	-0.06	0.09	S
Cultivar(Rawson) x high disease pres.	-0.36	-0.31	-0.16	S
Cultivar(Conlon) x fungicide applic.	-0.49	-0.36	-0.21	MS
Cultivar(Excel) x fungicide applic.	0.41	0.02	0.18	MS
Cultivar(FEG65-02) x fungicide applic.	-1.69	-0.88	-0.73	MR
Cultivar(Lacey) x fungicide applic.	-0.76	-0.48	-0.33	S
Cultivar(Quest) x fungicide applic.	-0.66	-0.44	-0.28	MR
Cultivar(ACMetcalf) x fungicide applic. X med disease pres.	-0.49	-0.36	-0.21	MS
Cultivar(M122) x fungicide applic. X med disease pres.	-0.47	-0.36	-0.20	MS
Cultivar(ND20448) x fungicide applic. X med disease pres.	-0.78	-0.49	-0.33	MS
Cultivar(Rawson) x fungicide applic. X med disease pres.	-0.63	-0.42	-0.27	S
Cultivar(Robust) x fungicide applic. X med disease pres.	-0.79	-0.49	-0.34	S
Cultivar(Scarlet) x fungicide applic. X med disease pres.	-0.74	-0.47	-0.32	MR
Cultivar(Tradition) x fungicide applic. X med disease pres.	-0.50	-0.37	-0.22	S
Fungicide applic.	0.41	0.02	0.18	
Resistance (resistance level reported by USWBSI)	0.25	-0.05	0.11	
Arcsine (incidence)	0.41	0.02	0.18	
Arcsine (severity)	0.14	-0.09	0.06	
Dummy: arcsine (incidence)	0.17	-0.08	0.07	
Location:Fargo	0.35	0.00	0.15	
Location: St. Paul	1.68	0.57	0.72	
Location:Volga	2.18	0.78	0.94	
Year:2009	0.23	-0.05	0.10	
Year:2010	0.33	-0.01	0.14	
Year:2011	0.42	0.03	0.18	

Summary

Statistical relationships were estimated between reduced wheat yield and reduced wheat or barley quality and scab presence and use of scab management techniques. The use of scab management techniques can reduce yield loss and mitigate penalties for relatively high levels of DON. Evaluating these statistical relationships under observed levels of scab presence and prospective scab management programs facilitates an estimate of the value of foregone yield loss or foregone quality loss.

Econometric models were specified to evaluate the impact of important independent variables on yield levels and DON in wheat and barley. The important independent variables include: yield, DON, variety, resistance, fungicide use, severity, scab incidence, disease pressure, wheat class, location, and year and management techniques. An extensive set of data across a broad geography and covering the periods of 2007-2010 and 2008-2015 for wheat and barley, respectively. Finally, among these variables, some of the effects are dependent on the effects of other variables, e.g., fungicide, and these effects were identified.

The statistical results were good and a number of significant variables were identified. Most important are:

- Each of class, location and year were significant indicating there are unique relationships that exist in the individual locations and classes, and/or similarly, there was some uniqueness in each of the crop years. The effect of these were captured statistically within the model;

- Fungicide was an important variable for both wheat and barley. Indeed, this was one of the most important variables impacting wheat yield, and DON in wheat and barley. In both cases fungicide had the impact of increasing yields in wheat, and lowering DON in wheat and barley. The impact of fungicide was dependent on the variety i.e., its impact varied across varieties;

- Scab resistance in varieties is important. By itself, moderately resistant varieties increase wheat yield by about 5 bu/ac; in the case of wheat, greater resistance has the impact of lowering DON, however, this effect varies across classes and is lesser for SRW. Importantly, the impact of variety resistance on yield and DON is impacted by the use of fungicide. This was very apparent in barley;

- Scab resistance in varieties had a negative impact on wheat yields. However, this impact was dependent on use of fungicide in the wheat yield equations. The combined impact of these two variables was positive on wheat yields, and, negative on DON levels in wheat and barley. The relationship is more complicated in barley.

The effect of scab resistance on DON is direct and increases as the resistance level increases. This is true for both wheat and barley;

- Other variables: Incidence and severity were each significant and impacted wheat yields and DON in a logical way;

- Tradeoffs between yield and wheat were estimated in the case of wheat. Specifically, DON has a significant and negative effect on wheat yield for each wheat class. This impact is also impacted by fungicide use. These results indicate there is a tradeoff between yield and DON: Decreasing DON from 1.0 to 0.5, would result in an increase in yield of about 7 bu/ac.

The analysis is not without limitations. Most important is the data. The data is as good as it gets in terms of aggregate pooled (cross-section and time series) data. However, at least for wheat it has not been comprehensively updated since 2010. Indeed, a number of the more resistant varieties have been released since then, and the impact of these were not captured in the data. Second, while fungicide is clearly important, it is included as a discrete variable. Likely as the importance of fungicide has escalated, there are probably a number of more important features of this management technique that should be included (e.g., timing, number of applications, type of fungicide, etc.). Finally, the survey data provides a distribution of observed management activities. However, the survey data does not describe the outcome of management activities (e.g., effects on yield or DON).

5. Impacts of DON on Grower Returns, Risks and Value of Mitigation Strategies[25]

FHB and DON that can form due to scab has important impacts on growers and has the effect of changing farm management practices. Importantly, scab has the impacts of increasing risks of DON arising in grain, and associated potential discounts, in addition to reducing yields. Taken together this results in a greater risk and lower returns than otherwise. In response, growers adopt varying strategies including choosing more resistant varieties, applying fungicide, or both and adopting crop rotations that mitigate scab and DON risks. The effect of these strategies is to reduce risk and increase returns.

Risk has a very important impact for diseases in general and for scab in particular. The reason for this is that the disease increases risk and lowers returns. Thus, in concept and in practice, the market has to compensate growers for the increased risk in the form of higher prices. This is commonly referred to as a 'risk premium.' Indeed, over time this has been observed in all of the affected wheat classes and malting barley relative to alternative crops (e.g., corn, soybean, canola, etc.), which are less risky. Due to the technologies or strategies that have been adopted to respond to the risk of DON in cereals, growers have been able to increase yields and lower the incidence of DON, having the impact of lowering risks and therefore the size of the 'risk premium' the market needs to pay to compensate growers for the otherwise greater risk.

This section develops an analytical model to evaluate these issues and to quantify the risk premiums alluded to above.

Analytical Model Overview

A model was developed using grower budgets to derive returns and risks. Separate specifications were made to allow different strategies including adopting more moderately resistant (MR) varieties, fungicide or both. Crop budgets were adopted from extension and/or USDA for each of the dominant regions for the particular classes of wheat and malting barley. The output variable of interest is returns to labor and management.

Some of the variables were specified as being risky, or random. These were the focus of this study and included: yields, DON, discounts for excessive DON levels, and factors affecting yields included severity of scab infestations. Other variables were all treated as non-risky including price which implicitly assumes growers have taken initiatives to mitigate those risks.

The models were simulated using stochastic simulation procedures. This allows us to derive the returns and risk, measured as standard deviation, for each crop strategy. These include no strategy, adopting more moderately resistant varieties, fungicide or both. The results for the distributions of returns were collected, analyzed, and ranked using Stochastic Efficiency with Respect to a Function (SERF). This

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[25] Research in this section was conducted by Bruce Dahl and Dr. Wilson.

procedure allows us to derive the certainty equivalents of alternatives, and a measure of the ‘risk premium’ for that alternative.

The methodology has been applied in several different situations to rank grower preferences across risk attitudes (Wilson et al. 2009; Wilson and Dahl 2011, 2014, Wilson et al. 2007). In addition, it has been used to evaluate the ‘value’ of new or alternative technologies, notably using GM technologies in wheat (Shakya et al. 2015), corn (Shakya et al. 2013), and canola (Wynn et al. 2016).

The scope of this analysis was somewhat limited to the data available. Separate models were estimated for each of HRS, HRW, and SRW, and malting barley. Durum was not included in the analysis as like data was not available for that crop. For each cereal, a representative or dominate growing region was used for the analysis. The analytics were representative of the 2015 or 2016 crop year grower crop budget. Finally, there are other strategies that are used to partly mitigate risks of scab and DON (e.g., crop rotations, planting timing, etc.), that are not included in this analysis due to unavailability of data for this purpose.

Data and Distributions

Data on prospective crop budgets were obtained from Swenson and Haugen (2015), Ohio State University, (2015) and USDA-ERS (2016). North Dakota and Ohio crop budgets for wheat were for 2016, and represent portions of North Dakota and the State of Ohio. The USDA-ERS (2016) represents a large portion of the Hard Red Winter Wheat production area for 2015. Budgets for Malting Barley represented portions of North Dakota for 2016 (Swenson and Haugen, 2015).

Budgets had similar cost categories and allowed computation of Returns to Labor and Management (Appendix Table C1). Two adjustments were made to these budgets. One is that for fungicide. Values for fungicide costs were treated as base-line budgets, indicated values of $5/ac. for North Dakota, but discussions with extension faculty indicated a more appropriate value which is shown in Appendix Table C1, assuming one treatment per year.

The second adjustment was inclusion of discounts for excessive DON. DON maximum limits were assumed to be 2 ppm. Discounts were applied on iterations having DON levels equal to or exceeding the maximum and also for each ppm or part thereof exceeding the maximum. DON discounts were assumed random with discrete values of $0.05/bu or $0.10/bu per ppm, each occurring 50% of the time. These discounts are highly representative of those at country elevators as discussed in the section above; and, tend not to change too much through time. The expected value of these is shown in Appendix Table C1 and described above. Sensitivities were conducted on the level and distribution of DON discounts.

The random variables were specified as distributions following results from McKee (forthcoming and as described above). This data was from field trials over the period 2007-2010 and allowed for different treatments of variety resistance, fungicide, etc.

Distributions for wheat yields were derived from the estimated functional relationship and distribution of FHB severity and DON. The data was used to estimate fitted distributions with 1) no fungicide applied and susceptible varieties (our base case), 2) fungicide and utilizing more moderately resistant varieties (Moderately Resistant, MR), 3) fungicide only, and 4) MR varieties only. These were fitted for each of the wheat classes (HRS, SRW, and HRW) and malting barley.

Fitted distributions, parameters, and correlations are shown in Appendix Tables C2-C4 for scab severity and DON levels for the wheat classes. These results indicate the distributions for severity and DON vary across management practices and classes. In addition, the correlation between severity and DON vary. Of particular importance is the large correlation for HRS, .927 between these variables for fungicide and MR varieties. That value is much greater than for other classes and impacts the relative results.

For HRW there were a subset of observations for which there was no corresponding DON observations and there was a subset not requiring DON management strategies (DON=0). These data were truncated to remove the effects from observations without DON and not requiring DON management strategies on other variables. To do this, observations were only included that had DON values exceeding 0.03.

For malting barley, data were truncated to include only those samples with DON greater than 0.03 to reduce the effect of those samples not requiring management strategies on those observations that did. The reason for this is that tools available for forecasting FHB were available and would indicate the application of fungicides only if conditions for FHB were present. Truncated distributions were estimated based on the four strategies and included those for yield and DON levels. Distributions best fitting the data were identified with AIC criteria and correlations between yield and DON were estimated for malting barley (Appendix Table C5).

DON discounts per acre were estimated based on fitted DON distributions (above) and random discounts per bushel. Discounts were assumed random uniformly distributed from $0.05/bu to $0.10/bu For malting barley, there was a base price assuming it meets specifications, and if not, it was sold at feed barley prices less DON discounts applied.

Yields for wheat classes were estimated from marginal yield effects relative to the intercept from McKee (above) and reported in Appendix Table C6. The marginal effect is interpreted as the impact of a treatment on yields. In this case this value varies across classes. Base Yields were 83.24 bu/ac for each of the classes. Random adjustments in yields were based on whether fungicide was applied, MR varieties used, and random draws from distributions for FHB severity and DON that represented the specific strategies. Yields were estimated for 4 cases, 1) no fungicide or MR varieties, 2) fungicide and MR varieties, 3) fungicide only, and 4) MR varieties only, for each of the wheat classes.

The result of particular importance is the value of “arcsine severity’ by class. This is a transformed variable estimated by applying the acrsine function to the value of scab severity. As shown, the value for HRS is quite large versus the other classes. The interpretation of this is that whereas severity impacts yields of each class, that effect is greater on HRS than other classes.

Simulation Procedures

The model was simulated using stochastic simulation procedures. It was simulated 10,000 iterations within @Risk (Palisade, 2015) for each of the four strategies defined above and three wheat classes and malting barley. The output of interest was returns to labor and management. From these simulations, values from each iteration for returns to labor and management were collected and analyzed in Simetar (Richardson et al. 2011) using SERF. This generated certainty equivalents for each of the cases and risk premiums over the base case (no fungicide and no MR varieties) across a range of risk attitudes for growers. Lower bounds for risk attitudes were estimated for each of the wheat classes following McCarl and Bessler (1989).

Certainty equivalents are the amount a decision maker would be indifferent between sure money in a safe investment, versus the random returns realized in each of these strategies. Or, it could be interpreted as the amount a grower would need to be compensated to take on a risky alternative. These vary by the risk attitude of the decision maker. Risk attitudes for growers were evaluated for values from risk neutral to highly risk averse. Risk premiums are simply the difference between certainty equivalents. They reflect the value or preference for one strategy measured in certainty equivalents over a base strategy (here no fungicide and no MR varieties). Both certainty and risk premiums also reveal at what risk aversion levels ranking of decision maker preferences change.

Results

Four strategies were simulated for each of the wheat classes (HRS, SRW, and HRW) and malting barley. The strategies are:

1) no fungicide and no MR varieties,
2) Both fungicide and MR varieties,
3) Fungicide only and
4) MR varieties only.

Then the simulated draws were evaluated to determine certainty equivalents and risk premiums for each case, wheat classes and malting barley.

Means and standard deviations for simulated returns to labor and management were estimated for each of the wheat classes and four cases. The results indicate higher returns for both fungicide and MR varieties for all three wheat classes and malting barley (Table 5.1). These were followed by Fungicide only, MR varieties only, and the lowest was the No Fungicide No MR varieties case. The variability of returns to labor and management was highest for MR varieties for HRS and HRW, while for SRW it was with both fungicide and MR varieties. Skewness and kurtosis were least for HRS and highest for HRW.

Table 5.1. Means and Standard Deviations of Simulated Returns to Labor and Management, by Wheat Class and for Malting Barley ($/ac)

HRS	**No Fungicide No Mod. Res. Varieties**	**Fungicide and Mod. Res. Varieties**	**Fungicide**	**Mod. Res. Varieties**
Mean	44.73	140.78	133.57	118.09
Std. Dev.	67.29	56.80	56.45	99.28
Skewness	0.16	1.02	-0.27	-1.49
Kurtosis	-0.16	0.61	-0.36	1.86
SRW				
Mean	-135.15	-62.68	-87.20	-84.45
Std. Dev.	67.95	80.37	80.87	81.08
Skewness	-0.44	-1.92	-2.72	-1.73
Kurtosis	0.74	23.84	50.01	17.65
HRW				
Mean	27.91	43.01	42.84	29.54
Std. Dev.	36.43	24.99	37.37	34.78
Skewness	-1.05	-1.51	-1.56	-1.60
Kurtosis	0.89	3.45	2.75	2.97
Malting Barley				
Mean	138.47	164.55	161.96	141.82
Std. Dev.	130.61	119.04	136.05	127.59
Skewness	0.32	0.03	0.28	0.30
Kurtosis	-0.93	-0.91	-0.43	-0.77

These results are particularly important. The impact of the new technologies for DON (i.e. fungicide, MR varieties etc.) is to reduce risk and increase return relative to the alternative of not adopting the technology. Or similarly, the impact of not having these technologies would be to increase risk and lower returns. These results are shown and interpreted for each class in using the column Fungicide and Res Varieties (Table 5.1). Of particular importance is that in each class and malting barley, the strategy of fungicide and MR varieties has the impact of having greater returns and lower risk (standard deviation) than any of the other strategies. The standard deviation for this strategy is lesser than the alternatives of fungicide alone or MR varieties alone.

For illustration, Figure 5.1 shows a cumulative distribution function (CDF) for HRS which compares no treatment to fungicide and MR varieties. As illustrated, the returns are greater, and the risk lower for fungicide and MR varieties vs neither. Simply, by adopting these strategies, growers can increase returns by $96/ac, and lower risk from $67 to $57/ac Both of these have value to growers. Without the transformations discussed below and ignoring risk, it means that without these technologies, the market would have to compensate growers by this amount to grow wheat. Though this figure is for HRS, the results are similar for the other classes. This would be as expected, but ultimately is the virtue of the scab strategies developed for this purpose.

Certainty equivalents were estimated for each wheat class, malting barley, and strategy and are shown in Appendix Table C7. For HRS, the risk premium for fungicide with MR varieties was highest across all risk attitudes and most valuable to high risk averse growers. Typically, these are in the range of $84 to $186/ac and indicate the value of these technologies relative to none; or, similarly, it indicates the amount by which growers would need to be compensated to grow wheat without these technologies.

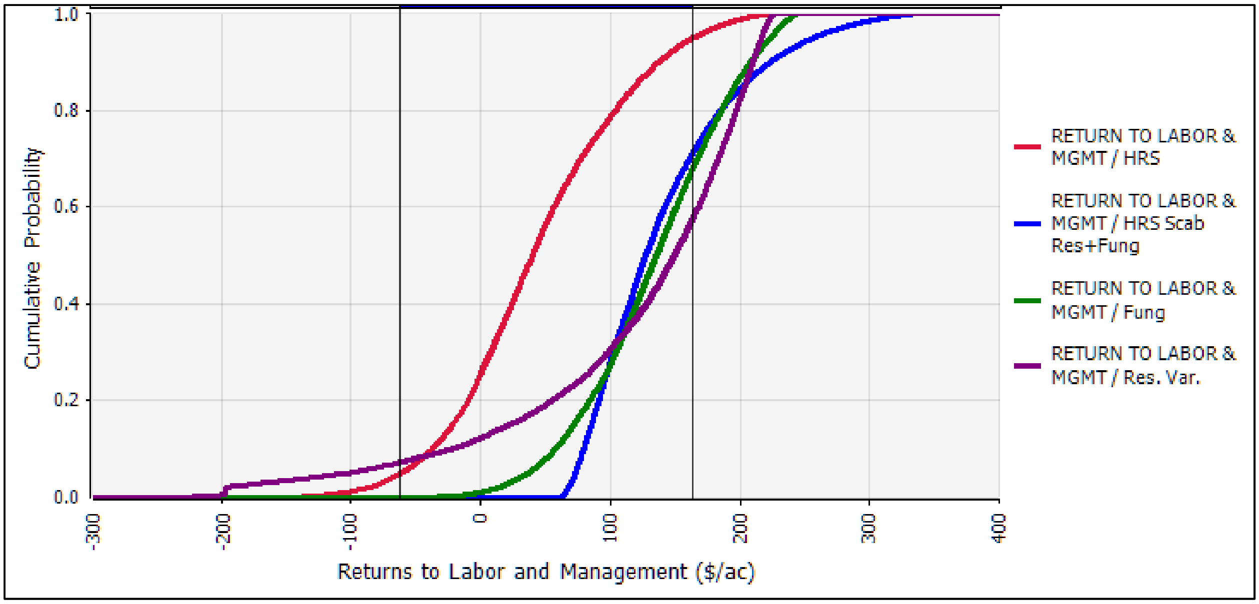

Figure 5.1. CDF of Returns to Labor and Management, by Strategy for HRS.

These values can also be used to infer the value of fungicide versus MR varieties. The risk premiums for fungicide indicates it is preferred to MR varieties, especially for risk averse and highly risk averse growers (Appendix Figure C1). Risk premiums for fungicide applications were near $80 to $106/ac over no fungicide and no MR varieties across risk attitudes. Taken together, these results indicate that the value of both fungicide and MR varieties is large and that of fungicide has a greater value than MR varieties, though the complement of these is more important.

The risk premiums in SRW for fungicide application and MR varieties was highest for risk neutral growers at $49/ac declining to $9/ac for the most risk averse growers. Preferences shifted to fungicide being ranked higher than fungicide and MR varieties for risk averse to highly risk averse growers. Risk premiums for fungicide application ranged from $33/ac for risk neutral growers, to about $12/ac for highly risk averse growers (Appendix Figure C2). The risk premiums for fungicide application are substantially lower than those for HRS. Risk premiums for MR varieties were lower and ranged from $32/ac for risk neutral growers to a low of $1/ac for the most risk averse growers.

Risk premiums for HRW for combined fungicide and MR varieties were relatively large. The combined fungicide and MR varieties risk premiums ranged from $15/ac for risk neutral decision makers to $42/ac for the most risk averse growers. Thus, for growers not liking risk, the value of these technologies is great. Risk premiums for fungicide application ranged from a high of $15/ac for risk neutral growers to a low of $-20/ac for the most risk averse growers (Appendix Figure C3). Risk premiums for MR varieties increase from $0/ac for risk neutral to about $2/ac for slightly risk averse growers before declining to a low of $-12/ac for the most risk averse growers.

Risk premiums for malting barley strategies were highest for the both fungicide and MR varieties strategy, followed by fungicide only and MR varieties only strategies (Appendix Figure C4). Risk premiums for both fungicide and MR varieties increase from $26/ac to a high of $31/ac, and then declines to $23/ac as risk aversion increased. Fungicide only had risk premiums that ranged from $23/ac for risk neutral decision makers and declined to -$1.70/ac for the most risk averse decision makers. MR varieties had risk premiums that were generally $3-5/ac.

Taken together these results are important. First, the value of fungicide and MR varieties was greater than either technology individually. This illustrates the complementary impacts of these technologies, i.e., the value and impact of fungicide is impacted by use of MR varieties (and, vice versa), and reflects the results of the statistical model described above. Second, the value of these technologies varies across classes, generally being greater for HRS than the other classes. The reason for this is partly determined by the marginal impacts of the technology on yields, which varies across classes and is greater for HRS.[26] Second, HRS has the largest returns and consequently a reduction in the standard deviation from use of fungicide and MR varieties is more valuable than the other classes and barley. Other factors that may impact the differences in value across classes include the price of the commodity, DON specifications, distributions for FHB Severity, DON levels and discounts. In addition, it is important that the margin per acre is greater for HRS vs. the other classes and this impacts the value of the risk premium. Certainly, the value of reducing risk is greater for crops with greater margins.[27]

Summary and Implications

Disease and disease mitigation strategies are very important to growers. These are particularly important in the case of DON and the Scab Initiative. The impacts of this disease are to increase the probability of DON being excessive, reducing yield and increasing the probability of discounts for excessive DON. Thus, any strategy that reduces DON has the opposite impacts: increasing yield, reducing probability of DON and associated price discounts. Taken together, these strategies have the impact of increasing returns, and reducing risks relative to the technologies not being adopted.

This section developed a model to evaluate risk and returns for growers. Alternative scab management strategies were evaluated using stochastic simulation procedures or returns and risks inherent in producing wheat and malting barley. Then risk preferences were generated by decision maker attitudes toward risk, wheat class, malting barley and strategy (No fungicide and no MR varieties, both fungicide and MR varieties, fungicide only, and MR varieties only).

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[26] Technically, the results of that analysis shows high Marginal yield effect relative to intercept for Arcsign(severity)*HRS which was -31.50 compared to -18.12 for HRW Arcsign(incidence) *HRW and +10.36 for SRW for arcsign*(incidence)*SRW.

[27] Upon further review, the reason for the low margin for some classes is due to their greater land costs, vs those of HRS.

One of the results of interest is the impact of these technologies on grower's returns and risks. These results indicate that for each wheat class and malting barley, these technologies have the impact of increasing returns, and lowering risk relative to the alternatives. These are particularly important in that both of these are positive outcomes. Simply, the technologies result in greater returns and lower risks than otherwise. The differences provide a partial indication of the amount by which growers are better off with the technologies, than without.

The model can also be used to interpret risk premiums. The results indicate risk premiums over a strategy with no fungicide and no MR varieties were generally highest for a strategy with both fungicide and MR varieties, followed by fungicide only, and MR varieties. The MR varieties were a lesser preferred strategy for HRS and HRW decision makers that were risk averse to highly risk averse, but third less preferred for risk neutral to slightly risk averse decision makers. Risk premiums for fungicide only were highest for HRS, followed by SRW and malting barley and HRW. This means that fungicide has had greater impacts on risks and returns for HRS growers, than for SRW, malting barley or HRW; though in all cases, MR varieties are important and have complementary impacts.

These values have particular interpretations. Specifically, the values indicate the amount by which growers would need to be compensated to adopt a riskier alternative i.e., as if the technologies were not available. These results indicate that growers would need to be compensated in the area of: HRS $130/ac; SRW $49/ac; HRW $28 and Malting Barley $29/ac to grow wheat without the technologies. Or, alternatively, these could be interpreted as the value of these technologies to growers.

Risk premiums for a strategy with fungicide and MR varieties, show complementary results over just the fungicide only and MR varieties only for HRS, a portion of risk neutral to slightly risk averse SRW producers, HRW and malting barley. Thus, risk premiums were higher for a strategy with both fungicide and MR varieties, over combinations of fungicide only and MR varieties only for HRS, HRW, malting barley and a portion of SRW growers.

The risk premiums for MR varieties were lower because most new varieties are only marginally resistant and don't have higher levels of resistance. The change in varieties at least for HRS, has been more a shift away from the most susceptible varieties and toward less susceptible varieties. Meanwhile strategies with fungicide applications appear to be better at controlling risk and returns for HRS, SRW, HRW wheats and malting barley.

These results are very important to assessing the role of disease on risk and returns for growers. However, there are some limitations. One is that the marginal effects though powerful were estimated using data from 2007-2010, and did not include durum. Certainly, since then, more MR varieties have been released for some classes, and these impacts would be important. Second, marginal effects were for fungicide, MR varieties and their interaction. However, these exclude other management practices.

Of particular importance are 1) crop rotations; and 2) the number, frequency and timing of fungicide implications. Certainty these are important, but, the data simply does not exist to quantify these impacts. Third, the analysis compares risks and returns for growing wheat using different technology strategies. An alternative would be to compare risks and returns for grower wheat using different technologies, to non-wheat crops (e.g., soybean and corn). It is expected that these alternatives are lower risk and higher return and these would impact the results.

6. Impacts of DON on End-Users on Operations and Costs[28]

This section reports the results of a survey of end-users of wheat and barley on the impacts of excessive DON on their operations and costs (Objective 3).

Impacts of DON on end-user's operations and costs are important, and probably irreversible. For purposes here, the end-user is defined as the primary processor (i.e., wheat millers and barley maltsters). Part of the impact of scab is due to the premiums (costs) in the market, and/or costs related to testing, segregation, storage, cleaning, etc. These were assessed using a 2-stage focused survey and the results were extrapolated to the rest of the industry.

Previous and Related Studies

There have been a few studies on the impacts of DON on these sectors. Sullins (2011, 2013) presented results of case studies on the impacts of DON on selected flour mills. These results illustrated the cost and technical implications on a flour mill of excessive DON. Important were the combined impacts of discounts, testing costs and the need to procure outside of traditional target region.

More recently, in response to the anticipated impacts of tightening of DON due to a proposed CODEX recommendation, some prospective impacts on the wheat milling sector were identified. Specifically, they indicated that despite that a CODEX maximum limit would only be required on exports from North America, it would impact the domestic milling sector. Importantly, if importers have to buy wheat with tighter DON limits, it would reduce the availability of wheat with DON within limits, thereby increasing costs on domestic millers.

Scope of Survey and Process

The scope of this study was to elicit information from intermediate users, wheat millers and barley maltsters, as to how excessive DON impacts their operations. Questions were structured around how DON impacts their procurement, including discounts, specifications for buying and selling, as well as costs of testing, cleaning, segregation etc.

In the process, we had the questionnaires pre-reviewed in person by a number of firms knowledgeable on the topics, and, based on that the initial questionnaire was revised. A final questionnaire was prepared, one each for wheat milling and barley malting. Copies of these are contained in Appendix A. To elicit information from the respondents, Dr. Don Sullins conducted a series of personal interviews for this study. The questionnaire was shared ahead to individuals that were identified by each firm thought to be most knowledgeable on the topic.

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[28] Research in this section was led by Dr. Wilson and assisted by Dr. Sullins and Bruce Dahl.

We sought to interview representatives from each firm in each industry. In the case of flour milling, names were collected from the Milling Annual (Sosland, 2015), and then, Don Mennel reviewed and suggested names of appropriate individuals. For malting barley, the AMBA (American Malting Barley Association) identified names of firms and individuals that would respond. We had responses from all firms as planned.

It is important that some of this information is readily available, and common knowledge in the industry. In other cases, it is proprietary and hence, we mask the responses of individual firms. In other cases, the data is more elusive: it simply does not exist. This was most problematic in terms of historical discounts for excessive DON. Whereas most firms could readily indicate the current discounts, only a few had the ability to extract like data historically. Hence, in these cases we relied on expert judgement.

Finally, differences potentially exist between origin and destination mills. This distinction is that the former buys from growers and/or handlers for delivery typically by truck, and importantly in many cases prior to being handled by elevators (which may include previous discounting, segregation, blending, etc.). In contrast, destination mills typically buy in trains of rail cars and use specifications which require the originator to test and/or blend and segregate to assure the specification conforms to requirements. Hence, destination mills are less vulnerable to the risks related to DON as origin mills. The distinction is particularly important.

Results Wheat Flour Mills

On average 90 percent of wheat mills were impacted by DON. Classes of wheat affected across firms were 60% HRW, 80% HRS, 70% SRW, and 30% HAD.

DON specifications or limits for products were mostly 1 ppm or lower for standard bulk flour, 1 ppm or lower for whole flour. For byproducts, most firms indicated 5 ppm or it was dictated by varying customer specifications.

Many indicated years in the mid to late 1990s along with recent years including 2015 to 2016. Some firms also noted mid to late 2000s were problematic for DON.

To respond to the incidence of DON, most firms had to expand their draw areas. Three firms indicated they didn’t have to do anything or they had to move purchases to non-vomitoxin areas within their target area. Otherwise, there were impacts of expanded or alternative market area for procurement. We asked mills the share of the purchases over time that this occurs, and the most common answer was 10% of the time, though it was highly variable across plants and through time. We also asked the added costs related to this expanded draw area. This also varied substantially across firms and through time. These ranged from 10-30c/b in a normal year; to upward to 250-300c/b in an epidemic year. This impact is important. If a plant has to expand its draw area: 1) the basis for purchasing would typically decrease; but 2) there would be increased shipping costs. The residual of these is the added cost, and this was on average 10-20c/b in spring wheats (HRS and Durum), and 10-65c/b in winter wheats.

Firms were also asked about how wheat buying strategies changed during normal, transition and epidemic years. Averages refer to ranking of importance with lower number more important than higher numbers (Table 6.1). For these, buying wheat strategies for targeting elevator origins, pre-harvest and pre-shipping testing, and excluding origins were all more important in epidemic years. Only restrictions in contracts were less important for epidemic years.

Table 6.1. Importance of Buying Wheat Strategies in Normal, Transition and Epidemic Years (Average Across Firms).

Strategy	Normal	Transition	Epidemic
Target Elevator Origins	3.5	3.2	3.2
Pre-Harvest Testing	2.5	2.9	2.2
Pre-Shipping Testing	3.6	2.3	1.7
Excluded Origins	4.8	3.6	2.0
Restrictions in Contracts	2.0	2.0	2.3
DON Rejection Level	2.0-4.0 ppm	1.5-4.0 ppm	1.5-4 ppm
What do you do with non-conforming shipments	Most Reject/Limited Blending	Most Reject/Limited Blending	Most Reject/Limited Blending

Discounts : Firms were asked about information on discounts for DON. Only one firm indicated data was available. Opinions on ranges for discounts varied from Nil, to within a range of $0.05-$3.00/bu with three observations less than $0.30/bu; two indicated discounts in the higher end of the range in epidemic years. Discounts were applied on varying classes of wheat. Two firms reported all classes, while others indicated HRW, HRS, SRW, or Durum.

Premiums paid for wheat conforming to FDA advisory level outside the normal draw area ranged from $.05/bu to $3.00/bu Three of firms were less than $1.00/bu, while three were over that value. Firms largely indicted having to purchase supplies in the target area (2 firms), or within the range of 100-2000 additional miles. Costs for expanding the reach for purchases ranged from $0.50/bu to $1.25/bu or indicated costs around $1.00/mile for trucking. Two firms indicated no additional costs. Reponses to effects on basis of greater distance or non-vomitoxin wheat were limited. Most firms indicated no response or varies.

In addition to these, one SRW miller was capable of reproducing the discounts they applied on wheat purchases through time.[29] These values were for SRW and HRW, were translated to crop year averages, varied across mill locations, and were for years including 2009/10 to 2015/16. These were aggregated across mills, and crop years and shown in Table 6.2

[29] All firms were asked for historical discounts, but, only one was capable of provided documentation for these values.

Table 6.2. Represented Mill Discounts Applied to DON (SRW and HRW).

Crop Yr	Average	
	SRW (¢/b)	HRW (¢/b)
2015/16	11	42
1014/15	5	4
1013/14	7	1
2012/13	4	0
2011/12	7	0
2010/11	26	0
2009/10	3	0
Average	9	7
Min	3	0
Max	26	42

Some generalizations about these were:

- The aggregate discounts across mills ranged from $101,862 to $357,250 per mill per year;
- The discounts (per bushel) seem to be highly random through time, with no apparent trends;
- Discounts seemed to be particularly problematic in SRW in 2010/11 and 2015/16, though there were non-nil discounts in each year;
- For HRW, the discounts were really minimal until 2015/16 when they were abnormally large.

Testing Technology Testing for DON was largely done using Neogen, but also included Charm and Lateral flow strip with verification from Gas Chromatograph.

Costs of testing for supplied labor and labor rate were generally not responded to. The average cost of testing was $13.66 and ranged from $6.00 to $25 with one firm indicating outside testing cost $35/test. Firms tested from none, to half of firms reporting all shipments. This averaged 62% of shipments tested or a total of greater than 226,650 tests in a normal year for all the firms.

Segregation and Blending Firms indicated a range of levels of DON where they segregated high DON wheat. Some firms segregated at 0.5 ppm, 1 ppm, 2 ppm and 3 ppm. They reported that this occurs as needed or daily in epidemic years, to 5%-10% of the time. Added costs for segregation were mostly none, but if present were $0.02/bu to $0.10/bu.

Blending in the milling process was done by all but three firms. Blending was reported to largely 1 or 2 ppm. If DON was present, firms indicated cleaning 1 or 2 times or not at all. All firms reporting using gravity tables, but two firms indicated they were not used for DON. Costs for equipment acquisition (including optical color sorter used in cleaning) ranged from $250,000 to $500,000, while operating costs were largely reported as negligible or unknown. All firms indicated use of gravity tables increased test weights and yield.

Firms indicated use of several technical costs were increased due to excessive DON. These included management time, Testing Time, field scouting, disposal of cleanout, premiums paid and rejected shipments. Effects of DON on firm's operations were largely the same as for impacts of excessive DON.

Evolution of DON and Other Diseases: Firms indicated DON was a problem for their firms in the 1990's, 2000's and 2010-2016. Firms indicated that the factors/innovations most important for improvement in DON were: 1) Fungicide (1.4); 2) Farm Management (2.2): 3) Varieties (2.4); 4) crop rotation (2.7); and 5) milling practices (5). Other factors identified included weather. All firms indicated resistance to DON in varieties has not decreased over time.

Other diseases indicated as potentially problematic included, UG99, Black Tip, Ergot, Other Fusarium, Rust and Smut.

Results Barley Malsters

Eight firms were surveyed for responses to questions on DON and their impacts on their operations. Of these, three of the eight firms indicated they had plants not impacted by DON. Average percent of firms impacted by DON was 79% or alternatively 74% of plants.

DON limits on selling malting barley was most often quoted as 0.4-0.5 ppm, but some firms reported limits as less than 1 ppm. For by-products, DON limits were as high as 5-10 ppm and as low as 0-0.5 ppm. One firm indicated no limit on DON, but byproducts sold as feed.

Bad years for DON varied by firm: ranging from one reporting none, to another indicating 1993-2016. Most indicated bad years for 2011, 2013, 2014 with some indicating 2015 or 2016.

In response to bad years, three firms indicated they had to expand target area, while others indicated that target areas were large enough they were able to draw adequate supplies. For firms reporting movement in target areas, these occurred in 2007, 2010, 2011, 2013 and 2014.

Firms were asked to rank impacts of DON and scab on their firms' operations. Of items indicated, the most devastating was on customer DON limits, followed by sourcing non-or low DON barley, testing costs, processing costs, gushing and taste (Table 6.3).

Table 6.3. Barley Firms Assessment of Devastating Impacts of DON and Scab.

Item	Average Ranking (1 is worst)
Taste	5.6
Gushing	4.6
Customer DON limits	2.3
Processing Costs	3.4
Sourcing non-or low DON barley	2.4
Other (Testing Costs)	3.0

Firms were asked about importance of factors in buying barley in normal versus transition and epidemic years. Firms ranked restrictions in contracts as most important in normal years, however, pre-shipment testing was more important in transition and epidemic years.

Rejection levels for DON were the same in normal and transition years, but higher and wider in epidemic years. Also firms tended to indicate they either isolated shipments that were non-conforming or reject them outright in epidemic years, while blending was an option in normal and transition years (Table 6.4).

Table 6.4. Importance of Strategy in Buying Barley in Normal vs. Transition and Epidemic Years.

Element of Strategy	Normal Year	Transition Year	Epidemic Year
Target elevator origins	3.0	2.8	3.3
Pre-harvest testing	4	3.7	3.2
Pre-shipping testing	2.3	1.4	1.6
Excluded origins	3.9	3.6	3.4
Restrictions in contracts	2.7	2.7	2.7
Discounts exceeding limits	1, 4 and 6 ppm	4 and 6 ppm	1 and 6 ppm
Storage of barley to reduce DON	6.0	6.0	4.7
Rejection Level DON	0.5-1.0 ppm	0.5-1.0 ppm	0.6 to 2.0 ppm
Shipments non-conforming	Reject/Reg-Blend	Isolate, Reject/Reg-Blend	Isolate, Reject

Firms indicated no history of premiums/discounts for DON was available, or that they did not discount. Minimal observations suggested discounts of $0.10 to $0.50/bu; or $1/Metric Ton for each 0.1 ppm above 0.5 ppm and $2/MT for each 0.1 ppm above 1 ppm for 6 row barley. Two row barley indicated $2/MT for each 0.1 ppm above 0.5 ppm.

In years where DON was problematic, firms indicated that they would have to expand target areas from not at all to as high as 1000 miles. About half of firms indicated no expansion. The added cost to bring in barley were mostly nil, with a few ranging from $1 to $2.5/bu.

Testing Barley for DON, Cleaning and Segmentation Testing technology included Neogen, Ez-Tox, Gas Chromatograph, and Environlogic with Neogen being most identified. Cost of testing ranged from a low of $6.25/test to a high of $50/test. Cost of testing averaged $19.86/test across the firms. Testing intensity ranged from every shipment to 20% of shipments (1 in 5). These were split about half and half.

Malster used cleaning for foreign material, thins and segregation of high DON barley extensively. They indicated use for these functions around 80-90% of the time at a cost of 8 to 8.5 c/bu (Table 6.5).

Aging high DON barley to reduce DON was used only 29% of the time at a cost of 5 c/bu.

Table 6.5. Processing Methods Used by Malster to Manage Scab/DON.

Function	Frequency (% of barley handled)	Estimated cost (c/bu)
Clean for foreign material	83%	8.5
Clean out thins	89%	8.5
Segregate high DON barley	83%	8.0
Age high DON barley	29%	5.0
Other	On farm store	4.0

Segregation Firms indicated they segregated DON at varying levels. Of those reporting levels, firms started to segregate at 0.5 ppm. The most reported level for segregation was 1 ppm. Use of segregation varied widely with firms indicating it varied based on year, bin space available and intensity of DON infestation. Most firms indicated no cost for segregation as either not tracked, not treated differently or grower absorbs the cost, with one firm indicating 8 c/bu.

Other costs from DON/scab were largely noted as additional management and testing costs. Firms indicated that main impacts on firm of DON/scab was management both at grower and processor levels. It also impacted the supply chain on both sides (growers and brewers) and increased car rejection costs.

Evolution of Vomitoxin (DON) on Barley. Years where DON was a problem were the same as reported above for wheat.

Malster did not think resistance to Vomitoxin had decreased, although one indicated it seems to be more virilant. Factors/innovations most important in reducing DON were: 1) farm management practices (1.6); 2) Fungicide (1.7); 3) Crop rotations (2.1); 4) Varieties (4.3); and 5) malting processing practices (4.9).

Diseases seen as prospective problems were barley yellow dwarf, rust (stem and leaf), Ergot, blights, mold and UG99.

7. Cost Summary (Scab Impacts on US Wheat and Barley)

This section provides a summary of the costs accrued by the wheat and barley industries in the United States. All of the data are from the results of the analysis and data described in the previous sections and explanations are provided below. Details of the calculations are described below:

- Results are taken to represent those accrued during approximately 2015 (it was not possible to conduct analysis for each item for each of the preceding individual years) and using the level of production and that used for domestic use and exports respectively;

- Fungicide costs are derived from the share of area planted by class and state, for which fungicide was applied. It was assumed 1 application per year was made at a cost of $15/ac;

- Risk premiums implied to be paid to growers were derived as reported above, but, could only be done for a couple of the wheat classes and barley;

- Results for end-users were taken from the survey results, and we used the average value of observations that were reported;

- Discounts to growers were derived as described above;

- Testing costs for elevators were derived from data inferred from the survey, including the cost and frequency of testing. Testing costs for trading firms (exporters) were derived from USDA-FGIS data on DON assuming they were done on the sublot level;[30]

- Discounts to traders and at flour mills were derived using: the estimated DON level by class, and the reported discounts by each function respectively;

- Segregation costs at mills were derived from the survey results and applied to wheat and barley used in the domestic processing sector;

- Added costs due to shipping were derived from the data above. Millers indicated the amount by which net costs (as increased shipping vs reduced origin basis, i.e., FOB mill net costs). This value was used along with the share of origin mills on the notion that it would be origin mills, not destination mills, that would accrue

[30] For reference, about 1/3 of the lots over the last five years were tested for DON by FGIS. Specifically, for HRS, about half of the lots were certified by FGIS. There would also be some significant percentage done by private labs. The average sublot size is about 700 MT. The HRS annual average ranges between 850 MT and 1,100 MT.

these costs. Respondents indicated that in recent years this added cost was accrued on about 10% of the annual purchases.[31]

A few comments are provided below in interpreting the results. First, these are listed as 'costs accrued'. This is important in that there are numerous costs that are incurred in the industry, all of which were discussed in the preceding sections. As listed, these are referred as accrued. There is no attempt to make them additive. It may not be correct to add them up. The reason is that some of the costs, as represented may be partly redundant of other costs. For example, the value of yield forgone, may be partly reflected in the "Risk Premium Implied." Similarly, discounts are accrued throughout the supply chain, and, in part these may be redundant. It is not possible to separate these impacts.

These are estimated costs accrued by the industry, not at the functional level for individual firms. Some firms may be more adversely impacted in some specific years, versus other firms. These values are intended to represent an aggregate value. Nevertheless, the results are useful in understanding the cost implications of DON on these industries. It is important that while the DON problem has decreased, the problem persists.

Other important observations from these results are:

- The largest single component of cost is the "Value of yield loss" and this decreased from $880 million/year 2000, to most recently at about $387 million.

- The most important costs accrued are the risk premiums paid to induce adopting DON reducing technologies, and the value of lost yield. This is followed by fungicide, added cost due to having to procure outside of traditional draw areas, and then, testing and related costs;

- Fungicide is the 2nd largest component of costs. These are very firm numbers and reflect 1 application per year. In some cases, there are multiple applications per year and these costs are not included;

- The next largest cost category is the risk premium implied to be necessary to induce growers to adopt scab-reducing technologies. That for HRS is particularly large;

- Testing costs are important and most are accrued at the country elevator level. This is due in part that this is the point in the marketing system with the greatest variability of DON, and to which specification limits do not necessarily reduce the level of DON.

[31] This was for 2015, but, more than one mill indicated that in recent years this value was as great as 30%.

- An important aspect of testing is that this is a cost that is accrued annually, even if DON may be minimal in a particular year. The reason for this is that it is common for growers that incur excessive DON in a particular year to store it, and either blend it internally and/or sell it in a subsequent crop year. Thus, buyers, to be assured, have to test virtually all shipments entering the system;

- Discounts are accrued throughout the marketing system. They are largest at the country elevator level, which are largely accrued directly by growers. Discounts are also accrued by flour mills and by traders. These are lesser in part that the common practice is for discounts and specifications to be applied fairly rigorously, and hence, if/as specifications are exceeded at these levels, it would more typically be adventitiously.

The overall conclusion from these results is that even though the impacts of scab have been reduced as described above, the problem persists and has persistent implications for the industry. Generally, this means increasing costs and risks to participants throughout these industries.

Table 7.1. Cost Accrued Due to Scab in US Wheat and Barley Industry 2015/16 ($)

		Wheat						
		HRS	Durum	HRW	SRW	Wheat Total	Malting Barley	Total
Value of Yield forgone		186,000,000	7,000,000	415,000,000	568,000,000	1,176,000,000	293,000,000	1,469,000,000
Costs accrued by Growers (Market)								
Fungicide		86,109,375	13,599,375	87,816,375	9,603,375	197,128,500	13,891,050	211,019,550
Risk premium implied		1,620,125,000		1,059,135,000	64,610,000	2,743,870,000	81,156,500	2,825,026,500
Discounts to growers		1,900,000			22,000,000	23,900,000	na	23,900,000
Testing costs by Elevators		6,598,815	976,616	4,173,956	9,653,981	21,403,369	2,452,500	23,855,869
Testing costs and discounts for trading firms								
Testing costs Traders (exporters--inbound)		315,084	32,948	152,018	276,585	776,634	1,603	778,237
Testing at export loading		1,942,077	202,065	826,724	1,560,166	4,531,032	75,783	4,606,815
Discounts		nil	nil	nil	nil		nil	
Added Costs Accrued at Flour Mills and Malt Plants								
Discounts		2,187,000	621,144	1,528,020	3,299,832	7,635,996	1,101,600	8,737,596
Testing		3,146,496	893,657	2,638,084	4,747,557	11,425,793	3,798,225	15,224,018
Segregation		1,366,875	388,215	1,146,015	2,062,395	4,963,500	10,729,125	15,692,625
Added trucking costs		3,037,500	776,430	4,775,063	6,874,650	15,463,643	9,753,750	25,217,393

8. Economic Value of Crop Losses Suffered by U.S. Wheat and Barley Producers Due to FHB[32]

Economic Impact of USWBSI

Fusarium Head Blight is a fungus affecting wheat and barley in the United States and around the globe. The purpose of this section is four fold. First, we estimate the direct economic loss of Fusarium Head Blight infestations for all wheat and barley producing states affected by the disease in the United States, from 1993 to 2014. This is the most comprehensive loss study to date in the United States. Second, we estimate the impact of the USWBSI in reducing FHB losses. Producers and other stakeholders in affected states have pooled their resources to form a consortium of scientists and agribusiness leaders to forward a "U.S. Wheat and Barley Scab Initiative." The goal of the Initiative is to find ways to combat this disease problem by targeting research and promoting agronomic and outreach measures. Because the Scab Initiative must compete with other agricultural and natural resource problems to secure funding, the consortium sought estimates of the economic impact of resistant varieties and management practices developed by USWBSI. Preliminary observations show trends in losses have been declining after the insertion of the Initiative in 1997 for most crops and regions. Third, we develop detailed methods to estimate the value of USWBSI and summarize these values with net present value (NPV), internal rate of return (IRR) and a risk adjusted aggregate return on investment (AROI). Average losses suffered by U.S. wheat and barley producers without the Initiative (1993 to 1996) were used as base period losses and losses from subsequent years (1997 to 2014) with the Initiative were then deducted from the base period. The detailed analysis provided measures of returns (or value) to research investment by the USWBSI. Finally, secondary economic impacts of the estimated value reveal even greater savings due to the Initiative.

States Included in the Analysis

States included for this study are a subset of wheat and barley producing states that have adopted scab varieties (moderate resistant and moderate susceptible varieties), fungicide use and/or management practices developed by USWBSI. For barley, these include North Dakota, Minnesota, Virginia, New York, and Maryland (Table 1). Durum wheat states were North Dakota, Minnesota, and Montana. Hard winter wheat states were Kansas, Nebraska, North Dakota, and South Dakota. Hard red spring wheat states included North Dakota, South Dakota, Minnesota, and Montana. Soft wheats states were Illinois, Indiana, Kentucky, Michigan, Missouri, New York, Ohio, Pennsylvania, Arkansas, Georgia, Louisiana, Maryland, North Carolina, Virginia, New York, and Oregon.

[32] Research in this Section and Section 9 were conducted by Dr. Nganje.

Table 8.1. Scope of the Study

Barley	Soft Wheats	Hard Wheats	Durum
MD	IL	KS	ND
MN	IN	NE	MN
ND	KY	ND	MT
VA	MI	SD	
NY	MO	MN	
	NY	MT	
	OH		
	AR		
	GA		
	LA		
	MD		
	NC		
	VA		
	PA		
	OR		

Estimation Method for Production Loss Due to Scab

The methodology for estimating lost crop value due to FHB is adopted from Johnson, et al. (1998) and Nganje et al. (2004). The direct losses (first-round effects) of FHB for each type of grain were calculated by establishing baseline conditions that would have existed without the presence of FHB in the affected states. Actual production data for multi-county Crop Reporting Districts (CRDs) in each state from 1993 to 2014 were then compared against this baseline. Differences between actual and base-line yields and harvested versus abandoned acreage were used to estimate the total quantity of production losses. The procedure and methods are discussed in the proceeding sections.

Total Quantity Impacts in Affected Areas: Total quantity supplied is affected in three ways: total acreage planted, yields from planted acreage, and the level of abandoned acreage.

Yield Shortfall due to FHB. To estimate the economic losses due to FHB in a given CRD, the value of production under 'normal' conditions was estimated (i.e., if there had been no outbreak). Normal crop value is the product of two variables: the price that farmers would have received and their expected production in absence of scab. For the years of a scab outbreak, both variables are unobserved and must be estimated. The lost crop value is then calculated as the difference between actual and normal crop value.

Estimated normal production is comprised of yield and harvested acres. To derive yield in the absence of FHB, the following regression model was used:

$$yf_{ijt} = \beta_0 + \beta_1 R_{ijt} + \beta_2 T_{ijt} + \beta_3 t + e \quad (1)$$

where yf_{ijt} is the expected harvested yield (or forecasted yield) for grain j in region i, R_{ijt} is rainfall in inches received during the growing season, T_{ijt} is the average temperature during the growing season, t is the year, and e is the error term. The last parameter is a measure of trend yield growth caused by changes in technology, input use, and farm size. Separate equations were estimated for each CRD, using data for years preceding a severe FHB outbreak. The results of estimated coefficients–βs and model fitness are shown in Appendix 7.A1. Regression models were then used to derive estimates of the yields that would have occurred in later years (given growing conditions) in the absence of FHB.

A complicating factor was that, in some producing regions, FHB occurred simultaneously with other wheat or barley diseases or in conjunction with other factors reducing yields (e.g., floods). It would be misleading to attribute all of the estimated yield shortfall in these regions to FHB. For that reason; researchers, extension specialists, and data on scab severity were used to provide input about the relative contribution of scab to yield shortfalls. The additional information were incorporated as follows. Let yn_{ijt} denote the normal yield in absence of FHB in production region i and year t. Let yf_{ijt} denote the forecast value from the regression equation and ys_{ijt} the actual yield in a scab-affected year. The fraction of a yield shortfall attributable to scab is denoted as α_{ijt} $(0 \le \alpha_{ijt} \le 1)$. Normal yields (i.e., the estimated yields that would have occurred in the absence of FHB) are given by

$$yn_{ijt} = \alpha_{ijt} yf_{ijt} + (1 - \alpha_{ijt}) ys_{ijt} \quad (2)$$

Normal yield is a weighted average of the regression forecast and actual yield. If $\alpha_{ijt} = 1$ for a given region and crop year, then normal yield equals the forecast value, and any estimated yield shortfall $(yf_{ijt} - ys_{ijt})$ is attributed entirely to FHB. If $\alpha_{ijt} < 1$, then normal yield lies between the regression forecast and actual yield, and part of the estimated yield shortfall is attributed to other factors. For example, suppose the yield forecast (yf_{ijt}) is 40 bu/ac, actual production (ys_{ijt}) is 28 bu/ac, but only 80 percent of the shortfall is attributed to FHB. The (adjusted) normal yield is then calculated as $yn_{ijt} = 0.8 \times (40) + (1 - 0.8) \times (28) = $ 37.6 bu/ac.

For SRW and Durum, 1998 and 1999 predicted and adjusted yields in the respective CRDs coincided, hence the estimated yield shortfalls are attributable to FHB (i.e., $\alpha_{ijt} = 1$). For HRS yields in northeastern North Dakota (ND - NE), only a small fraction of the yield shortfall was attributable to FHB in 1999, hence the low adjustment factor of α_{ijt}= 0.037.

<u>Acreage Effects</u>***.*** FHB outbreaks can induce a higher-than-average rate of acreage abandonment. To account for this, a ‘normal’ ratio of harvested to planted acres was incorporated in the estimate of normal production. R_{ijt} represents the olympic average[6] of the ratio (ah_{ijt}/ ap_{ijt}), where ah_{ijt} denotes harvested acres and ap_{ijt} planted acres,

using data from seven years preceding the FHB outbreak. The 'normal' ratio (for region i, grain j, year t) is calculated as:

$$Rn_{ijt} = \alpha_{ijt}R_{ijt} + (1-\alpha_{ijt})\frac{ah_{ijt}}{ap_{ijt}} \qquad (3)$$

Equation 3 uses the same adjustment factor as was used to calculate normal yield. If α_{ijt}= 1 for a given region, grain and year, then the 'normal' ratio of harvested to planted acres is equal to the olympic average. Otherwise, if α_{ijt} < 1, the supposition is that factors other than FHB contributed to an abnormal ratio, and Rn_{ijt} is adjusted accordingly. Normal production, denoted qn_{ijt}, is given by the following formula:

$$qn_{ijt} = \left[\max\left(yn_{ijt}\,,\; ys_{ijt}\right)\right]\cdot[\max\left(Rn_{ijt}\,,\; \frac{ah_{ijt}}{ap_{ijt}}\right)]\cdot ap_{ijt} \qquad (4)$$

The first bracketed term represents harvested yield. The second bracketed term is the ratio of harvested-to-planted acres. The product of the second term and acres planted (ap_{ijt}) equals normal harvested acres. The max function is used to correct for two types of data anomalies. If the estimated normal yield falls below the actual yield in a scab year (i.e., $yn_{ijt} < ys_{ijt}$), the latter value is selected. Similarly, if the normal ratio falls below the actual ratio of harvested-to-planted acres (i.e., Rn_{ijt}< [ah_{ijt} / ap_{ijt}]), the latter value is used. Thus, in the unlikely event that production is higher than normal during a scab year, the analysis will not (falsely) attribute a positive impact to the disease. Estimated production with and without scab provides the basis to calculate "aggregate production loss", "revenue loss", and "savings by the Initiative" presented later.

Data Sources Data on temperature and precipitation by region were obtained from the National Climatic Data Center (U.S. Department of Commerce, Various). Data on planted and harvested acres, harvested yield, production, and average prices received by producers were obtained from the National Agricultural Statistics Service (U.S. Department of Agriculture, NASS, 2016). Average CBT and MGE futures prices were derived from a database of weekly quotes collected from Grain Market News (U.S. Department of Agriculture) and the Wall Street Journal. Basis was calculated as the difference between the average price received in a region and the average futures price. For North Dakota, prices received were available by crop reporting district; in other states, prices are based on state averages. Data on national wheat and barley supplies were from the Wheat Yearbook published by the Economic Research Service of the U.S. Department of Agriculture (USDA-ERS, Various).

Results of Production Loss, Revenue Loss and Savings by USWBSI

Aggregate Production Loss Aggregate production loss for each CRD (per acre) is the shortfall from yield and acreage multiplied by the total production for that CRD (in bushels). We report aggregate values of production loss for all affected states by years in Tables 8.2 to 8.5.

Durum Production Loss The average production loss for durum wheat has declined from the base period of 1993 to 1996 for all years (Table 8.2). The average loss for the base period was approximately 10.02 million bushels compared to a 2007 average high of 2.50 million bushels. Also the variability of production loss has declined significantly from 15.99 million bushels for the base period compared to the average high of 2.70 million bushels in 1997.   The reduction in variability of losses for all years (1997 to 2014) is a good indication that the Initiative has made a significant positive impact in reducing FHB Losses.

Table 8.2. Production Loss for Durum (000 bu)

State/Crop	Year									
	1993-1996	**1997**	**1998**	**1999**	**2000**	**2001**	**2002**	**2003**	**2004**	**2005**
Durum (000 bu)										
MT	1050.58	561.56	776.45	345.45	500.22	656.99	768.68	460.35	366.15	540.67
ND	28489.64	4375.21	706.56	3942.64	4556.92	2885.75	2901.64	2348.88	1844.96	2545.16
MN	530.66	-	12.14	15.84	1.42	-	16.38	1.38	12.07	12.18
Total Durum	30070.88	4936.77	1495.15	4303.93	5058.56	3542.74	3686.70	2810.61	2223.19	3098.01
Mean	10023.63	2468.39	498.38	1434.64	1686.19	1771.37	1228.90	936.87	741.06	1032.67
STDEV	15994.15	2696.66	422.55	2178.23	2498.61	1575.97	1496.68	1244.19	972.26	1336.25
	2006	**2007**	**2008**	**2009**	**2010**	**2011**	**2012**	**2013**	**2014**	
MT	357.52	295.69	562.87	596.98	485.29	565.19	655.61	593.53	467.58	
ND	421.33	711.72	1174.56	920.09	2050.61	943.25	956.40	869.57	1014.38	
MN	10.36	11.17	11.09	11.05	11.12	11.25	10.98	11.33	11.44	
Total Durum	789.21	1018.57	1748.52	1528.11	2547.03	1519.70	1622.99	1474.44	1493.39	
Mean	263.07	339.52	582.84	509.37	849.01	506.57	541.00	491.48	497.80	
STDEV	221.17	352.33	581.99	460.81	1067.29	468.76	483.02	438.13	502.15	

Barley Production Loss The average production loss for barley has declined from the base period of 1993 to 1996 compared to most years (Table 8.3). The average loss for the base period was approximately 11.38 million bushels, higher than all years with the exception of 2014. The variability of production loss, as measured by standard deviation, has declined significantly from 13.30 million bushels for the base period compared to all years, other than 2014. The reduction in variability of losses is a good indication that the Initiative has made a significant positive impact. However, the absence of resistant varieties in barley could have resulted in higher losses in 2014.

Table 8.3. Production Loss for Barley (000 bu)

State/Crop	Year									
	1993-1996	1997	1998	1999	2000	2001	2002	2003	2004	2005
	Barley (000 bu)									
MD	4077.06	782.01	847.39	578.14	25686.48	855.74	1558.93	743.40	2526.03	1658.31
NY	481.64	132.22	151.77	99.25	127.08	158.59	75.73	102.64	225.05	126.60
ND	34264.02	14934.29	7768.18	8200.92	13654.22	9399.00	24913.54	39651.32	21107.59	24046.08
MN	9644.29	4710.11	13222.84	4559.74	1059.88	757.68	2949.54	4789.76	2478.32	1943.04
VA	8441.55	1933.06	848.35	745.98	816.99	734.34	1585.18	676.57	230.12	570.12
Total Barley	56908.56	22491.69	22838.52	14184.03	41344.64	11905.35	31082.92	45963.68	26567.09	28344.15
Mean	11381.71	4498.34	4567.70	2836.81	8268.93	2381.07	6216.58	9192.74	5313.42	5668.83
STDEV	13298.81	6091.16	5751.72	3489.61	11249.04	3932.70	10501.23	17129.34	8902.17	10300.51
	2006	**2007**	**2008**	**2009**	**2010**	**2011**	**2012**	**2013**	**2014**	
MD	854.61	610.27	2284.58	408.39	647.72	4759.92	792.19	1457.16	1824.44	
NY	367.63	93.09	127.58	1227.99	125.47	93.79	104.94	92.91	94.62	
ND	10976.43	13828.58	17847.51	12763.58	7504.17	5106.73	22166.75	46811.95	18460.32	
MN	2429.27	3958.10	2070.32	1566.13	1126.62	972.10	1817.41	2075.46	1983.92	
VA	4517.95	2155.99	526.26	409.91	437.75	1843.34	4094.84	2093.50	49538.26	
Total Barley	19145.89	20646.02	22856.25	16376.00	9841.72	12775.88	28976.13	52530.97	71901.55	
Mean	3829.18	4129.20	4571.25	3275.20	1968.34	2555.18	5795.23	10506.19	14380.31	
STDEV	4311.26	5627.47	7480.82	5328.46	3115.96	2260.67	9275.65	20311.82	21024.56	

Production Loss for Hard Wheats The average production loss for hard wheats has declined from the base period of 1993 to 1996 compared to all other years (Tables 8.4 and 8.5). The average loss for the base period was approximately 113.03 million bushels compared to a 1997 average high of 25.09 million bushels. Also the variability of production loss has declined significantly from 92.43 million bushels for the base period to the average high of 22.25 million bushels in 2001. Similar to durum wheat, the reduction in variability of losses for all years (1997 to 2014) is a strong indication that the Initiative has made a significant positive impact.

Table 8.4. Production Loss for Hard Wheats (000 bu)

State/Crop	Year									
	1993-1996	1997	1998	1999	2000	2001	2002	2003	2004	2005
	Hard Wheat (000 bu)									
ND	140947.03	34167.06	4767.44	2009.43	5859.67	12642.65	24049.10	29106.28	21148.46	21016.90
SD	15953.97	1305.71	242.14	-	-	477.65	607.19	923.58	809.19	998.06
KS	270556.42	57547.75	54099.03	47933.13	49884.97	62365.88	50063.40	58703.51	57260.52	53805.59
NE	100262.6	20975.90	20378.61	22804.57	18411.90	18952.94	16548.48	21614.40	21997.76	22369.07
MN	123591.3	28057.74	3381.36	3766.45	3504.20	14361.63	19426.26	16826.45	15665.58	16593.10
MT	26858.97	8460.06	7747.75	26251.71	4541.07	5235.63	7421.50	4379.96	5222.68	4092.02
Total Hard Wheat	678170.4	150514.2	90616.34	102765.3	82201.81	114036.4	118115.9	131554.2	122104.2	118874.73
Mean	113028.4	25085.70	15102.72	20553.06	16440.36	19006.06	19685.99	21925.70	20350.70	19812.46
STDEV	92431.25	20019.39	20335.63	18794.07	19642.54	22248.90	17123.98	20876.82	19991.81	18841.43

	2006	2007	2008	2009	2010	2011	2012	2013	2014
ND	18806.01	18836.59	19362.74	18973.79	18722.37	18819.94	12930.66	13870.02	21277.89
SD	886.65	791.82	865.06	828.60	526.11	511.95	352.05	527.22	536.95
KS	54260.02	54436.93	53946.13	47260.71	42174.82	50976.11	52131.29	51287.31	52077.81
NE	19883.15	23997.36	20377.03	21634.75	21092.52	19887.84	14551.24	21528.26	18981.79
MN	13803.95	16573.70	17339.76	15247.31	15568.09	16469.97	13157.47	14037.05	14834.11
MT	4253.36	3576.84	4049.86	3423.26	5273.66	5258.31	7648.03	5634.84	4308.26
Total Hard Wheat	111893.14	118213.24	115940.59	107368.41	103357.58	111924.11	100770.74	106884.71	112016.81
Mean	18648.86	19702.21	19323.43	17894.73	17226.26	18654.02	16795.12	17814.12	18669.47
STDEV	19057.30	19251.58	18856.15	16644.51	14588.53	17661.36	18088.07	17951.29	18290.77

Production Loss for Soft Wheats The average production loss for soft wheats has declined from the base period of 1993 to 1996 compared to all other years (1997-2014). The average loss for the base period was approximately 10.66 million bushels compared to a 1997 average high of 3.38 million bushels. Also the variability of production loss has declined significantly from 10.75 million bushels for the base period to the average high of 3.53 million bushels in 2013.   Similar to durum wheat, the reduction in variability of losses for all years (1997 to 2014) is a strong indication that the Initiative has made a significant positive impact.

Table 8.5. Production Loss for Soft Wheats (000 bu)

State/Crop	Year									
	1993-1996	1997	1998	1999	2000	2001	2002	2003	2004	2005
					Soft Wheat(000 bu)					
IL	15725.56	-	2111.89	226.99	449.78	630.52	430.19	610.69	938.41	425.00
IN	1111.38	-	583.10	189.92	204.49	109.46	358.12	667.97	389.81	327.60
MI	3421.81	-	2302.22	496.13	656.71	933.30	2369.50	3541.53	2724.51	2669.87
MO	7594.74	-	286.64	138.78	599.27	1059.25	216.31	32.71	125.84	54.69
OH	13049.45	-	1307.47	109.13	-	673.24	667.02	1377.53	628.13	616.34
KY	53.88	-	306.52	352.03	725.39	-	148.01	402.02	236.88	238.23
NY	1526.01	413.56	429.37	432.01	476.81	385.71	352.68	371.20	314.01	291.49
AR	7796.74	1690.70	2073.87	2208.13	3021.87	3439.27	2773.69	2352.49	1700.66	1150.70
GA	13969.02	3558.18	2837.69	2294.37	2686.80	2945.93	2218.33	2793.05	2432.01	2415.32
LA	2864.91	818.82	837.45	778.76	1454.04	1013.21	1272.24	1037.63	1327.59	781.84
MD	8241.22	2009.00	2049.06	1982.12	1886.58	1597.45	1476.00	1333.86	1322.49	1244.61
NC	25651.89	8059.99	7571.80	6814.07	6377.50	7928.34	6356.34	5371.03	5545.67	5625.92
VA	9553.04	2354.62	2250.02	2361.31	1789.39	1937.25	2003.36	1371.39	1516.65	1628.42
PA	8373.84	2288.43	2286.86	2605.53	2470.34	2407.51	2501.20	2274.36	1813.15	1997.22
OR	41018.73	9255.57	8847.40	6078.53	6704.44	6826.38	7836.83	9805.95	7044.32	8032.89
Total Soft Wheat	159952.22	30448.86	36081.37	27067.80	29503.42	31886.81	30979.82	33343.42	28060.13	27500.14
Mean	10663.48	3383.21	2405.42	1804.52	2107.39	2277.63	2065.32	2222.89	1870.68	1833.34
STDEV	10753.32	3138.31	2514.72	2108.67	2085.92	2377.31	2253.29	2531.09	1978.68	2230.64

Table 8.5 (continued)

	2006	2007	2008	2009	2010	2011	2012	2013	2014
IL	622.49	673.63	665.32	537.47	253.29	455.86	488.81	558.09	571.52
IN	699.86	430.12	2503.97	501.32	216.14	377.05	444.43	524.53	1238.87
MI	9166.34	2390.51	3018.92	3361.57	2512.61	3557.47	2835.65	2835.64	5399.10
MO	215.26	606.80	119.51	180.36	202.37	196.52	96.57	101.00	197.66
OH	705.47	735.39	779.11	685.11	551.52	634.70	481.51	481.43	1814.89
KY	215.03	405.22	306.21	162.45	97.50	305.50	295.90	487.36	319.78
NY	327.96	483.95	416.43	379.16	379.72	495.51	425.88	540.23	746.41
AR	858.34	2399.99	4030.03	1532.16	1093.90	1891.38	2197.48	2173.75	1578.72
GA	1593.26	2560.21	4755.52	3413.33	1493.23	2395.41	2966.39	4751.82	3722.51
LA	1044.71	1935.87	2818.28	2332.29	2477.30	2532.26	2529.62	2573.81	2605.36
MD	2650.51	1948.64	1798.57	1798.90	1558.58	2155.36	2446.17	2435.46	2277.54
NC	6188.71	6585.81	9953.10	7770.39	5427.32	8940.49	10077.18	13068.44	10671.21
VA	2059.96	2064.81	2720.71	2470.11	1579.94	2350.92	2666.06	3115.96	2878.14
PA	2155.16	2494.81	2682.76	2738.28	2275.73	2276.39	2342.18	3132.66	3353.20
OR	6788.30	5921.84	7339.48	7367.78	9935.03	10809.52	10037.83	8477.25	7600.54
Total Soft Wheat	35291.36	31637.59	43907.94	35230.68	30054.16	39374.35	40331.67	45257.43	44975.44
Mean	2352.76	2109.17	2927.20	2348.71	2003.61	2624.96	2688.78	3017.16	2998.36
STDEV	2767.49	1884.52	2748.42	2400.93	2598.55	3142.91	3178.69	3534.34	2923.38

Revenue Loss Revenue losses were obtained from the product of production losses (yield and acreage effects) and prices received by growers. The average revenue loss from 1993 to 1996 (prior to the Initiative) was used as the base period. The difference from each subsequent year after USWBSI (1997 to 2014) was calculated. The revenue losses due to FHB by state, crop, and year are presented in Tables 8.6 to 8.9 in millions of dollars. The average revenue loss results are similar to the production loss in most part. However, wide fluctuations in price affect the losses differently in certain regions. Similar to production loss results, the reduction in variability of revenue loss for all years (1997 to 2014) is a strong indication that the Initiative has made a significant positive impact.

Revenue Loss for Barley The average revenue loss for the base period (1993-1996) was $20.08 million. The years proceeding the Scab Initiative (1997-2014) had lower revenue loss except the years 2003, 2008, 2012, 2013, and 2014. The variability of revenue losses were also lower, except for the years 2002, 2003, 2007 2008, 2012, 2013, and 2014. Increased variability in prices resulted in higher revenue losses compared to the base year. Good management practices developed by the USWBCI have been beneficial. However, continued research to develop scab resistant varieties for barley could lead to further decreases in variability in revenue losses.

Table 8.6. Revenue Loss for Barley (million $)

State/Crop	Year									
	1993-1996	**1997**	**1998**	**1999**	**2000**	**2001**	**2002**	**2003**	**2004**	**2005**
					Barley(million $)					
MD	8.02	1.60	1.10	0.78	35.96	1.11	2.18	1.34	4.85	2.42
NY	0.97	0.26	0.20	0.13	0.21	0.25	0.15	0.21	0.46	0.23
ND	57.83	32.64	15.94	13.32	23.19	15.90	63.78	102.70	44.75	47.85
MN	17.70	8.86	21.42	7.02	1.77	1.17	7.73	12.07	5.50	3.91
VA	15.88	4.06	1.19	0.98	1.10	0.94	2.28	1.05	0.40	0.91
Total Barley	100.40	47.42	39.85	22.23	62.23	19.38	76.12	117.37	55.96	55.32
Mean	20.08	9.48	7.97	4.45	12.45	3.88	15.22	23.47	11.19	11.06
STDEV	22.13	13.35	9.98	5.69	16.28	6.73	27.29	44.55	18.91	20.61
	2006	**2007**	**2008**	**2009**	**2010**	**2011**	**2012**	**2013**	**2014**	
MD	1.32	1.65	9.12	0.97	1.52	19.75	3.64	6.02	6.57	
NY	0.66	0.26	0.61	4.30	0.46	0.53	0.57	0.43	0.35	
ND	29.09	54.07	92.45	49.14	28.07	27.68	145.41	285.08	97.84	
MN	6.36	15.04	10.91	6.42	4.41	4.87	11.60	12.91	10.67	
VA	6.96	5.95	2.22	0.97	1.15	7.89	15.89	7.96	178.34	
Total Barley	44.38	76.97	115.30	61.80	35.60	60.72	177.11	312.40	293.77	
Mean	8.88	15.39	23.06	12.36	7.12	12.14	35.42	62.48	58.75	
STDEV	11.65	22.38	39.04	20.69	11.81	11.24	61.79	124.52	77.90	

Revenue Loss for Durum The average revenue loss for the base period (1993-1996) was higher than all proceeding years with the Scab Initiative (1997-2014). The variability of revenue losses were also lower, indicating a positive impact from the Initiative. These results are consistent with a declining production loss result for durum.

Table 8.7. Revenue Loss for Durum (million $)

State/Crop	Year									
	1993-1996	**1997**	**1998**	**1999**	**2000**	**2001**	**2002**	**2003**	**2004**	**2005**
					Durum (million $)					
MT	5.14	2.91	2.51	1.19	1.76	2.50	3.45	1.87	1.41	1.87
ND	124.84	19.46	1.98	100.62	12.53	7.56	11.39	9.26	6.90	8.65
MN	2.46	-	0.04	0.04	0.10	-	0.07	0.01	0.04	0.04
Total Durum	132.44	22.37	4.53	101.86	14.39	10.06	14.90	11.14	8.35	10.55
Mean	44.15	11.18	1.51	33.95	4.80	5.03	4.97	3.71	2.78	3.52
STDEV	69.89	11.70	1.30	57.74	6.75	3.58	5.81	4.89	3.63	4.53
	2006	**2007**	**2008**	**2009**	**2010**	**2011**	**2012**	**2013**	**2014**	**Total**
MT	1.65	2.74	5.45	3.07	3.02	5.82	5.32	4.24	0.00	
ND	1.88	7.83	10.62	4.37	13.09	8.84	7.49	6.30	7.27	
MN	0.05	0.12	0.10	0.05	0.07	0.11	0.09	0.08	0.08	
Total Durum	3.58	10.69	16.17	7.50	16.18	14.77	12.90	10.63	7.35	
Mean	0.96	3.98	5.36	2.21	6.58	4.47	3.79	3.19	3.68	
STDEV	1.30	5.45	7.44	3.05	9.21	6.18	5.24	4.40	5.08	

Revenue Loss for Hard Wheats The average revenue loss for the base period (1993-1996) was higher than all proceeding years with the Scab Initiative (1997-2014). The variability of revenue losses were also lower, indicating a positive impact from the Initiative. These results are consistent with a declining production loss result for hard wheats.

Table 8.8. Revenue Loss for Hard Wheats (million $)

State/Crop	Year									
	1993-1996	**1997**	**1998**	**1999**	**2000**	**2001**	**2002**	**2003**	**2004**	**2005**
					Hard Wheat (million $)					
ND	525.69	134.29	14.06	8.01	25.01	34.85	87.04	104.62	71.70	75.46
SD	49.52	4.11	0.72	-	-	-	2.30	3.35	2.84	3.73
KS	1057.82	181.85	136.87	107.85	132.20	167.76	170.72	184.92	186.10	178.10
NE	382.28	67.12	51.76	50.17	48.06	52.12	59.57	69.60	71.05	75.16
MN	438.95	102.38	9.76	12.00	11.12	42.97	74.99	61.58	52.17	60.73
MT	110.74	30.29	24.25	77.97	13.76	16.02	30.28	16.56	19.27	15.55
Total Hard Wheat	2565.01	520.04	237.42	256.00	230.15	313.72	424.89	440.62	403.13	408.73
Mean	427.50	86.67	39.57	51.20	46.03	62.74	70.82	73.44	67.19	68.12
STDEV	361.20	66.26	50.79	42.80	50.32	60.20	57.84	65.88	64.56	61.91
	2006	**2007**	**2008**	**2009**	**2010**	**2011**	**2012**	**2013**	**2014**	
ND	82.23	140.33	139.21	92.97	129.55	153.79	104.14	88.90	100.71	
SD	3.88	4.99	6.32	4.93	3.60	4.18	2.94	3.90	3.21	
KS	247.43	322.81	374.39	226.38	216.78	358.36	389.94	358.50	304.66	
NE	90.87	139.66	136.12	102.33	111.16	133.25	114.52	149.66	110.09	
MN	62.81	120.99	122.94	71.97	95.28	132.91	107.10	93.91	82.33	
MT	19.48	26.79	29.81	19.58	36.23	43.96	64.17	37.75	-	
Total Hard Wheat	506.69	755.58	808.78	518.16	592.59	826.45	782.81	732.61	601.00	
Mean	84.45	125.93	134.80	86.36	98.77	137.74	130.47	122.10	120.20	
STDEV	86.93	112.82	130.46	79.00	74.84	122.97	133.78	126.20	111.38	

Revenue Loss for Soft Wheats The average revenue loss for the base period (1993-1996) was higher than all proceeding years with the Scab Initiative (1997-2014). The variability of revenue losses were also lower, indicating a positive impact from the Initiative. These results are consistent with a declining production loss result for soft wheats.

Table 8.9. Revenue Loss for Soft Wheats (million $)

State/Crop	Year									
	1993-1996	1997	1998	1999	2000	2001	2002	2003	2004	2005
	Soft Wheat(million $)									
IL	63.11	-	4.96	0.48	0.95	0.96	1.33	2.24	3.17	1.47
IN	1026.54	-	1.38	0.41	0.41	0.38	1.07	2.38	1.34	1.12
MI	13.04	-	5.36	1.05	1.32	1.45	7.13	11.23	8.06	8.84
MO	25.13	-	0.66	0.29	1.35	2.20	0.66	0.10	0.41	0.18
OH	51.43	-	2.96	0.22	-	1.62	2.11	4.41	1.98	1.95
KY	0.17	-	0.69	0.77	1.52	0.98	0.45	1.27	0.70	0.79
NY	5.77	1.39	0.91	0.89	0.93	1.02	1.16	0.90	0.88	0.97
AR	28.84	6.75	6.47	5.03	7.34	8.49	8.60	8.61	5.75	3.97
GA	46.41	11.35	7.38	5.30	6.58	6.04	5.55	8.52	8.39	7.37
LA	7.00	2.48	2.59	2.39	5.01	5.38	6.96	5.09	7.96	5.59
MD	23.77	5.77	6.38	7.61	7.79	6.91	4.78	3.01	2.97	2.73
NC	88.65	25.79	19.31	15.88	14.99	19.03	17.48	15.31	17.19	17.27
VA	32.08	7.18	5.42	4.72	3.58	4.44	5.65	4.09	4.47	4.74
PA	32.27	7.71	5.92	6.49	5.41	6.45	8.50	7.53	6.16	6.99
OR	163.47	32.67	23.18	16.96	17.50	22.25	28.84	35.89	25.64	26.03
Total Soft Wheat	1607.70	101.09	93.57	68.48	74.66	87.61	100.26	110.57	95.09	90.00
Mean	107.18	11.23	6.24	4.57	5.33	5.84	6.68	7.37	6.34	6.00
STDEV	257.63	10.75	6.55	5.42	5.30	6.57	7.60	8.95	6.90	7.08

Table 8.9 (continued)

	2006	2007	2008	2009	2010	2011	2012	2013	2014
IL	1.94	2.71	4.36	3.26	1.16	2.59	3.21	4.38	4.01
IN	2.23	1.65	15.14	3.10	1.07	2.07	2.84	3.98	8.93
MI	31.62	12.62	16.91	15.46	14.40	24.08	20.56	18.63	29.43
MO	0.76	3.14	0.64	0.77	1.00	1.31	0.67	0.66	1.06
OH	2.36	3.95	4.53	3.02	2.87	4.27	3.82	3.15	10.07
KY	0.74	2.14	1.71	0.75	0.56	2.07	2.15	3.20	1.74
NY	1.32	3.35	2.56	1.86	2.41	3.41	3.52	3.57	4.11
AR	2.68	9.67	26.44	9.28	5.00	10.74	14.44	17.04	11.08
GA	5.90	16.64	28.30	14.68	7.47	18.16	21.65	30.89	21.59
LA	6.60	9.83	10.82	10.91	11.07	11.23	11.35	11.49	11.64
MD	5.99	4.73	4.57	5.44	4.91	6.38	7.57	8.01	7.79
NC	20.18	32.27	57.93	34.81	26.11	65.00	68.32	82.07	55.21
VA	6.67	11.93	16.00	10.05	8.22	15.09	19.70	21.51	15.54
PA	7.59	16.47	14.54	11.35	11.38	14.86	18.67	21.40	19.11
OR	29.87	48.32	46.68	36.75	62.59	70.80	80.70	59.26	51.30
Total Soft Wheat	126.44	179.43	251.12	161.49	160.19	252.06	279.16	289.23	252.61
Mean	8.43	11.96	16.74	10.77	10.68	16.80	18.61	19.28	16.84
STDEV	10.26	12.94	16.90	11.27	15.90	21.86	23.99	23.06	16.69

Model Logic: Estimating Savings by the USWBSI Savings by the USWBSI accrued when revenue loss declines after the base period (1993-1996), due to reduction in FHB occurrences. The difference in revenue loss between the base period and each subsequent year could be negative or zero. We assume that a positive difference in revenue losses could induce zero savings by the Initiative, since the Initiative could only have a positive or null impact.

Revenues Savings/Impacts of the Initiative The effect of savings from resistant varieties and management practices represent savings to small grain producers and also represent direct economic benefits to regional economies.

Hard wheats Savings from hard wheats were estimated at $3.16 billion in North Dakota, Minnesota, South Dakota, Kansas, Nebraska, and Montana from 1997 through 2014. Total direct losses were greatest in Kansas ($1.037 billion), followed by North Dakota ($821 million), Minnesota ($705 million) and Nebraska ($320 million) over the period. Direct savings were greatest in 1999 and lowest in 2008.

Durum Savings from durum were estimated at $395 million in North Dakota and Minnesota from 1997 through 2014. The economic gains from FHB in durum were limited primarily to North Dakota. North Dakota represented over 97 percent of the two-state total savings.

Barley Savings from barley were estimated at $45 million in North Dakota, Minnesota, Maryland, New York, and Virginia from 1997 through 2014. Total direct gains over the period were greatest in Virginia ($30.5 million), followed by Maryland ($6.7 million) and Minnesota ($6.4 million).

Soft red winter wheat Savings from SRW wheat were estimated at $6.1 billion in Illinois, Indiana, Kentucky, Michigan, Missouri, Ohio, New York, Arizona, Georgia, Maryland, North Carolina, Virginia, Pennsylvania, Idaho, Oregon, and Washington from 1997 through 2014. Total direct gains over the period were greatest in Indiana ($4.4 billion), followed by Washington ($634 million), Illinois ($241 million), Idaho ($195 million), Ohio (178 million), and Oregon ($154 million).

Summary of Total Savings The combined savings from hard wheats (hard red spring and hard red winter), soft red wheat, durum, and barley were estimated at $9.69 billion from 1997 through 2014. The direct economic gains over the period were greatest for SRW wheat ($6.1 billion), followed by hard wheats ($3.16 billion). Savings for barley and durum were estimated at $45 million and $395 million, respectively. Combined gains with the four crops were greatest in 2000 ($880 million) and were lowest in 2008 ($297 million).

Gains from all crops were summed by state. Indiana, with economic gains from FHB reduction in soft red wheat incurred the greatest impact ($4.4 billion) of all states from 1997 through 2014. Other states with considerable economic gains over the period included North Dakota ($1.1 billion), Kansas ($1 billion), Minnesota ($721 million), and Washington ($634 million).

9. Returns to the USWBI Investment

Return on Investment Analysis

Analysts have found a strong link between investments in research and innovation and agricultural productivity growth. However, there is a long lead time between the research stage of a new technology and the point at which that technology is adopted and begins to affect productivity (Magni 2015). An economic assessment of payoffs from public investments in agricultural research have attempted to determine the "social rate of return" to this expenditure. This is reported as a percent return on each dollar spent on research. The return is "social" because it includes all of the economy wide benefits from higher productivity. These returns benefit not only farmers but also stakeholders along the food supply chain. As a benchmark, social returns to public expenditures are often compared with the return to U.S. Treasury Bonds as a measure of the opportunity cost of public funds.

NPV Estimates

Net Present Value (NPV) is the difference between the present value of cash inflows and the present value of cash outflows. It is an absolute measure of worth. The following is the formula for calculating NPV:

$$NPV = \sum_{t=1}^{T} \frac{C_t}{(1+r)^t} - C_o \qquad (5)$$

Where C_t is annual aggregate revenue savings for all crops, C_o is total investment costs, r is the discount rate, and t is the number of time periods (1997 - 2014). Two costs were used in this analysis; an annual average of $4.2 million from federal support to USWBSI and a trigger annual expense ranging from $98 to $110 million for increased fungicide use. A positive net present value indicates that the projected earnings generated by a project or investment (in present dollars) exceeds the costs (also in present dollars) and vice versa.

Internal Rate of Return

Based on previous research, we calculated the Internal Rate of Return (IRR) to figure out the Return on Investment. The internal rate of return (IRR) is a metric used in capital budgeting methods to measure the profitability of potential investments. The internal rate of return is a discount rate that makes the net present value (NPV) of all cash flows from a particular project equal to zero. IRR calculations rely on the same formula as NPV does and both are widely used. However, IRR has the added advantage of supplying information on the efficient use of capital that NPV cannot supply. The difference between IRR and opportunity cost of capital (6.22 percent for long term federal bonds) relates information about the efficient use of funds by the Initiative.

Unfortunately, IRR also suffers from certain weaknesses with multiple IRRs and wider swings with higher risks and uncertainty in savings. Another appropriate measure of value creation under risk and uncertainty is the aggregate return on investment (AROI).

The Aggregate Return on Investment

This rate of return is the amount of return per unit of invested capital, when returns are stochastic. Following the formulation of Magni (2015) the AROI can be computed as the ratio of total cash flow to total capital:

$$i = \frac{F}{C} \quad (6)$$

Where $F = -c_0 + \sum_{t=1}^{n} f_t + s_n$.

Magni (2015) showed that AROI is consistent with $NPV = \sum_{t=0}^{n} f_t(1+r)^{n-t} + s_n - c_0(1+r)^n$.

Value creation is measured by the net of the cost of capital and the invested capital C. Therefore, the project is worth undertaking if and only if the AROI exceeds the cost of capital: $i > r$.

Note that the value created per unit of invested capital is

$$\frac{NPV_n}{C} = \frac{NPV_0}{PV[C]}$$

which is an adjusted profitability index (API) with value creation when savings are positive. For example, consider revenue savings (million dollars) in 1997, 1998 and 1999 to be $f_1 = 20$, $f_2 = 50$ and $f_3 = 80$, with the average discount rate is $r = 6.22\%$. The infused capital amounts are $c_0 = 100$, $c_1 = 100 * (1 + 6.22\%) - 20 = 86.2$, $c_2 = 86.2 * (1 + 6.22\%) - 50 = 41.5$.So, the project's Capital is $C = 100 + 86.2 + 41.5 = 227.7$, then total cash flow will be $F = -100 + 20 + 50 + 80 = 50$. The project's AROI then will be $i = \frac{F}{C} = \frac{50}{227.7} = 21.96\%$, which is greater than 6.22%, indicating savings by the Initiative.

Results of all three measures are summarized in Tables 9.1 and 9.2. NPV results are presented in Table 9.1. IRR and AROI results are presented in Table 9.2. As indicated in the methodology section additional trigger expenses were estimated for fungicide use. Fungicide expenses and funds provided to the Initiative were used as cost. The economic impacts of the scab program were calculated by obtaining fungicide usage by state and crop from USDA-NASS for the years before the program began and after the program began.

Unfortunately, data were not complete as the USDA did not survey producers every year. The missing data were interpolated from entries before and after the missing numbers and missing state data were interpolated from data from surrounding states. Application activity due to the program was calculated by multiplying the difference between the application frequency of fungicides before the program and the application frequency of fungicides after the program by average planted acres in the various states. That value was used to estimate the direct impact of the scab program benefits. The program began in 1997 although the full benefits did not begin until 1999. The $4.23 million in average program funding generated an average of $110 million in fungicide application costs on about 6.5 million acres of wheat and barley per year.

During the same 18-year period, direct funding of research through USWBSI totaled $76 million (for an average of $4.23 million per year). The $76 million triggered other investments in fungicide use ($110 million per year), extension and in-kind contributions ($12.76 million) (USWBSI 2016).

Net Present Value Results

Cash flows (net savings) were discounted with a 6.22% cost of capital, representing average returns on long term bonds during the same period. Findings indicate that Net Present Value ("net savings") for the period 1997 through 2014 attributable to the USWBSI total nearly $5.4 billion.

Table 9.1. Savings and NPV Due to USWBSI

Year	Savings (All Grains)	Funds Provided	Net Savings
Fungicide Investment (Annually)	-	-$110,000,000	-$110,000,000
Other Research and Outreach	-	-$12,764,016	-$12,764,016
1997	$444,633,690.17	-$200,000.00	$444,433,690.17
1998	$635,396,348.02	-$200,000.00	$635,196,348.02
1999	$760,191,837.36	-$3,050,192.00	$757,141,645.36
2000	$759,156,194.72	-$4,228,846.00	$754,927,348.72
2001	$675,176,159.09	-$4,916,501.00	$670,259,658.09
2002	$554,084,960.58	-$4,923,885.00	$549,161,075.58
2003	$532,098,360.60	-$4,922,301.00	$527,176,059.60
2004	$585,082,491.22	-$5,125,318.00	$579,957,173.22
2005	$581,338,447.35	-$5,054,864.00	$576,283,583.35
2006	$474,580,971.44	-$4,993,646.00	$469,587,325.44
2007	$313,823,140.04	-$4,991,809.00	$308,831,331.04
2008	$297,170,976.14	-$4,956,802.00	$292,214,174.14
2009	$447,311,657.44	-$4,927,432.00	$442,384,225.44
2010	$387,610,779.80	-$4,928,531.00	$382,682,248.80
2011	$312,392,773.08	-$4,862,721.00	$307,530,052.08
2012	$344,617,558.05	-$4,423,440.00	$340,194,118.05
2013	$371,667,378.73	-$4,536,580.00	$367,130,798.73
2014	$386,931,312.21	-$4,911,835.00	$382,019,477.21
Mean	$492,403,613.11	-$4,230,816.83	$488,172,796.28
NPV (billion $)			$5.29 -$5.37*

*Low range estimate includes in-kind research and outreach expenses

Internal Rate of Return Results

Internal Rate on Return (IRR) for the USWBSI-funded research averaged 34% annually. This average is greater than the opportunity cost of 6.22%, return on long-term bonds. It also falls within the range of return on investment to agricultural research.

Aggregate Rate of Return Results

The AROI of 33% annually is very profitable. Stemming from a research investment of $76 million given to the Initiative from 1997 to 2014. This suggests a “very positive story” in terms of the U.S. Wheat & Barley Initiative’s impact and effectiveness.

Table 9.2. IRR and Discount Rate

Year	IRR	Discount Rate	AROI
1997	0%	9.94%	0%
1998	0%	14.92%	0%
1999	15%	-8.25%	16%
2000	23%	16.66%	24%
2001	28%	5.57%	28%
2002	30%	15.12%	30%
2003	32%	0.38%	32%
2004	33%	4.49%	33%
2005	33%	2.87%	33%
2006	34%	1.96%	34%
2007	34%	10.21%	34%
2008	34%	20.10%	34%
2009	34%	-11.12%	34%
2010	34%	8.46%	34%
2011	34%	16.04%	34%
2012	34%	2.97%	34%
2013	35%	-9.10%	34%
2014	35%	10.75%	34%

Summary of Returns on Investments

The Initiative yields important societal returns. A large body of economic literature, including 35 studies published over the time period of 1965-2005, indicates that the median estimate of the social rate of return was 45 percent per year and that for every $1 spent on agricultural research, approximately $10 worth of benefits were returned to the economy (Fuglie and Heisey 2007). Investments with the Scab Initiative has triggered significant investments from producers and other research and outreach efforts. The $76 million triggered other investments in fungicide use ($110 million per year), extension and other research ($12.76 million). These aggregate investments suggest the Initiative has resulted in significant net savings for the period 1997 through 2014, totaling nearly $5.4 billion.

10. Secondary Economic Impacts of Losses Attributable to FHB[33]

Combined Direct and Secondary Savings by the Initiative

Economic activity from a project, program, policy, or event can be categorized into direct and secondary impacts. Direct impacts are those changes in output, employment, or income that represent the initial or first-round effects of the activity. Secondary impacts (often categorized into indirect and induced effects, also known as multiplier effects) result from subsequent rounds of spending and re-spending within an economy.

The secondary economic effects were estimated using input-output (I-O) analysis. I-O analysis is a mathematical tool that traces linkages among sectors[34] of an economy and calculates changes in employment, business activity, personal income, and net-value added resulting from a direct impact in an economic sector. I-O coefficients used in this analysis were obtained from Regional Input-Output Modeling System II (RIMS II) (U.S. Bureau of Economic Analysis 2016a).

RIMS II coefficients for 2015 for small grain farming sector were obtained for each state. Type I and Type II multipliers were used to generate separate estimates of the combined indirect and induced economic impacts of the Initiative. RIMS II coefficients were developed from 2007 national benchmark input-output data and 2015 regional data (U.S. Bureau of Economic Analysis 2016b).

Regional Economic Effects of USWBSI

Economic activity from a project, program, policy, or event can be categorized into direct, indirect, and induced impacts. Direct impacts are those changes in output, employment, or income that represent the initial or first-round effects of the activity. Indirect impacts are based on backward linkages between the affected economic sector(s) on the demand for inputs and services provided by other economic sectors. Induced effects are based on changes in economic activity created by personal consumption of workers whose earnings are affected by a change in sales to final demand in the affected economic sectors.

Direct, indirect, and induced effects represent categories of causality of economic impacts. The metrics used to describe the size or magnitude of the impacts are most commonly employment, earnings (personal income), economic output (business volume of all transactions in affected sectors), and net value-added (contribution to gross state product) (Figure 10.1).

[33] Research in this Section was conducted by Dr. Nganje and Dean Bangsund.

[34] An economic sector is a group of similar economic units (e.g., communications and public utilities, retail trade, construction).

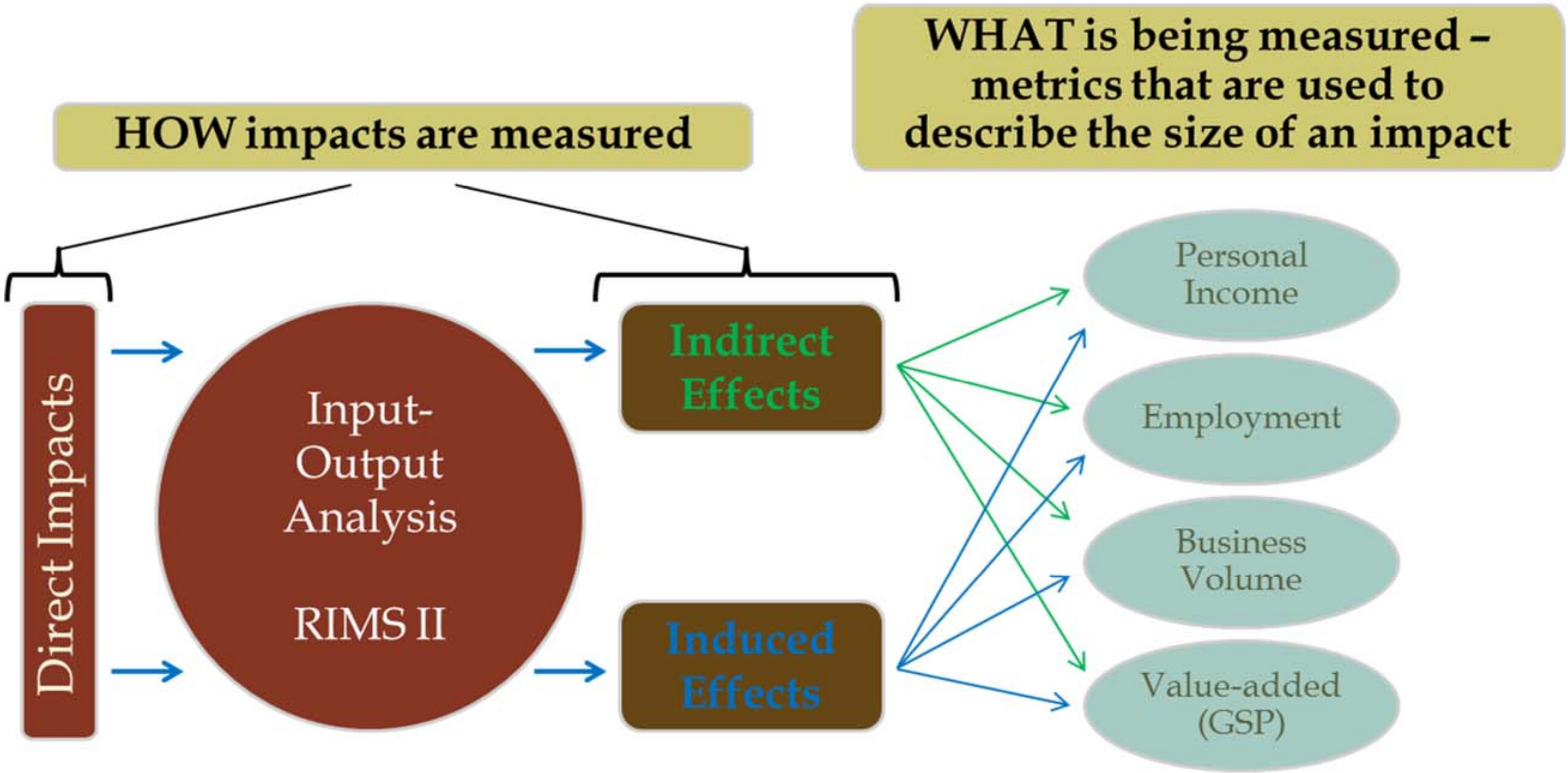


Figure 10.1. Representation of Traditional Impact Assessment using Input-Output Analysis.
Source: Bangsund and Hodur (2017).

Economic Output Economic output is the combination of direct, indirect and induced economic effects associated with the sum of gross receipts among all affected sectors. FHB affects small grain producers of hard wheats, durum, barley, and soft red winter wheat. Those combined effects serve to reduce small grain revenues for producers. The effects of FHB were evaluated using the small grain production sector for RIMS II. Economic output coefficients were specific for each state.

Hard Wheats Direct economic impacts (gains in small grain revenues) from FHB reduction on hard wheats totaled $3.16 billion from 1997 to 2014. Indirect economic impacts from FHB on hard wheats were estimated at $1.19 billion over the period. Induced economic impacts from FHB on hard wheats were estimated at $2.62 billion over the period. Total economic gains were $6.97 billion.

Durum Direct economic impacts of FHB in durum totaled about $395 million from 1997 to 2014. Indirect economic impacts from FHB on durum were estimated at $124 million over the period. Induced economic impacts from FHB on durum were estimated at $294 billion over the period. Total economic gains attributed to FHB reduction in durum was $813 million.

Barley Direct economic impacts of FHB in barley were estimated at $45 million from 1997 through 2014. Indirect economic impacts from FHB on durum were estimated at $14.8 million over the period. Induced economic impacts from FHB on durum were estimated at $23 billion over the period. Total economic gains attributed to FHB reduction in barley was $82.8 million.

Soft Red Winter Wheat Direct economic impacts of FHB in SRW were estimated at $6.1 billion from 1997 through 2014. Indirect economic impacts from FHB on durum were estimated at $2.6 billion over the period. Induced economic impacts from FHB on durum were estimated at $5.1 billion over the period. Total economic gains attributed to FHB reduction in SRW was $13.7 million.

Total Direct, Indirect, and Induced Economic Output Total direct and secondary economic gains from FHB reduction in HRS wheat, barley, durum, and SRW wheat from 1997 to 2014 were estimated at $21.6 billion. Total economic impacts were greatest for SRW and HRS wheat, which accounted for 96 percent of all gains.

Personal Income Personal income includes all forms of income to households, including wages and salaries, tips, bonuses, rent, dividends, interest and return to sole proprietors and partnerships. Personal income is estimated for both indirect and induced effects. The effects of FHB reduction on economy-wide personal income were evaluated using the small grain production sector for RIMS II. Personal income coefficients were specific for each state.

Hard Wheats Indirect effects on personal income from FHB reduction on hard wheats were estimated at $1.15 billion over the period. Induced effects on personal income from FHB on hard wheats were estimated at $345 million over the period. Total gains of personal income was $1.5 billion.

Durum Indirect effects on personal income from FHB reduction on durum were estimated at $140 million over the period. Induced effects on personal income from FHB on durum were estimated at $36 million over the period. Total gains of personal income was $176 million.

Barley Indirect effects on personal income from FHB reduction on barley were estimated at $13 million over the period. Induced effects on personal income from FHB on barley were estimated at $4 million over the period. Total gains of personal income was $17 million.

Soft Red Winter Wheat Indirect effects on personal income from FHB reduction on SRW were estimated at $2.18 billion over the period. Induced effects on personal income from FHB on barley were estimated at $757 million over the period. Total gains of personal income was $2.93 billion.

Total Indirect and Induced Effects on Personal Income Indirect effects on personal income from FHB reduction on SRW, barley, durum, and hard wheats were estimated at $3.48 billion over the period. Induced effects on personal income from FHB on barley, durum, SRW, and hard wheats were estimated at $1.14 million over the period. Total gains of personal income for the four crops was $4.62 billion.

Value-added Output Value-added is a measure of the increase in the net value of all goods and services produced as a result of a change in demand in an economic sector. Value-added also is considered the contribution to gross state product (GSP). GSP is different from total business volume since not all transactions included in total business volume can be considered as generating additional value within the economy. The effects of FHB reduction on value-added economic output were evaluated using the small grain farming sector within RIMS II. Value-added coefficients were specific for each state.

Hard Wheats Indirect effects on GSP from FHB reduction on hard wheats were estimated at $1.74 billion over the period. Induced effects on GSP from FHB on hard wheats were estimated at $690 million over the period. Total savings in GSP was $2.43 billion.

Durum Indirect effects on GSP from FHB reduction on durum were estimated at $207 million over the period. Induced effects on GSP from FHB on durum were estimated at $72 million over the period. Total savings in GSP was $279 million.

Barley Indirect effects on GSP from FHB reduction on barley were estimated at $19 million over the period. Induced effects on GSP from FHB on barley were estimated at $9 million over the period. Total savings in GSP was $28 million.

Soft Red Winter Wheat Indirect effects on GSP from FHB reduction on SRW were estimated at $3.29 billion over the period. Induced effects on GSP from FHB on barley were estimated at $1.47 billion over the period. Total savings in GSP was $4.76 billion.

<u>Total Indirect and Induced Effects on Value-added Economic Output</u> Indirect effects on GSP from FHB reduction on SRW, barley, durum, and hard wheats were estimated at $5.26 billion over the period. Induced effects on GSP from FHB on barley, durum, SRW, and hard wheats were estimated at $2.24 billion over the period. Total savings in GSP for the four crops was $7.5 billion.

Secondary Employment Secondary employment estimates represent the number of full-time jobs generated based on various levels of business activity within an economic sector. The gains of producer revenues from FHB reduction in small grains affects employment in a number of economic sectors.

Estimates of employment effects using Input-Output analysis must be interpreted within the confines of the methodology limitations (U.S. Bureau of Economic Analysis 2016b). Therefore, estimates of increased employment were provided for each crop, based on the range of estimates provided by RIMS II coefficients. However, for sustained employment effects, gains in economic activity must be realized each year. As a result, the gains of a job in one year does not necessarily mean that job is also gained in the subsequent year. Similarly, if gains in economic output produce a job gain in year 1 and are sufficient for a job gain in year 2, the gain of jobs over that two year period is still just one job. Effects on employment can not be summed across years.

The economic gains from FHB reduction varied substantially among years, crops, and states. To avoid over emphasizing the variability in employment gains, employment effects are presented for the low value and high value over the study period (Table 10.1 -10.3). An average of the time series of gain was provided as a more representative estimate of the employment effects since jobs cannot be summed across years.

Consistent with overall gains in economic output, the largest increases in employment were from FHB reduction in SRW (4,600 FTE jobs per year) and the least gains in employment were from FHB reduction in barley (28 FTE jobs per year). Across all affected crops and states, annual employment gains ranged from 3,700 to 5,850 per year, with an annual average gain of 4,600 FTEs.

Table 10.1. Gains in Total Economic Output by the Initiative in Barley, Durum, Hard Wheats and Soft Red Winter, by State, 1997 through 2014

State and Crop		Low Year	High Year	Total	Annual Average
		------------------------- millions $		---------------------------	
ND					
	Barley	0	1.86	1.85	0.1
	Durum	0	49.96	656.05	36.4
	Hard Wheats	0	210.22	1,397.94	77.66
SD					
	Hard Wheats	10.05	20.52	278.15	15.5
MT					
	Hard Wheats	0	49.67	189.46	10.5
MN					
	Barley	0	5.82	11.53	0.6
	Durum	0.88	1.10	17.94	1.0
	Hard Wheats	0	178.88	1,261.31	70.1
NE					
	Hard Wheats	0	87.13	587.18	32.6
KS					
	Hard Wheats	0	282.78	1,871.64	104.0
MD					
	Barley	0	1.92	10.42	0.6
	SRW	0	5.04	22.80	1.3
VA					
	SRW	0	7.02	46.24	2.6
IL					
	SRW	20.25	29.55	451.04	25.1
IN					
	SRW	254.68	456.99	7,878.25	437.7
MI					
	SRW	-3.54	5.49	11.98	0.7
MO					
	SRW	5.79	11.56	178.97	9.9
OH					
	SRW	4.99	23.05	319.32	17.7
KY					
	SRW	0	0.08	0.08	0.004
AR					
	SRW	0	8.12	26.66	1.5
GA					
	SRW	0	11.32	85.87	4.8
NC					
	SRW	0	13.03	77.80	4.3
PA					
	SRW	0	4.59	21.33	1.2
ID					
	SRW	0	56.13	338.01	18.8
OR					
	SRW	0	42.05	270.82	15.0
WA					
	SRW	0	156.56	1,120.48	62.25
All States and Crops		670.43	1,949.62	21,605.15	1,200.3

Table 10.2. Economic Effects of Fusarium Head Blight in Barley, Durum, Hard Wheats and Soft Red Winter, All Study Regions, 1997 through 2014

	Barley	Durum	Hard Wheats	Soft Red Winter	Totals
	----------------------------	----------------------------	millions $	----------------------------	----------------------------
Personal Income	17	176	1,495	2,933	4,621
Net value-added	27	279	2,430	4,760	7,496
Total Business Volume	83	813	6,965	13,744	21,605

Table 10.3. Estimates of the Gains of Secondary Employment in All Economic Sectors, Fusarium Head Blight in Barley, Durum, Hard Wheats and Soft Red Winter, All Study Regions, 1997 through 2014

	Low Year	High Year	Period Average
	------------------------	FTEs	------------------------
Barley	0	80	28
Durum	7	386	283
Hard Wheats	63	5,286	2.146
Soft Red Winter	3,740	5,857	4,604

Summary of Direct and Secondary Losses

This section evaluates the secondary impacts of the crop losses estimated above due to FHB (Objective 4).

The value of the USWBSI goes beyond production to other sectors in the economy (agribusiness industry, input supplies, trade, etc.). Total direct and secondary economic gains from FHB reduction in HRS wheat, barley, durum, and SRW wheat from 1997 to 2014 were estimated at $21.6 billion. This will enable policy makers, industry representatives, and those in academia to evaluate the comprehensive economic value of the USWBSI for HRS only.

11. Summary and Conclusions

Fusarium Head Blight (FHB) has led to major economic losses for wheat and barley producers. Deoxynivalenol (DON) is a mycotoxin associated with FHB. Grain products and feed grain contaminated with DON (commonly known as vomitoxin) are subject to FDA advisory limits and as a result end-users place restrictions on their use. This has led to steep price discounts, as well as higher risks for producers and grain merchandisers and taken together have contributed in part to large reductions in the area planted to wheat and barley in the United States.

Varietal research has led to development of varieties that are resistant to moderately resistant to FHB. Other studies indicate combinations of fungicide, genetic resistance, and management practices (combine settings, tillage practices, etc.) all contributed to decreases losses due to FHB. These approaches were developed beginning in 1997, with the introduction of the USWBSI. However, the detailed economic impacts of the Initiative (combined genetic resistance, fungicide uses and some management practices) are yet to be estimated.

The purpose of this study was to estimate the economic impacts of reducing FHB on cereal producers, traders and handlers and processors. To do so we developed a number of economic models, analyzed extensive data and conducted surveys of wheat flour millers, barley maltsters, and grain handlers. Taken together these procedures allowed us to make an assessment of 1) the costs to these industries of FHB, 2) the impact of mitigating strategies on yields and DON levels; 3) the marketing practices of the supply chain, 4) the impact of the Scab Initiative on reducing yield losses, 5) the return on investment of the Scab Initiative, and 6) the secondary impacts of the Initiative.

To do so we conducted several quantitative analyses. One analyzed the statistical relationship using field trial data of the effects of fungicide, varieties and management practices on wheat yields, and DON in wheat and barley. These results were used to estimate the risk premium necessary for the market to induce growing these crops that have otherwise become highly risky due to DON. We also conducted several surveys in part to determine the implication of DON on wheat and barley handling and trading; and on the operations and costs of intermediate use industries, wheat milling and barley malting. A major component of the analysis is to estimate the impacts of DON on lost yields and production in wheat and barley, by class and through time. These results were used to estimate the value of lost production and its change through time following the inception of the Scab Initiative. The results were used to estimate the returns to the Scab Initiative, from which a number of measures of return on investment were derived. Finally, secondary impacts were derived. In addition, a summary of the costs of scab to the wheat and barley industry in the United States were derived for the most recent year available.

Summary of Results

The results are summarized below by topical area of the study. The last subsection provides a summary of the costs of DON to the wheat and barley industries, and the section that follows identifies implications for the industry and the Scab Initiative.

Evolution of DON DON has evolved to be an important problem since at least 1993. It has impacted the entire supply chain including inputs, farm production practices, marketing and handling, in addition to processing and distribution. Taken together it has increased risk and cost throughout the marketing system, and has contributed to the declining area planted to wheat and barley which has ensued since the early 1990's.

The level of DON in the US wheat and barley crops has varied through time and across states. It appears that in most cases it has been improving, however, there were spikes in DON in SRW in 2015 and in durum in 2016.

Breeding Breeding for reduced DON became a high priority following the 1993 epidemic. Improvements were first adopted in HRS wheat, and that for other classes lagged. Most of the work to date has used conventional breeding.

There have been efforts to reduce DON using GM techniques, but have largely been abandoned due in part to public concerns over biotechnology. Fusarium may now be addressed using newly developed gene-editing technologies (e.g., CRISPR, TALEN, and Zink-Fingers). And more recently, an important breakthrough has been made in potentially overcoming scab problems in wheat. The breakthrough was the cloning of the resistance gene.

DON Mitigation Traditionally, tools used to mitigate the impacts of DON include: 1) Variety section and best management practices; 2) Toxin prediction (fungicide application and increased sampling); 3) Disease forecasting; 4) Source management cleaning 5) Processor specifications and 6) Surveillance.

Of particular importance has been the notable increase in use of fungicide, and planting of more resistant varieties. Fungicide use quickly became adopted in about the mid-2000's and now is largely used on 70-80% of wheat and barley area planted in the United States. Concurrent has been the adoption of more resistant varieties in most producing states affected by DON.

Statistical Relationships between Wheat Yields, and DON in Wheat and Barley: Models were specified to evaluate the impacts of important independent variables on levels of yield and DON in wheat, and DON in barley. The statistical results were good and a number of significant variables were identified. Most important are:

1) Fungicide was an important variable for both wheat and barley. Indeed, this was one of the most important variables impacting wheat yield, and DON in wheat and barley. In both cases fungicide had the impact of increasing yields in wheat,

and lowering DON. The impact of fungicide was dependent on the variety i.e., its impact varied across varieties;

2) Scab resistance in varieties is important. By itself, moderately resistant varieties increase wheat yield by about 5 bu/ac; in the case of wheat, greater resistance has the impact of lowering DON. Importantly, the impact of variety resistance on yield and DON is impacted by the use of fungicide;

3) These results indicate there is a tradeoff between yield and DON: Decreasing DON from 1.0 to .5 ppm, would result in an increase in yield of about 7 bu/ac.

Risk Premiums to Induce Growers Technology Decisions The impacts of DON on growers are to increase the probability of DON being excessive, reducing yield and increasing the probability of discounts for excessive DON. Thus, any strategy that reduces DON has the opposite impacts: increasing yield, reducing probability of DON and associated price discounts. Taken together, these strategies have the impact of increasing returns, and reducing risks relative to the technologies not being adopted.

An analytical model was developed to interpret these impacts on growers. Specifically,

1) The technologies result in greater returns and lower risks than otherwise.

2) The values indicate the amount by which growers would need to be compensated to adopt a more risky alternative i.e., as if the technologies were not available. These results indicate that growers would need to be compensated in the area of: HRS $130/ac; SRW $49/ac; HRW $28 and Malting Barley $29/ac to grow wheat without the technologies.

   Or, alternatively, these could be interpreted as the value of these technologies to growers.

3) If evaluated individually, the value of fungicide exceeds that of MR varieties, thought these are complementary technology choices.

Risk premiums for a strategy with fungicide and MR varieties are complementary results. Thus, risk premiums were higher for a strategy with both fungicide and MR.

Simply, by adopting these strategies, growers can increase returns and lower risk/ac. These mean that without these technologies, the market would have to compensate growers by this amount to grow wheat. This would be as expected, but, ultimately is the virtue of the scab strategies that were developed for this purpose.

Market Discounts and Testing: One of the impacts of DON is for the market to apply discounts for excessive DON content. Generalizations about marketing wheat with DON include:

1) Procurement strategies involved simply applying specification limits and discounts in purchase specifications. In addition, blending was used if/as necessary;

2) Specification limits: Virtually all buyers use a specification of 2 ppm without discounts. The reason for this is that mills would typically reject if DON>2 ppm. Also, exporters or terminal markets would discount or reject if DON>2 ppm.

3) Typically, and in recent years, the specification at which nil discount is applied is 2 ppm. Discounts would apply for levels greater than this and in recent years are from 5 to 10c/b per ½ ppm, and larger for excessive DON levels.

4) Estimates of testing costs range from $15 to $20 or as high as $30/test. Testing protocols were to routinely test 1 test per 5 rail cars (i.e. a composite sample from 5 rail cars) at $15/test;

5) Testing in SRW: Results indicated 1 test per rail car or truck, typically at $5/test; and tests were only conducted if early season shipments from an elevator or region had DON values exceeded 2 ppm

Traders were of the perception that the reasons for improved DON was 1) increased use of fungicide, 2) adoption of MR varieties; and 3) making adjustments in the harvester; though the former was of greater importance.

Survey Findings: Impacts of DON on end-user's operations and costs are important, and probably irreversible. Part of the impact of DON is due to the premiums (costs) in the market, and/or costs related to testing, segregation, storage, cleaning, etc. These were assessed using a focused survey and the results were extrapolated to the rest of the industry. Some of the important results for wheat mills were:

1) 90 percent of wheat mills were impacted by DON. Classes of wheat affected across firms were 60% HRW, 80% HRS, 70% SRW, and 30% HAD;

2) To respond to the incidence of DON, most firms had to expand their draw areas, for about 10% of their purchases at an added cost that ranged from 10-30c/b in a normal year; to upward to 250-300c/b in an epidemic year.

3) Ranges for discounts varied from None, to within a range of $0.05-$3.00/bu with three observations less than $0.30/bu;

4) Technology used for testing for DON was largely Neogen, but also included Charm and Lateral flow strip with verification from Gas Chromatograph.
The average cost of testing was $13.66 and ranged from $6.00 to $25;

5) Firms indicated costs for segregating and blending at about $0.02/bu to $0.10/bu;

6) Firms indicated that the factors/innovations most important for improvement in DON were: 1) Fungicide; 2) Farm Management: 3) Varieties; 4) crop rotation; and 5) milling practices

7) Other diseases indicated as potentially problematic included, UG99, Black Tip, Ergot, Other Fusarium, Rust and Smut.

Some results of interest for barley are:

1) DON Limits on selling malting barley was most often quoted as 0.4-0.5 ppm, but some firms reported limits as less than 1 ppm;

2) In bad years, firms indicated they had to expand target area, while others indicated that target areas were large enough they were able to draw adequate supplies;

3) Firms ranked restrictions in contracts as most important in normal years, however, pre-shipment testing was more important in transition and epidemic years;

4) Observations suggested discounts of $0.10 to $0.50/bu; or $1/MT for each 0.1 ppm above 0.5 ppm and $2/mt for each 0.1 ppm above 1 ppm for 6 row barley. two row barley indicated $2/mt for each 0.1 ppm above 0.5 ppm.

5) In years where DON was problematic, firms indicated that they would have to expand target areas from not at all to as high as 1000 miles. About half of firms indicated no expansion. The added cost to bring in barley were mostly nil, with a few ranging from $1 to $2.5/bu.

6) Testing technology included Neogen, Ez-Tox, Gas Chromatograph, and Environlogic with Neogen being most identified. Cost of testing ranged from a low of $6.25/test to a high of $50/test. Cost of testing averaged $19.86/test across the firms. Testing intensity ranged from every shipment to 20% of shipments;

7) Factors/innovations most important in reducing DON were: 1) farm management practices; 2) Fungicide; 3) Crop rotations; 4) Varieties; and 5) malting processing practices.

Summary of Costs: A detailed assessment of costs was made and summarized below (Table 11.1). The most important costs accrued by the wheat and barley industries were the value of yield forgone; and the risk premium paid to induce adoption of DON reducing technologies. These were followed by the costs of fungicide, added shipping costs, testing and segregation and discounts.

Table 11.1 Summary of Costs of DON to Wheat and Barley Industries 2015/16 ($)

	Wheat Total	Malting Barley	Total
Value of Yield forgone	1,176,000,000	293,000,000	1,469,000,000
Costs accrued by Growers (Market)			
Fungicide	197,128,500	13,891,050	211,019,550
Risk premium implied	2,743,870,000	81,156,500	2,825,026,500
Discounts to growers	23,900,000	na	23,900,000
Testing costs by Elevators	21,403,369	2,452,500	23,855,869
Testing costs and discounts for trading firms			
Testing costs Traders (exporters--inbound)	776,634	1,603	778,237
Testing at export loading	4,531,032	75,783	4,606,815
Discounts		nil	
Added Costs Accrued at Flour Mills and Malt Pl			
Discounts	7,635,996	1,101,600	8,737,596
Testing	11,425,793	3,798,225	15,224,018
Segregation	4,963,500	10,729,125	15,692,625
Added trucking costs	15,463,643	9,753,750	25,217,393

Value of Yield Forgone: An important impact of DON is that it results in reduced yields versus what would otherwise be achieved in normal growing conditions. This is substantial (as is common knowledge, and we document in the analyses above) and has had an important impact on the industry.

Models were developed to estimate the amount by which crop production was reduced due to scab, its value in addition to the returns on research of the Scab Initiative. The model evaluates these changes from 1993 to 2014, by crop reporting district within each state for wheat, by class, and barley. The model includes impacts of normal yield changes, weather, technology, scab severity and area not harvested. A summary of the major findings is below:

1) The quantity of lost production varied by year. In 2014, this was:

HRS	41 mb;
Durum	1.5 mb;
HRW	71 mb;
SRW	107 mb; and
Barley	72 mb.

Thus, holding all else constant, these results suggest that in 2014, HRS production was 7% less than would have been the case without scab, and, similarly for the other classes.

2) The value of lost production also varied by year, and generally has been declining. In 2014, these values were: HRS $186 mill; Durum $7 mill; HRW $415 mill; SRW $569 mill; and Barley $294 mill.

3) Taken together, the net savings to the Scab Initiative was derived and defined as the reduced value of crop loss, less the direct expenditures on the Scab Initiative, by year (and excluding impacts of 'in-kind' costs). The net savings due to the Scab Initiative varied by year, ranging upwards to $880 million in 2000. Since then these been declined, and in 2014 was $387 million.

   The net present value of these savings from 1993-2014 was $5.9 billion.

4) Several measures of return on investment to the funding of the Scab Initiative were derived. The results showed an IRR (internal rate of return) using conventional methodologies and assumptions was 38% in recent years. Comparably, the MIRR (modified internal rate of return) was 15% and the AROI (aggregate rate of return) was 34%.

By comparison to other studies on agriculture research (e.g., Fuglie and Heisey (2007) these are very favorable returns.

There were some qualifications to this analysis including 1) not accounting for the reduced area planted to wheat which occurred over this period; 2) in-kind costs (i.e. as accrued by PI's operating at Universities) were not included (there were attempts to quantify these but results were not achieved) and 3) the price effects (as estimated in Nganje et al, 2004) were not derived.

Implications for the Wheat and Barley Industries: These results have important implications for the wheat and barley industries. Important is that it appears that the incidence of DON has improved. However, though improved, the problems persist and has the implications of adding cost and risk to the supply chain. Importantly, the impact of these vary through time, and geographically, thus impacting firms differently.

The most important direct costs are those related to increased use of fungicide, testing and increased draw areas. While reliance on fungicide is notable, it is risky. Importantly, there is growing consumer resistance to excessive chemical use in agriculture (e.g., use of pre-harvest glyphosate) and at some time may become under scrutiny.

There is an indirect cost of reduced production due to DON. Finally, the industry accrues an indirect cost of having to pay implicit risk premiums via the market place to induce planting and use of DON reducing technologies. Without these technologies, the cost to the industry would increase substantially.

Finally, the market place plays an important role in resolving problems related to excessive DON. Though not perfect, and not without pain, the market works. Important in this resolution are the combined impacts of discounts, specification limits, testing, blending and segregation and targeting shipment across end-users depending on their requirements. Though DON may have improved, use of the mechanics persists in part due to inter—temporal marketing of cereals with DON.

Scab Initiative: Finally, some important implications regarding the Scab Initiative can be deduced from the results in this study. One is that the DON problems has improved. However, it has not been eliminated and remains a temporally and spatially sporadic problem. Second, while there are a number of risk mitigation tools, and all of these prospectively have impacts of reducing the impacts of DON, two are particular important. One is fungicide use, which has increased from virtually nil in the 1990s' to being applied to 70-80% of the cereals area planted in recent years. This is substantial, and at a high cost, but, also is effective though not perfect. Indeed, there are some places and times where multiple applications of fungicide are applied in one growing season. The second is the development and adoption of resistant varieties. The statistical analysis reported here documents the importance of these, though the effect varies across classes.

Fungicide and resistant varieties are complementary and have an interdependent impact on reducing DON. Both the statistical and economic analysis highlights these complementarities, and suggests that fungicide has greater impacts. Finally, perceptions of both traders and processors recognize these same conclusions.

For these reasons, an important future implication for the Scab Initiative should be to foster more extensive grower outreach regarding use of risk mitigating tools including fungicide, variety selection, among others.

There are also other breeding technologies that are emerging which may go a long way towards reducing the impacts of DON. DON has devastating impacts on producers and the supply chain. It imposes substantial costs throughout the marketing system and increases risks to all participants. The returns and net savings from funding the Scab Initiative have been substantial and have contributed to reducing the impacts of the disease. There are a number of further challenges and several technologies are showing further prospect toward mitigating these problem

Scab Initiative and Declining Losses for Growers: The average production and revenue losses for the base period (1993-1996) was higher than all proceeding years with the Scab Initiative (1997-2014). The variability of revenue losses were also lower, indicating a positive impact from the Initiative, with few exceptions. For example, the average production loss for soft wheats declined from the base period of 1993 to 1996 compared to all other years (1997-2014). The average loss for the base period was approximately 10.66 million bushels compared to a 1997 average high of 3.38 million bushels. Also the variability of production loss has declined significantly from 10.75 million bushels for the base period to the average high of 3.53 million bushels in 2013.

These was consistent across years and states. These results are consistent with improved varieties and management practices.

Savings with the Scab Initiative: The combined savings from hard wheats (hard red spring and hard red winter), soft red wheat, durum, and barley were estimated at $9.69 billion from 1997 through 2014. The direct economic gains over the period were greatest for SRW wheat ($6.1 billion), followed by hard wheats ($3.16 billion). Savings for barley and durum were estimated at $45 million and $395 million, respectively. Combined gains with the four crops were greatest in 2000 ($880 million) and were lowest in 2008 ($297 million).

Gains from all crops were summed by state. Indiana, with economic gains from FHB reduction in soft red wheat incurred the greatest impact ($4.4 billion) of all states from 1997 through 2014. Other states with considerable economic gains over the period included North Dakota ($1.1 billion), Kansas ($1 billion), Minnesota ($721 million), and Washington ($634 million).

Returns on Investment: This study estimated the return on investment to the research expenditures of the Scab Initiative, which has spent $76 million over its life, including in-kind contributions $12.76 million. The NPV of net savings from reduced production loss ranged from $5.3 to $5.4 billion over the period 1993-2014 for both wheat and barley. Or, during the study period a $76 million investment resulted in $5.4 billion in savings, i.e., for every $1 invested there were $71 in benefits![35] This is significant and compares very favorably to other studies on agriculture research. The return on investment for expenditures on the Scab Initiative (ignoring in-kind costs) is in the area of 34%, which is substantial**.**

Direct and Indirect Benefits: The value of the USWBSI goes beyond production to other sectors in the economy (agribusiness industry, input supplies, trade, etc.). Total direct and secondary economic gains from FHB reduction in HRS wheat, barley, durum, and SRW wheat from 1997 to 2014 were estimated at $21.6 billion. This will enable policy makers, industry representatives, and those in academia to evaluate the comprehensive economic value of the USWBSI for HRS only.

[35] PCAST notes that the United States is deriving a substantial societal return on its current investments in agricultural research. Based on an analysis of nearly three dozen studies focused on the impact of agricultural research on food, feed, and energy production and on food safety and nutrition over the past several decades, "PCAST concludes that the economy has gained at least $10 in benefits for every $1 invested in agricultural research" (President's Council of Advisors on Science and Technology 2012)

References

Aakre, D., G. Flaskerud, K. Hellevang, G. Lardy, M. McMullen, J. Ransom, B. Sorenson and A. Swenson, 2005. DON (Vomitoxin) in Wheat: Basic Questions and Answers, NDSU Extension Service, Fargo.

AgResource, 2016. Lack of Profitability Will Push US Wheat Area to Lowest Level in Over 50 Years, e-message to clients, Nov 26, 2016.

Ali, M. and G.Vocke. 2009. Consequences for Higher Input Costs and Wheat Prices for U.S. Wheat Producers. U.S.D.A. Economic Research Service, USDA, WHS-09c-01, March.

Bangsund, Dean A. and N.M. Hodur. 2017. Economic Contribution of the Petroleum Industry on North Dakota's Economy. AAE report 766. Department of Agribusiness and Applied Economics, North Dakota State University, Fargo

Bianchini, A., Horsley, R., Jack, M.M., Kobeilush, B., Ryu, D., Tittlemier, S., Wilson, W., Abbas, H.K., Abel, S., Harrison, G., Miller, D.J., Shier, W.T., Weaver, G., 2015. DON Occurrence in Grains: A North American Perspective, *Cereal Foods World*. Vol. 60 (1):31-56.

Beddow, J.M. T.M. Hurley, D.J. Kriticos, and P.G. Pardey. 2013. Measuring the Global Occurrence and Probabilistic Consequences of Wheat Stem Rust. http://croppest.org/doc/Beddow_et_al_2013_HC--Stem_rust_tech_note%2820130411a%29.pdf

Cowger, C., and A.L. Sutton. 2005. The southeastern U.S. Fusarium head blight epidemic of 2003. Plant Health Progress. Doi:10.1094/PHP-2005-1026-01-RS

Dahl, B., W. Wilson, and D. Johnson. 2004 Valuing New Varieties: Tradeoffs between Growers and End-Users in Wheat. Review of Agricultural Economics 26(1):82-96.

Dahl, B., W. Wilson, and W. Nganje. 2004 Stochastic Dominance in Wheat Variety Development and Release Strategies. Journal of Agricultural and Resource Economics 29(1):94-111.

Demaree, H. 2016. KSU scientists closer to overcoming wheat scab disease, World Grain, November 2, 2016

Flagg, I. 2008. The Valuation of Agricultural Biotechnology: The Real Options Approach, May. Impact of Agricultural Productivity Changes. *Available at www.ag.ndsu.edu https://www.ag.ndsu.edu/agecon/research-extension-centers/theses.*

Fuglie, K.and P. Heisey (2007*).* Economic Returns to Public Agricultural Research ECONOMIC BRIEF NUMBER 10 • September 2007 United States Department of Agriculture Economic Research Service

GMO Compass, 2016*.* Poisonous Fusarium Infestations: New Solutions with Genetic engineering?" retrieved Oct 20 2016, available at http://www.gmo-compass.org/eng/grocery_shopping/crops/22.genetically_modified_wheat.html

Haidukowski, M., et al. 2005. Effect of fungicides on the development of Fusarium head blight, yield and deoxynivalenol accumulation in wheat inoculated under field conditions with Fusarium graminearum and Fusarium culmorum. Journal of the Science of Food and Agriculture 85(2): 191-198.

Hollingsworth, C.R., C.D. Motteberg, J.V. Wiersma, and L.M. Atkinson. 2008. Agronomic and Economic Responses to Spring Wheat management of Fusarium head blight. Plant Disease, Vol 92:1339-1348.

ISAAA (International Service for the Acquisition of Agro-biotech Applications), Pocket K No. 38: Biotech Wheat accessed Oct 20 2016. Available at http://www.isaaa.org/resources/publications/pocketk/38/default.asp

Johnson, D. D. and W. Nganje. 2000. Impacts of DON in the malting barley supply chain: aggregate costs and firm-level risks, Department of Agricultural Economics, Agricultural Experiment Station, North Dakota State University.

Johnson, D.D., G.K. Flaskerud, R.D. Taylor and V. Satyanarayana. 1998. Economic Impacts of Fusarium Head Blight in Wheat. Department of Agricultural Economics, North Dakota State University, Fargo, ND. Agricultural Economics Report No. 396, June.

Johnson, D.D., G.K. Flaskerud, R.D. Taylor and V. Satyanarayana. 2003. Quantifying Economic Impacts of Fusarium head blight in wheat. Fusarium Head Blight of Wheat and Barley. Pp. 461-483, ISBN 0-89054-302-X, St. Paul, Minnesota, USA.

Johnson, D., W. Wilson and M. Diersen. 2001. Quality Uncertainty, Procurement Strategies an Grain Merchandising Risk: Vomitoxin in Spring Wheat. Review of Agricultural Economics. 23(1):102-119.

Leslie, J.F. and A. Logrieco. Forthcoming. Mycotoxin Reduction in Grain Chains. Wiley Blackwell, Ames IA.

Levine, M. 2015. Oreos, Vomitoxin and the Price of Wheat, Crains Chicago Business.com.

Lilleboe, D. 2010. FHB in 2010-An overiew. Fusarium Focus 10:2. http://scabusa.org/pdfs/fus-focus_09-10_newsletter.pdf.

Lilleboe, D. 2011. Fusarium head blight in 2011: An overview. http://scabusa.org/PDFS/USWBSI-Article_2011-Update_9-29-11.pdf

Lilleboe, D. 2016. Scab's Impact Low in Majority of U.S. What & Barley Areas in 2016 available at http://scabusa.org/pdfs/USWBSI-Article_2016_FHB-Summary_10-12-16.pdf.

Madden, L.V., and Paul, P.A. 2009. Assessing Heterogeneity in the Relationship Between Wheat Yield and Fusarium Head Blight Intensity Using Random-Coefficient Mixed Models. Phytopathology. Vol. 99(7): 850-860.

Magni, C.A. 2015. Aggregate Return On Investment for Investments under Uncertainty. International Journal of Production Economics. International Journal of Production Economics, 165 (July):29-37.

McCarl, B.A. and D.A. Bessler. 1989. Estimating an Upper Bound on the Pratt Risk Aversion Coefficient When the Utility Function is Unknown. Australian Journal of Agricultural Economics, Vol. 33(1, April):55-63.

McKee,G. Forthcoming. Estimated Statistical Relationship between Scab Infested Small Grains and Associated Determinants. University of Nebraska, Lincoln.

McKee, G., J. Ransom and M. McMullen. 2013. Determinants of Adoption of Fusarium Head Blight Management Techniques in Wheat. Journal of Agribusiness. 31(1):181-196.

McMullen, M., G. Bergstrom, E. De Wolf, R. Dill-Macky, D. Hershman, G. Shaner, and D.V. Sanford. 2012. A Unified Effort to Fight an Enemy of Wheat and Barley: Fusarium Head Blight. Plant Disease, Vol 96(12):1712-1728.

McMullen, M., R. Jones, and D, Gallenberg. 1997. Scab of Wheat and Barley: A Re-emerging Disease of Devastating Impact. *Plant Disease* Vol. 81: 1340-1348.

MGEX. 2003. Minneapolis Grain Exchange. http://www.mgex.com/documents/MGEXDeferredRules1-19-12.pdf

National Grain and Feed Association. 2011. FDA Mycotoxin Regulatory Guidance: A Guide for Grain Elevators, Feed Manufacturers, Grain Processors and Exporters, Washington DC.

Nganje, W.E., D.A. Bangsund, F.L. Leistritz, W.W. Wilson and N.M. Tiapo. 2004a. Regional Economic Impacts of Fusarium Head Blight in Wheat and Barley. Review of Agricultural Economics, Vol. 26(3):332-347.

Nganje, W.E., D.D. Johnson, W.W. Wilson, F.L. Leistritz, D.A. Bangsund, and N.M. Tiapo. 2001. *Economic Impacts of Fusarium Head Blight in Wheat and Barley: 1998-2000.* Agribusiness and Applied Economics Report No. 464, Department of Agribusiness and Applied Economics, North Dakota State University, Fargo.

Ngange, W.E., S. Kaitibie, W.W. Wilson, F.L. Leistritz and D.A. Bangsund. 2004b. Economic impacts of Fusarium head blight in wheat and barley: 1993-2001. Agribusiness & Applied Economics Report No. 528.

Office of the Secretariat CFTC. 2008.

Ohio State University. 2015. Wheat Production Budget, 2016. Ohio State University, College of Food, Agricultural and Environmental Sciences. Accessed, Oct, 2016. Available at: http://aede.osu.edu/research/osu-farm-management/enterprise-budgets.

Palisade. 2015. Decision Tools Suite Version 7.5. Palisade Corporation, Ithaca, NY.

Pardey, P.G., J.M Beddow, D.J. Kriticos, T.M. Hurley, R.F. Park, E. Duveiller, R.W. Sutherst, J.J. Burdon, and D. Hodson. 2013. Right-Sizing Stem-Rust Research. Science. Vol 340 (No. 12): 147-148.

Paul, P.A., P.E. Lipps, and L.V. Madden. 2005. Relationship between visual estimates of Fusarium head blight intensity and deoxynivalenol accumulation in harvested wheat grain: A meta-analysis. Phytopathology 95(10): 1225-1236.

Paul, P.A., P.E. Lipps, and L.V. Madden. 2006. Meta-Analysis of Regression Coefficients for the Relationship Between Fusarium Head Blight and Deoxynivalenol Content of Wheat. Phytopathology. Vol 96(9): 951-961.

Paul, P.A., P.E. Lipps, D. Hershman, M. McMullen, M. Draper, and L.V. Madden. 2007. A quantitative review of tebuconazole effect on Fusarium head blight and deoxynivalenol content in wheat. Phytopathology 97:211-220.

Prandini, A., S. Sigolo, L. Filippi, P. Battilani, and G. Piva. 2009. Review of predictive models for Fusarium head blight and related mycotoxin contamination in wheat. Food and Chemical Toxicology. Vol 47: 927-931.

President's Council of Advisors on Science and Technology, 2012. Report to the President on Agricultural Preparedness and The Agriculture Research Enterprise, Washington, DC. Dec 2012.

ProAg. 2016a. Vomitoxin Prompts Dakota Corn Movement Eastward. Nov 30, 2016. Accessed Dec 1, 2016.

ProAg. 2016b. Time to Drop Durum? Vomitoxin, Price Discounts Are Huge Concerns October 5, 2016. Accessed Oct 5. 2016.
Richardson, J.W., K.D. Schumann and P.A. Feldman. 2011. Simetar. Simetar, Inc. College Station, Texas
Rudd, J.C., R.D. Horsley, A.L. McKendry, and E.M. Elias. 2001. Host Plant Resistance Genes for Fusarium Head Blight: Sources, Mechanisms, and Utility in Conventional Breeding Systems. Crop Science, Vol. 41:620-627.
Salgado, J.D., L.V. Madden and P.A. Paul. 2014. Efficacy and Economics of Integrating In-Field and harvesting strategies to manage fusarium head blight of wheat. Plant Disease. 98:1407-1421.
Shakya, S., W. Wilson, and B. Dahl, 2015 Valuing New Random Genetically Modified (GM) Traits: The Case of Drought- Tolerant Wheat, Agricultural Finance Review AFR-05-2014-0014.R1
Shakya, S., W. Wilson, and B. Dahl. 2013. Valuing New Random Genetically Modified (GM) Traits in Corn. Journal of Agricultural and Resource Economics. 38(1):107–123.
Sosland. 2015. *Milling Annual.* Sosland Publishing. Kansas City, MO.
Sullins, R.D. 2011. The Economics of Mycotoxin Contamination to the Milling Industry and Consumers, presentation to National Fusarium Head Blight Forum, Session 4, Food Safety, Toxicology and Utilization of Mycotoxin-Contaminated Grain. St. Louis, Mo.
Sullins, R.D. 2013. *The Cost of Compliance*. Presentation to the Joint Special Meeting of the Toxicology Forum/Regulatory Governance Initiative. Mycotoxins-Unavoidable Natural Contaminants in Staple Crops: Public Health, Food Security and International Trade. Carlton University, Ottawa, Ontario.
Swenson, A. and R. Haugen. 2015. North Central North Dakota Projected 2016 Crop Budgets. North Dakota State University Extension Service.
Thomson Reuters. 2016. Andersons testing corn for vomitoxin at Indiana ethanol plant. *Inside Agriculture*. Extracted Nov 21 2016.
Thomson Reuters. 2017. EXCLUSIVE-Vomitoxin makes nasty appearance for U.S. farm sector, *Inside Agriculture*. Extracted April 24, 2017.
U.S. Bureau of Economic Analysis. 2016a. Regional Input-output Modeling System II.
U.S. Bureau of Economic Analysis. 2016b. *RIMS II: An essential tool for regional developers and planners*. U.S. Bureau of Economic Analysis, U.S. Department of Commerce, Washington, D.C.
U.S. Department of Commerce, Various. U.S. Department of Commerce, National Oceanic and Atmospheric Administration. Washington, D.C.
U.S. Department of Agriculture. Multiple years. Data diskette. National Agricultural Statistics Service, Washington, DC.
U.S. Department of Agriculture. *Grain Market News*, Various issues. Agricultural Marketing Service, Grain and Feed Division, Washington, DC.
U.S. Department of Agriculture. 2016. *State Level Data for Field Crops*. U.S. Department of Agriculture, National Agricultual Statistics Service.
National Agricultural Statistics Service, http://www.usda.gov/nass/, Washington, DC.
U.S. Department of Agriculture. Various years. *Wheat Yearbook*. Economic Research Service, U.S. Department of Agriculture, Washington, D.C.

USWBSI. 2014. FHB Forecasting Models. http://scabusa.org/research_mgmt#mgmt_pred-models. Accessed 7/18/2014.
USWBSI. 2016. Personal communication.
U.S. Industry Response. 2014. Comments on CODEX Committee on Contaminants in Food (CCCF) Agenda Item 7 (Deoxynivalenol (DON) in Cereal Grains.
U.S. Wheat Associates. 2004-2016. Crop Quality Reports. U.S. Wheat Associates. Available at http://www.uswheat.org/cropQuality.
U.S. Hard Red Spring Wheat Regional Quality Report. 2016. U.S. Wheat Associates. Available at http://www.uswheat.org/cropQuality.
U.S. Durum Wheat Regional Quality Report. 2016. U.S. Wheat Associates. Available at http://www.uswheat.org/cropQuality.
USDA-ERS. 2016. Wheat Production Costs and Returns Per Planted Acre, Excluding Government Payments, 2014-15. USDA, Economic Research Service. Accessed Oct, 2016. Available at http://www.ers.usda.gov/data-products/commodity-costs-and-returns.aspx.
USDA-NASS. Quick Stats Database. USDA-NASS. Accessed June 2016.
Wegulo, S.N., W.W. Brockus, J.,Hernandez Nopsa, E.D. De Wolf, K.M. Eskridge, K.H.S. Peiris, and F.e. Dowell. 2011. Effects of Integrating Cultivar Resistance and Fungicide Application on Fusarium Head Blight and Deoxynivalenol in Winter Wheat. Plant Disease. 95: 554-560.
Wiersma, J. 2016. Growers' Needs and Industry Wants: A Retrospective of Two Decades in the Trenches in the Battle with FHB., to the 2016 National Fusarium Head Blight Forum, St. Louis, Dec 6, 2016, and in proceedings of the 2016 National Fusarium Head Blight Forum, p. 103, available at hrrp://www.scabusa.org.
Willyerd, K. T., C. Li, L.V. Madden, C.A. Bradley, G.C. Bergstrom, L.E. Sweets, M. McMullen, J.K. Ransom, A. Grybauskas, L. Osborne, S.N. Wegulo, D.E. Hershman, K. Wise, W.W. Bockus, D. Groth, R. Dill-Macky, E. Milus, P.D. Esker, K.D. Waxman, E.A. Adee, S.E. Ebelhar, B.G. Young, and P.A. Paul. 2012. Efficacy and stability of integrating fungicide and cultivar resistance to manage Fusarium head blight and deoxynivalenol in wheat. *Plant Dis*. 96:957-967.
Wilson, W., B. Dahl and D. Johnson. 2007. Quality Uncertainty and Challenges to Wheat Procurement. Canadian Journal of Agricultural Economics. 55(3):315-326.
Wilson, W. and B. Dahl. 2011. Grain Contracting Strategies: The Case of Durum Wheat. Agribusiness: An International Journal. Vol. 27(3):344-359.
Wilson, W. and B. Dahl. 2014. Contracting for Canola in the Great Plains States. Canadian Journal of Agricultural Economics. Vol. 62:89-106.
Wilson, W., B. Dahl and W. Nganje, 2017. "The Economic Costs of Scab," World Mycotoxin Journal, forthcoming.
Wilson, W., C. Gustafson and B. Dahl. 2009. Crop Insurance in Malting Barley: A Stochastic Dominance Analysis. Agricultural Finance Review. Vol 69(1):98-112.
Wilson, W., B. Dahl and B. Maxwell. 2007. Grower Response to Contracts and Risk in Genetically Modified (GM) Crops. Journal of Agricultural and Resource Economics. Vol. 32(1):135.153.

Wilson, W., G. McKee and W. Nganje, Economic Impact of USWBSI's Research on Reducing FHB. Keynote presentation to the 2016 National Fusarium Head Blight Forum, St. Louis, Dec 4, 2016.

Wynn, K., G. Spangenberg, K.F., Smith, and William Wilson, 2016. Valuing transgenic drought tolerant canola using real options, Agricultural Sciences, #3001548, forthcoming, accepted Oct 17, 2016.

Appendix A: Survey Instruments

Impacts of Reducing FHB Under the USWBSI's

Wheat Mills: *High-level interviews*

Purpose: Focused interview of millers conducted to estimate the financial impacts of scab on the wheat milling industries.

Instructions: We would like your input on the following. All information will be held confidentially and only released in aggregation with others. Don Sullins will conduct an interview on these issues and information will be provided through that interview. Some information may be provided later and/or as a follow-up.

Contact:

- Don Sullins 1-913-449-8982 Gmail don.sullins65@gmail.com
- William W Wilson 1 701 231 7472 william.wilson@ndsu.edu

1. Firm name

2. Plants/Mill reported in this interview: [Instructions: Discuss with Don S to determine which mills are appropriate to include].

   1) Which of your mills are not impacted operationally due to DON? Why?
      1) Not in the geography where DON is problematic?
      2) Purchases specify limits such that DON must conform to specifications.
      3) Other

   2) Which mills are impacted by DON? [the questions below pertain to these mills]

   3) Which classes were impacted?
      ______HRW
      ______HRS
      ______SRW
      ______Durum
      ______Other

3. Selling products: What are limits of product sales ref DON
   By product
   1) Standard bulk flour ________________
   2) Whole flour ________________
   3) By-Products (mill-feeds): ________________

4. What years has DON been problematic and impacting procurement strategies?

5. Describe how your target procurement area changed during epidemic years regarding DON? Which years were these?

6. Buying wheat:--Rank among below with 1, 2,….6 with 1 being most important during epidemic years

Element of Strategy	*Normal Year*	*Transition Year*	*Epidemic Year*
Target elevator origins			
Pre-harvest testing			
Pre-shipping testing			
Excluded origins			
Restrictions in contracts			
Discounts for exceeding limits			
	Specific questions ref grain purchasing:		
At what level or range of DON do you reject and not allow it in to mill			
What do you do w/shipments that do not conform to requirements (i.e., reject, blend, other)			
Other			

*Normal is a year where DON is not known to be a problem; Transition year is a year following a year in which DON was a problem; and Epidemic year is a year in which DON is known to be a problem

7. Can you provide a history of basis values and/or premiums/discounts for DON (even as a follow-up to the first call)?

   Ideally, provide data on DON discounts over time (i.e. by crop year). This should include the level at which discounts begin.

   If hard data does not exist, provide your judgment of the range of discounts that have occurred over time and through the crop years from the 1990s.

    1) Hard data is available
    2) Opinion on ranges of discounts
    3) By class (HRS, HRW, SRW, durum)

8. In years where vomitoxin is a problem,

   1) What is the premium paid (estimated) for wheat conforming to FDA advisory level for flour from outside the normal draw area?
   2) How far (miles) do you have to expand from your normal market area
   3) What is your trucking costs $/mile
   4) How much does your basis increase due to
      1) Greater distance
      2) Premiums for non-vomitoxin

9. Testing

   1) Testing technology i.e. type of test used ______________________________

   2) Cost per test (or, see 3) below)
      1) Supplies (test kits)
      2) Personnel/labor costs
      3) Hourly rate w/benefits

   3) Or, Total Cost per test (e.g., $22/test)

   4) How frequently do you test?
      1) Number of tests per year
      2) Frequency of test (e.g., 1:1 (every shipment), 1:5 (one in five shipments) etc.)

   5) Number of samples tested/year
      1) Normally
      2) In years when DON is a problem

10. Segregation (we realize this is difficult to quantify, but an estimate would suffice)

    1) At what level do you segregate wheat due to excessive DON?
    2) How often does this occur? Provide a range
    3) Added cost due to segregation

11. Cleaning in the milling process:

    1) Do you/can you
        1) Blend to meet limits
        2) What limits can/do you place on blending

    2) If DON is excessive, how many times would you clean (or pre-clean)

    3) Clean (gravity table (or separator)/color sorter) to meet requirements
        1) Is this a practice in your mill?
        2) What is approximate cost for
            1) Equipment acquisition
            2) Operating cost

    4) How are the following impacted due to use of gravity tables for cleaning?
        1) Test weight
        2) Yield

12. Other/Added technical costs: What other costs are incurred due to excessive DON?

13. Describe the overall impact of SCAB on your operations

14. Evolution of Vomitoxin (DON)

    1) What were the years when DON was problematic?
    2) Over time, has resistance to vomitoxin decreased over time?
    3) Which factors/innovations have been most important (rank 1 to 6 where 1 is most important)
        ___Varieties
        ___Fungicide
        ___Farm management practices
        ___Crop rotations
        ___Milling/processing practices
        ___other (list)

15. What other diseases do you envision will become similarly problematic in the future? (e.g., UGG99, other)

Impacts of Reducing FHB Under the USWBSI's
Malting Barley: *High-level interviews*

Purpose: Focused interview of maltsters conducted to estimate the financial impacts of Fusarium head blight, *aka* scab, on the barley malting industries.

Instructions: We would like your input on the following issues and information. All information will be held confidentially and only released in aggregation with others. Don Sullins will conduct interviews on these issues and information will be provided through that interview. Some information may be provided later and/or as a follow-up.

Contact:

- Don Sullins 1-913-449-8982 Gmail don.sullins65@gmail.com
- William W Wilson 1-701-231-7472 william.wilson@ndsu.edu

1. Firm name

2. Plants reported in this interview: [Instructions: Discuss with Don S to determine which plants are appropriate to include].

   a. Which of your plants are not impacted operationally due to DON? Why?
      i. Not in the geography where DON is problematic?
      ii. Purchases specify limits such that DON must conform to specifications.
      iii. Other

   b. Which plants are impacted by DON? [the questions below pertain to these plants]

3. Selling or use of products: What are limits of product sales ref DON

By product
   i. Malted barley ________________
   ii. By-Products: ________________

4. What years has DON been problematic and impacting procurement strategies?

5. Describe how your target procurement area changed during epidemic years regarding DON? Which years were these?

6. What are the effects of DON and SCAB that are most devastating (Rank 1, 2, … with 1 being most devastating)

____Taste
____Gushing

____Customer DON limits
____DON testing costs
____Processing costs
____Sourcing non or low DON barley
____Other

7. Buying barley:--Rank among below using 1, 2,….6 with 1 being most important during epidemic years

Element of Strategy	*Normal Year*	*Transition year*	*Epidemic Year*
Target elevator origins			
Pre-harvest testing			
Pre-shipping testing			
Excluded origins			
Restrictions in contracts			
Discounts for exceeding limits			
Storage of barley to reduce DON			
Specific questions ref grain purchasing:			
At what level or range of DON do you reject and not allow it in to plant			
What do you do w/shipments that do not conform to requirements (i.e., reject, blend, other)			
Other			

*Normal is a year where DON is not known to be a problem; Transition year is a year following a year in which DON was a problem; and Epidemic year is a year in which DON is known to be a problem

8. Can you provide a history of premiums/discounts for DON (even as a follow-up to the first call)?

Ideally, provide data on DON discounts over time (i.e. by crop year). This should include the level at which discounts begin.

If hard data does not exist, provide your judgment of the range of discounts that have occurred over time and through the crop years from the 1990s.

i. Hard data is available
ii. Opinion on ranges of discounts
iii. By class 6R or 2R vs Feed

9. In years where vomitoxin is a problem,

   a. What is the premium paid (estimated) for barley conforming to customer specifications (or, discounts for nonconforming samples)?
   b. How far (miles) do you have to expand from your normal market area
   c. What is your trucking costs $/mile
   d. How much does your procurement cost increase due to
      i. Greater distance
      ii. Premiums for non-vomitoxin

10. Testing

   a. Testing technology i.e. type of test used

      ____

   b. Test cost per test (or, see 3) below)
      i. Supplies (test kits)
      ii. Personnel/labor costs
      iii. Hourly rate w/benefits

   c. Or, Total Cost per test (e.g., $22/test)

   d. How frequently do you test?
      i. Number of tests per year
      ii. Frequency of test (e.g., 1:1 (every shipment), 1:5 (one in five shipments) etc.)

   e. Number of samples tested/year
      i. Normally
      ii. In years when DON is a problem

11. Processing methods used by maltsters to manage scab/DON:

Function	Frequency Estimate (% of barley handled in the malt plant)	Estimated cost c/bushel
Clean for FM		
Clean out thins		
Segregate high-DON barley		
Aging (or storing) high-DON barley		
Other		

12. Segregation (we realize this is difficult to quantify, but an estimate would suffice)

    a. At what level do you segregate barley due to excessive DON?
    b. How often does this occur? Provide a range or percent of time
    c. Added cost (estimated) due to segregation

13. Other/Added technical costs: What other costs are incurred due to excessive DON?

14. Describe the overall impact of SCAB on your operations

15. If you are a craft maltster, are their special impacts not considered above?

16. Evolution of Vomitoxin (DON)

    1) What were the years when DON was problematic?
    2) Over time, has resistance to vomitoxin decreased over time?
    3) Which factors/innovations have been most important (rank 1 to 6 where 1 is most important)
       ___Varieties
       ___Fungicide
       ___Palisade Growth Regulator for Barley
       ___Farm management practices
       ___Crop rotations
       ___Malting/processing practices
       ___other (list)

17. What other diseases do you envision will become similarly problematic in the future?

Interview questionnaire for Wheat Traders

____ I would like to contact you to discuss how you handle(d) DON and VOM in the wheat supply chain. Below is a brief set of questions I would like to ask. Look over, and I will give a call and you can share me your views on this topic (you don't have to fill it out, just talk it through w/me).

If possible, could we speak any afternoon (Wed-Fri) at a time of your convenience. Shoot me a time and I will call you.

FYI, this is intended as a high level interview of the Scab Initiative, a USDA funded organization whose purpose is to reduce DON.
Briefly, look over below and if you have a response, note it for our discussion. In most cases, a judgement regarding the response is sufficient.

1. What years has DON been problematic and impacting procurement strategies?

2. Describe how your target procurement area changes during epidemic years regarding DON?

3. What is your current treatment of DON (by class/port area if/as appropriate)?

    a. Specification for DON

    b. Limits at which discounts begin

    c. What are current discounts

    d. Limits at which you would reject

4. What do you do w/shipments that do not conform to requirements (i.e., reject, blend, other)

5. Buying wheat: Which strategies do you use when buying wheat when DON is at risk? (Rank 1…6 where 1 is most important/applicable)

Target elevator origins	
Pre-harvest testing	
Pre-shipping testing	
Excluded origins	
Restrictions in contracts	
Discounts for exceeding limits	

6. Would you by chance have a history of premiums/discounts for DON that could be shared? If not, just explain how it may have changed over time

7. Testing

    a. Testing technology i.e. type of test used ______________________________

    b. Cost per test (e.g., $15/test/truck, or, something like this):

        i. $/truck
        ii. $/rail car

    c. How frequently do you test for DON?

        i. Frequency of test (e.g., 1:1 (every shipment), 1:5 (one in five shipments) etc.)
        ii. Number of tests per year (estimate)

Appendix B: Estimated Consequences of Scab Management in Infested Small Grains: Data Sources and Model Specification:

Data Sources and Interpretation Observations of yield, grain quality, and scab presence are made annually in field trials by USBWSI PIs between 2007 and 2010 for hard red spring (N=194), hard red winter (N=516), soft red winter (N=1764), and soft white winter (N=64) wheat classes. Observations were made in 14 sites, found in multiple states, including IL, IN, LA, MD, MO, ND, NY, SD, OH and VA. 1698 observations with a non-missing value of DON were available. No description was provided as to whether field trials were done in producer fields or at experiment stations. An indication is made as to whether the trial was inoculated with scab. Data are provided by Willyerd and Paul (Ohio State).

Values of DON or yield are standardized. Prior to standardizing, and after removing observations with DON less than 1.0 PPM, the mean DON in wheat was 1.45 PPM, the standard deviation was 0.64; the mean wheat yield was 66.87 bu/ac, the standard deviation was 19.44.

For barley, the data (N=2382) are observed annually in field trials by USBWSI PIs between 2008 and 2015. No description was provided as to whether field trials were done in producer fields or at experiment stations. An indication is made as to whether the trial was inoculated with scab. Observations were made in MN, ND and SD. Data are obtained from Friskop (ND State). Values of DON in barley are standardized. Prior to standardizing, the mean was 0.42 PPM, the standard deviation was 0.43.

Observations of producer scab management by Cowger (NC State), on land managed by agricultural producers instead of in field trials, were collected in 2013. Management practices observed in these data include (1) growing moderately resistant varieties, (2) applying a recommended fungicide with scab as the primary target at heading or flowering, (3) rotating crops so that growing wheat rarely or never follows another small grain or corn crop, (4) growing varieties that head at different times, and (5) staggering planning dates so that the crop does not flower on the same date. These data contain 15,903 observations of scab management choices, self-reported by agricultural producers. Simulations using this data were conducted and merged with the other data.

Method Ordinary least squares, with fixed effects for year and locations, is used to estimate the models specified below of the relationship between wheat yield, or DON level in wheat and barley, and plant variety, absolute and relative scab incidence, scab severity, class (of wheat) and management techniques.

Wheat Yield: The following model was specified for wheat yield.

$$Y_t = \propto + \sum_{i=1}^{M} \theta_i cultivar + \sum_{i=1}^{M} \omega_i cultivar\ x\ disease_{medium} +$$
$$\sum_{i=1}^{M} \omega_i cultivar\ x\ disease_{high} + \sum_{i=1}^{N} \delta_i (cultivar\ x\ fungicide) +$$
$$\sum_{i=1}^{N} \rho_i (cultivar\ x\ fungicide\ x\ disease_{medium}) +$$

$$\sum_{i=1}^{N} \rho_i\big(cultivar\ x\ fungicide\ x\ disease_{high}\big) + \gamma_1 Fungicide + \gamma_2 Resistance +$$
$$\beta_1 Incidence + \beta_2 Severity + \beta_3 DON + \sum_{i=1}^{5} \vartheta_i Location + \mu_t Year +$$
$$\varphi_1(Class1\ x\ arcsev) + \varphi_2(Class1\ x\ arcinc) + \varphi_3(Class1\ x\ DON) +$$
$$\varphi_4(Class2\ x\ arcsev) + \varphi_5(Class2\ x\ arcinc) + \varphi_6(Class2\ x\ DON) +$$
$$\varphi_7(Class3\ x\ arcsev) + \varphi_8(Class3\ x\ arcinc) + \varphi_9(Class3\ x\ DON) + \varepsilon \qquad [1]$$

where y_t is final wheat harvest in bushels per acre. The observed value of y_t is standardized, meaning that coefficients for all independent variables describe marginal changes relative to the standardized average.

Dummy variables *(θ_i)* were included for each unique variety (Table B1). The hypothesis is tested for whether any of the 95 observed varieties have a different yield than the average. 15 varieties with statistically different yields from the average are listed in Table B1. Interpretation of this variable is an incremental difference in the average yield.

Disease is a dummy variable used to indicate disease pressure. No information was found to indicate boundaries for low, medium and high disease pressure. For purposes of this study, low disease pressure refers to observed values of *Severity* within the lowest 10% of all observations; medium disease pressure refers to observed values of *Severity* within the 10.1% to 74.9% of observations; high disease pressure refers to observed values in the largest 25% of observations. This coefficient is used to test the hypothesis of whether the average wheat yield changes, for any given variety, under low, medium, or high scab levels; the low case is dropped from the equation. A significant coefficient indicates that a particular variety, under a given disease pressure, will have a different yield relative to the average.

Dummy variables *(δ_i)* were included for an interaction term for each observed fungicide-variety combinations. The hypothesis was tested for whether any of the 94 observed varieties have a yield statistically different from the average when a fungicide is applied to them. Although no specific fungicide is listed in the observed data, observations of the effects of fungicide applications are made for all 94 observed varieties; all varieties received a fungicide application in the experimental trials. Varieties with a yield statistically different from the average only when a fungicide is applied are listed in Table B1. A statistically significant coefficient indicates a complementary relationship between scab and the observed plant variety in generating yield.

Fungicide is a dummy variable denoting (1=yes, 0=no) fungicide use as reported by USBWSI PI. This variable is used to test the hypothesis of whether application of a fungicide, by itself, affects the average yield. All varieties received a fungicide treatment in field trials.

Table B1. Estimated Coefficients for Equation 1: Wheat Yield.

Variable	Parameter Estimate	Heteroscedasticity Consistent Standard Error	t Value	Pr > |t|
Intercept	0.84	0.00	611.47	<.0001
Cultivar: Alice	-0.51	0.00	-357.46	<.0001
Cultivar: Bess	-0.24	0.00	-331.11	<.0001
Cultivar: Brick	-0.61	0.00	-546.98	<.0001
Cultivar: Coker9155	-0.51	0.00	-476.93	<.0001
Cultivar: Elkhart	-0.42	0.00	-369.38	<.0001
Cultivar: INW0801	-0.35	0.00	-335.59	<.0001
Cultivar: Kaskaskia	0.14	0.00	194.45	<.0001
Cultivar: McCormick	-0.37	0.00	-414.01	<.0001
Cultivar: P2137	-0.93	0.00	-277.79	<.0001
Cultivar: P25R47	0.51	0.00	836.68	<.0001
Cultivar: P26R15	-0.39	0.00	-362.93	<.0001
Cultivar: Roane	-0.28	0.00	-356.02	<.0001
Cultivar: SS8641	-0.47	0.00	-355.51	<.0001
Cultivar(Excel5530) x Med disease pres.	0.63	0.00	473.76	<.0001
Cultivar(Wesley) x Med disease pres.	0.87	0.00	657.02	<.0001
Cultivar(Exc5170) x fungicide applic.	-0.44	0.00	-402.67	<.0001
Cultivar(P26R15) x fungicide applic.	0.37	0.00	272.32	<.0001
Cultivar(Richland) x fungicide applic.	0.88	0.00	525.88	<.0001
Cultivar(Bess) x fungicide applic. X high disease pres.	-0.55	0.00	-285.37	<.0001
Cultivar(P25R47) x fungicide applic. X high disease pres.	-0.24	0.00	-195.62	<.0001
Fungicide applic.	0.19	0.00	563.46	<.0001
Resistance (resistance level reported by USBWI)	-0.06	0.00	-209.82	<.0001
Arcsine (severity)	-0.04	0.00	-41.30	<.0001
Ln(DON)	-0.58	0.00	-1439.30	<.0001
Arcsine(severity) x Class1(HRSW)	-1.62	0.00	-509.75	<.0001
Arcsine(incidence) x Class2(HRWW)	-0.93	0.00	-513.18	<.0001
Ln(DON) x Class2(HRWW)	0.53	0.00	439.04	<.0001
Arcsine(incidence) x Class3(SRWW)	0.21	0.00	268.44	<.0001
Location:Beltsville	-0.68	0.00	-673.08	<.0001
Location:Bradford	0.22	0.00	272.33	<.0001
Location:Brookings	-0.99	0.00	-679.56	<.0001
Location:Barbondale	0.31	0.00	305.09	<.0001
Location:DIX	-1.05	0.00	-994.08	<.0001
Location:Forman	-1.00	0.00	-627.15	<.0001
Location:IN	0.53	0.00	452.64	<.0001
Location:Monmouth	-0.45	0.00	-461.68	<.0001
Location:Princeton	1.27	0.00	1206.50	<.0001
Location:Urbana	-1.50	0.00	-1813.70	<.0001
Location:WYE	0.26	0.00	306.87	<.0001
Year:2008	0.19	0.00	241.10	<.0001
Year:2009	0.46	0.00	522.86	<.0001
Year:2010	-0.38	0.00	-399.04	<.0001

R-Sq = 0.71

Resistance is a dummy variable indicating the subjective assessment, reported in the USWBSI data, of the observed variety's resistance to scab; no description is made regarding how this was categorized. This variable is used to test the hypothesis of whether a marginal increase in degree of scab resistance, without regard to variety, affects average wheat yield. *i* refers to resistant, moderately resistant, moderately susceptible, susceptible and very susceptible varieties respectively. A significant coefficient indicates that an increase in a variety's resistance to scab (e.g. from moderately susceptible to moderately resistant) will change yield.

Incidence is defined as the number of scab-diseased spikes in the number of sampled spikes (Paul et al. 2005). It is measured as the arcsine transformation of this percentage. The estimated coefficient is used to test the hypothesis of whether a one-unit change in the arcsine value of incidence affects the average wheat yield.

Severity is defined as sum of the proportion of diseased spikelets per diseased spike divided by the total number of diseased spikes sampled from field observations (Paul et al. 2005). It is measured as the arcsine transformation of this percentage. The estimated coefficient is used to test the hypothesis of whether a one-unit change in the arcsine value of severity affects the average wheat yield. *DON* is the measure, in PPM, of deoxynivalenol present in the grain collected in trial field observations. The estimated coefficient is used to test the hypothesis of whether a one-unit change in the natural log of the observed DON affects the average wheat yield.

Location is a dummy variable representing location of the field observation. The estimated coefficient is used to test whether conditions unique to any particular location during the observed period affects the average wheat yield.

Year is a dummy variable representing the year of the field observation. The estimated coefficient is used to test whether conditions unique to any particular year during the observed period affects the average wheat yield.

Class$_i$ is a dummy variable representing wheat classes; *i* refers to HRSW (class=1), HRWW (class=2), SRWW (class=3), and SWWW (class=4). The class variable is used to test the hypothesis of whether there is a relationship, unique to each wheat class, between severity, incidence or DON levels and wheat yield. A significant coefficient for any of these interaction terms indicates a complementary relationship between the observed wheat class (e.g. HRSW) and incidence or severity or DON, respectively. ε is an error term.

Wheat Quality (DON) The following model was specified for wheat quality.

$$DON_t = \propto + \partial_1 Relative\ incidence\_med + \partial_2 Relative\ incidence\_high + \theta_1 HRW\ x\ Fungicide + \theta_2 SRW\ x\ Fungicide + \theta_3 SWW\ x\ Fungicide + \vartheta_1 HRW\ x\ Incidence + \vartheta_2 SRW\ x\ Incidence + \vartheta_3 SWW\ x\ Incidence + \beta_1 Resistance + \beta_2 Severity + \sum_{i=1}^{10} \mu_i Location + \sum_{i=1}^{3} \mu_i Year + \varepsilon \quad [2]$$

where DON_t is observed DON in wheat field trials. *DON* is the measure, in PPM, of deoxynivalenol present in the grain collected in trial field observations. The observed value is standardized, meaning that coefficients for all independent variables describe marginal changes on DON (ppm) relative to the standardized average. The results are shown in Table B2.

Relative incidence is a dummy variable used to indicate relative disease pressure. No information was found to indicate boundaries for low, medium and high relative disease pressure. For purposes of this study, low relative disease pressure refers to observed values of *Incidence* within the lowest 25% of all observations, across all years and locations; medium relative disease pressure refers to observed values of *Incidence* within the 25.1% to 75.0% of observations; high relative disease pressure refers to observed values of *Incidence* in the largest 25% of observations. This coefficient is used to test the hypothesis of whether the average DON in wheat changes, for any given variety, under low, medium, or high scab incidence levels; the low pressure case is dropped from the equation. A significant coefficient indicates that all wheat classes, under medium or high scab incidence, will have a different observed level of DON relative to the average.

Dummy variables (θ) are estimated for a interaction term for each observed fungicide-wheat class combinations. The hypothesis is tested for whether any of the 4 observed wheat classes have a DON level statistically different from the average when a fungicide is applied to them. Although no specific fungicide is listed in the observed data, observations of the effects of fungicide applications are made for all 4 observed classes; all varieties in each class received a fungicide application in the experimental trials. A statistically significant coefficient indicates a complementary relationship between fungicide applications and wheat class on DON level.

Dummy variables (ϑ) are estimated as an interaction term for each observed scab incidence-wheat class combination. In this case, absolute scab incidence, instead of relative, incidence is used. This variable is used to test whether any marginal change in scab incidence has a distinct complementary effect on observed DON in different classes of wheat. A significant coefficient indicates that a one-unit increase in scab incidence, for varieties in a given wheat class, will have a different observed level of DON relative to the average of other wheat classes.

$Resistance_i$ is a dummy variable indicating the subjective assessment, reported in the USBWSI data, of the observed variety's resistance to scab; no description is made regarding how this was categorized. This variable is used to test the hypothesis of whether a marginal increase in degree of scab resistance, without regard to variety, affects average wheat DON level. *i* refers to resistant, moderately resistant, moderately susceptible, susceptible and very susceptible varieties respectively. A significant coefficient indicates that an increase in a variety's resistance to scab (e.g. from moderately susceptible to moderately resistant) will change DON.

Severity is defined as sum of the proportion of diseased spikelets per diseased spike divided by the total number of diseased spikes sampled from field observations (Paul et al. 2005). It is anticipated to affect DON levels and is measured as the arcsine of this percentage. The estimated coefficient is used to test the hypothesis of whether a one-unit change in the arcsine value of severity affects the average wheat DON level.

Location is a dummy variable representing location of the field observation. The estimated coefficient is used to test whether conditions unique to any particular location during the observed period affects the average wheat DON. *Year* is a dummy variable representing the year of the field observation. The estimated coefficient is used to test whether conditions unique to any particular year during the observed period affects the average wheat DON. ε is an error term.

Outlying observations may lead to a biased estimate. These are excluded from the regression based on the Cook's D and leverage statistics, as well as having residual values greater than 2. This series of constraints reduces the number of observations used to draw 1,000 replicates from 1698 to 1178.

Barley DON The following model was specified for barley quality.

$$DON_t = \propto + \sum_{i=1}^{M} \theta_i cultivar + \sum_{i=1}^{M} \omega_i cultivar\ x\ disease_{medium} + \sum_{i=1}^{M} \omega_i cultivar\ x\ disease_{high} + \sum_{i=1}^{N} \delta_i (cultivar\ x\ fungicide) + \sum_{i=1}^{N} \rho_i (cultivar\ x\ fungicide\ x\ disease_{medium}) + \sum_{i=1}^{N} \rho_i \left(cultivar\ x\ fungicide\ x\ disease_{high}\right) + \gamma_1 Fungicide + \gamma_2 Resistance + \beta_1 Incidence + \varphi Incidence + \beta_2 Severity + \sum_{i=1}^{5} \vartheta_i location + \mu_t year + \varepsilon \quad [3]$$

DON is the measure, in PPM, of deoxynivalenol present in the grain. Scab does not affect barley yield, but grain quality. It is measured as the natural log of the observed DON level. The observed level is then standardized, based on the mean and standard deviation of all observed DON levels in the sample. Coefficients for all independent variables in Equation 3 describe marginal changes relative to the standardized average.

Dummy variables *(θ_i)* are included for each unique variety. The hypothesis is tested for whether any of the 25 observed varieties have a different DON than the average. 18 barley varieties with statistically different DON levels from the average are listed in Table B3. The interpretation of the variable is an incremental difference in the average level of DON in the grain.

Table B2. Estimated Coefficients for Equation 2: Wheat DON.

Variable	Heteroscedasticity Consistent			
	Parameter Estimate	**Standard Error**	**t Value**	**Pr > |t|**
Intercept	-0.27	0.13	-2.08	<.0001
Middle 50% of observed incidence	-0.06	0.04	-1.48	<.0001
HRW_fungicide appl.	-0.22	0.08	-2.86	<.0001
SRW_fungicide appl.	-0.12	0.04	-2.78	<.0001
SWW_fungicide appl.	-1.14	0.22	-5.19	<.0001
HRW_incidence	0.22	0.12	1.84	<.0001
SRW_incidence	0.69	0.08	8.63	<.0001
SWW_incidence	1.27	0.41	3.10	<.0001
Resistance	0.02	0.00	12.86	<.0001
Severity	0.23	0.09	2.66	<.0001
Location: Beltsville	-0.70	0.10	-6.80	<.0001
Location: Bradford	-0.27	0.08	-3.26	<.0001
Location: Brookings	-1.74	0.11	-16.23	<.0001
Location: Carbondale	-0.98	0.12	-8.29	<.0001
Location: DIX	-0.24	0.11	-2.13	<.0001
Location: Forman	-0.26	0.10	-2.64	<.0001
Location: IN	-0.58	0.09	-6.24	<.0001
Location: Monmouth	-0.56	0.07	-8.30	<.0001
Location: Urbana	-1.08	0.13	-8.21	<.0001
Location: Wooster	1.27	0.10	12.78	<.0001
Year:2008	0.56	0.10	5.53	<.0001
Year:2009	0.39	0.11	3.59	<.0001
Year:2010	-0.27	0.13	-2.08	<.0001

R-Sq = 0.56

$Disease_i$ is a dummy variable used to indicate disease pressure. No information was found to indicate boundaries for low, medium and high disease pressure. For purposes of this study, low disease pressure refers to observed values of *Severity* within the lowest 10% of all observations; medium disease pressure refers to observed values of *Severity* within the 10.1% to 74.9% of observations; high disease pressure refers to observed values in the largest 25% of observations. This coefficient is used to test the hypothesis of whether the average DON level changes, for any given variety, under low, medium, or high scab levels; the low case is dropped from the equation. A significant coefficient indicates that a particular variety, under a given disease pressure, will have a different DON level relative to the average.

Dummy variables (δ_i) are estimated for a interaction term for each observed fungicide-variety combinations. The hypothesis is tested for whether any of the 25 observed varieties have a different DON level than the average when a fungicide is applied to them. Although no specific fungicide is listed in the observed data, observations of the effects of fungicide applications are made for all 25 observed varieties; all varieties received a fungicide application in the experimental trials. Varieties with a statistically significant marginal effect are listed in Table B3. A statistically significant coefficient indicates a complementary relationship between scab and the observed plant variety in producing DON in the grain.

Fungicide is a dummy variable denoting (1=yes, 0=no) fungicide use as reported by USBWSI PI. This variable is used to test the hypothesis of whether application of a fungicide, by itself, affects the average DON level. All varieties received a fungicide treatment in field trials.

$Resistance_i$ is a dummy variable indicating the subjective assessment, reported in the USWBSI data, of the observed variety's resistance to scab; no description is made regarding how this was categorized. This variable is used to test the hypothesis of whether any degree of scab resistance, regardless of variety, affects average DON level in barley. $i=0$ for moderately susceptible, susceptible and very susceptible varieties and $i=1$ for moderately resistant varieties; no resistant varieties were observed.

Incidence is defined as the number of scab-diseased spikes in the number of sampled spikes (Paul et al. 2005). It is measured as the arcsine transformation of this percentage. The estimated slope coefficient, β_1, is used to test the hypothesis of whether a one unit change in the arcsine value of incidence affects the average wheat DON. Analysis of the relationship between the error term ε and this variable suggests a distinct relationship between incidence and DON at incidence levels between 1.0 and 2.1. Hence, a second, dummy, φ, variable is included in Equation 2 to test the hypothesis of whether a incidence affects DON levels differently at these levels of scab incidence.

Severity is defined as sum of the proportion of diseased spikelets per diseased spike divided by the total number of diseased spikes sampled (Paul et al. 2005). It is measured as the arcsine transformation of this percentage. The estimated coefficient is used to test the hypothesis of whether a one-unit change in the arcsine value of severity affects average DON level.

Location is a dummy variable representing location of the field observation. The estimated coefficient is used to test whether conditions unique to any particular location during the observed period affects average DON level. *Year* is a dummy variable representing the year of the field observation. The estimated coefficient is used to test whether conditions unique to any particular year during the observed period affects average DON level. ε is an error term.

Outlying observations may lead to a biased estimation for Equation 2. These are excluded from the regression based on the Cook's D and leverage statistics, as well as having residual value greater than 2.0. This series of constraints reduces the number of observations used to draw 1,000 replicates from 2382 to 1363.

Scab management outcomes in field trials are considered representative of the outcomes observed in commercial production conditions. Cowger (2005) observed the distribution of scab management choices among producers. Given that these observations are one draw from the theoretical distribution of scab management choices made by producers, we assume each producer decides whether to adopt any of the four observed scab management practices ((1) growing moderately resistant varieties, (2) applying a recommended fungicide with scab as the primary target at heading or flowering, (3) rotating crops so that growing wheat rarely or never follows another small grain or corn crop, and (4) growing varieties that head at different times). Field trial outcomes from any combination of any of the four management practices are assumed to hold in any commercial production condition using the same combination of scab management techniques. Hence, each wheat field trial observation with a given combination of scab management techniques is assumed to generate similar wheat yield and quality results under production settings.

Each unique combination of the four scab management practices observed in field trials is matched with a corresponding commercial production setting using the same combination of scab management practices. In other words, observations of field experiment management conditions are matched with producer-reported management conditions (e.g. if a producer indicated fungicides are applied, only field trial observations using fungicides are considered in the regression; or, if a producer indicated small grain crops were present in the field prior, only field trial observations wherein a host crop was present previously are linked with this observation.) Equation 1, 2 or 3 were re-estimated with each matched set of yield or quality results replicated 1,000 times, with the probability of whether any given management combination occurs derived from a Bernoulli distribution of mean and variance equal to that observed in the Cowger data, with the exception of management option staggering planting dates since all plants observed in field trial data are planted simultaneously (Friskop, personal communication). Similarly, each barley field trial observation is repeated 1,000 times with the probability of whether any given management combination occurs derived from a Bernoulli distribution of mean and variance equal to that observed in the Cowger data for barley production.

Table B3. Estimated Coefficients for Equation 3: DON Level in Barley.

Variable	Parameter Estimate	Heteroscedasticity Consistent Standard Error	t Value	Pr > |t|
Intercept	-1.33	0.00	-856.08	<.0001
Cultivar: ACMetcalf	0.11	0.00	57.67	<.0001
Cultivar: Celebration	0.45	0.00	166.54	<.0001
Cultivar: Conlon	0.20	0.00	115.72	<.0001
Cultivar: Eslick	0.40	0.00	139.38	<.0001
Cultivar: FEG65-02	0.71	0.00	144.55	<.0001
Cultivar: Innovation	0.43	0.00	143.81	<.0001
Cultivar: Rasmusson	0.34	0.00	82.99	<.0001
Cultivar: Rawson	0.23	0.00	115.48	<.0001
Cultivar: Robust	0.23	0.00	86.10	<.0001
Cultivar: Tradition	0.19	0.00	71.79	<.0001
Cultivar(Excel) x Med disease pres.	0.34	0.00	131.79	<.0001
Cultivar(Lacey) x Med disease pres.	0.68	0.00	173.37	<.0001
Cultivar(M122) x Med disease pres.	0.46	0.00	160.37	<.0001
Cultivar(Merit) x Med disease pres.	0.20	0.00	70.68	<.0001
Cultivar(ND Genesis) x Med disease pres.	-0.53	0.00	-166.06	<.0001
Cultivar(ND20448) x Med disease pres.	0.70	0.00	238.43	<.0001
Cultivar(Pinnacle) x Med disease pres.	0.22	0.00	99.11	<.0001
Cultivar(Quest) x Med disease pres.	0.18	0.00	78.58	<.0001
Cultivar(Robust) x Med disease pres.	0.36	0.00	115.33	<.0001
Cultivar(Tradition) x Med disease pres.	0.21	0.00	70.95	<.0001
Cultivar(Rawson) x high disease pres.	-0.36	0.00	-126.09	<.0001
Cultivar(Conlon) x fungicide applic.	-0.49	0.00	-141.02	<.0001
Cultivar(Excel) x fungicide applic.	0.41	0.01	57.40	<.0001
Cultivar(FEG65-02) x fungicide applic.	-1.69	0.01	-311.60	<.0001
Cultivar(Lacey) x fungicide applic.	-0.76	0.01	-126.15	<.0001
Cultivar(Quest) x fungicide applic.	-0.66	0.00	-192.48	<.0001
Cultivar(ACMetcalf) x fungicide applic. X med disease pres.	-0.49	0.00	-101.31	<.0001
Cultivar(M122) x fungicide applic. X med disease pres.	-0.47	0.01	-52.46	<.0001
Cultivar(ND20448) x fungicide applic. X med disease pres.	-0.78	0.01	-123.21	<.0001
Cultivar(Rawson) x fungicide applic. X med disease pres.	-0.63	0.00	-169.78	<.0001
Cultivar(Robust) x fungicide applic. X med disease pres.	-0.79	0.00	-172.45	<.0001
Cultivar(Scarlet) x fungicide applic. X med disease pres.	-0.74	0.00	-168.86	<.0001
Cultivar(Tradition) x fungicide applic. X med disease pres.	-0.50	0.00	-119.50	<.0001
Fungicide applic.	0.41	0.00	194.95	<.0001
Resistance (resistance level reported by USWBSI)	0.25	0.00	133.87	<.0001
Arcsine (incidence)	0.41	0.00	346.98	<.0001
Arcsine (severity)	0.14	0.00	29.47	<.0001
Dummy: arcsine (incidence)	0.17	0.00	137.40	<.0001
Location:Fargo	0.35	0.00	346.46	<.0001
Location: St. Paul	1.68	0.00	473.47	<.0001
Location:Volga	2.18	0.00	753.16	<.0001
Year:2009	0.23	0.00	173.96	<.0001
Year:2010	0.33	0.00	286.80	<.0001
Year:2011	0.42	0.00	299.12	<.0001

R-sq = 0.52

Appendix C: SERF Figures and Tables

Appendix Table C1. Crop Budgets by Wheat Class and for Malting Barley

	HRS	SRW	HRW	Malting Barley
Price	5.23	4.70	4.90	4.32/2.95
Other Income		0.34	0.26	
Scab Discounts	0.19	0.32	0.32	-0.01
Market Revenue	164.75	396.40	315.82	343.17
Direct Costs				
Seed	13.41	43.40	11.82	11.48
Fertilizer	44.89	87.80	33.95	45.22
Herbicides	25.20	9.50	8.63	23.70
Fungicides[1]	15.00	15.00	14.00	14.00
Insecticides	0.00	0.00	0.00	0.00
Crop Insurance	10.90	10.00	0.00	13.50
Fuel and Lubrication	7.46	10.13	13.68	8.02
Repairs	15.61	20.32	21.00	16.03
Drying	0.00	0.00	0.00	0.00
Custom Operations			11.86	
Miscellaneous	7.50	4.43	0.07	7.50
Operating Income	2.76	5.53	0.09	2.77
Sum of Listed Direct Costs	142.73	206.11	115.10	128.22
Indirect Costs				
Misc Overhead	6.51	12.60	16.07	6.83
Machinery Depreciation	18.17			18.95
Machinery Investment	9.87	125.86	81.35	10.25
Land Charge	35.00	187.00	52.93	35.00
Sum of Indirect Costs	69.55	325.46		71.03
Return to Labor & Mgmt	-47.53	-135.17	50.37	143.91

1 Fungicide costs only considered for cases applying fungicides.

2. Prices for barley are $4.32/bu for malting and $2.95/bu for feed.

Appendix Table C2. FHB Severity and DON Distributions for HRS and Farm Management Practice.

	None	Fungicide and Mod. Res. Varieties	Fungicide	Moderately Resistant Varieties
HRS				
Severity				
Distribution	Kumaraswamy	Triangle	Exponential	Pearson5
Parameter 1	.60425	0	8.9433	2.7371
Parameter 2	1.9555	0		23.428
Parameter 3	1	22.137	Shift (-0.092199)	Shift (-3.2673)
Parameter 4	93.653			
Min				0.1
Max				
DON				
Distribution	Triangle	Uniform	Exponential	Pareto
Parameter 1	.2	.033333	1.0275	.66039
Parameter 2	.2	1.8667		0.2
Parameter 3	8.9674		Shift (0.17431)	
Parameter 4				
Min				0
Max				
Correlation Between Severity and DON	.028	.927	.334	.492

Appendix Table C3. FHB Severity and DON Distributions for SRW and Farm Management Practice.

	None	Fungicide and Mod. Res. Varieties	Fungicide	Moderately Resistant Varieties
SRW				
Severity				
Distribution	Exponential	Exponential	Exponential	Exponential
Parameter 1	25.668	14.449	17.885	17.529
Parameter 2				
Parameter 3	Shift (-0.04194)	Shift (-0.057335)	Shift (-0.0207)	Shift (-0.034849)
Parameter 4				
Min				
Max				
DON				
Distribution	Inverse Gaussian	LogLogistic	LogLogistic	LogLogistic
Parameter 1	4.5438	-0.019465	-0.035725	-0.018985
Parameter 2	4.6533	0.79253	1.3372	1.0946
Parameter 3	Shift(-0.31168)	1.5009	1.5962	1.5116
Parameter 4				
Min				
Max				
Correlation Between Severity and DON	.419	.258	.376	.325

Appendix Table C4. FHB Severity and DON Distributions for HRW and Farm Management Practice.

	None	Fungicide and Mod. Res. Varieties	Fungicide	Moderately Resistant Varieties
HRW				
Severity				
Distribution	Triangular	Triangular	Weibull	Inv. Gauss
Parameter 1	0	0	1.1195	28.354
Parameter 2	9	0	27.696	52.925
Parameter 3	100	67.549	Shift -0.1871	Shift -4.1937
Parameter 4				
Min	0	0	0	0
Max	100	62.48	100	100
DON				
Distribution	Inv. Gauss	Pareto	Lognormal	Inv. Gauss
Parameter 1	4.1332	.61097	5.8002	6.1576
Parameter 2	1.3458	.5	25.065	1.539
Parameter 3	Shift 0.34255		Shift 0.47593	Shift 0.29521
Parameter 4				
Min	.50	.50	.50	.50
Max	22.10	21.80	26.10	30.20
Correlation Between Severity and DON	.501	-.185	.449	.128

Appendix Table C5. Yields and DON distributions for Malting Barley and Farm Management Practice.

	None	Fungicide and Mod. Res. Varieties	Fungicide	Moderately Resistant Varieties
Malting Barley Yields				
Distribution	Kumaraswamy	Beta General	Kumaraswamy	Beta General
Parameter 1	1.0158	2.4756	2.3378	1.5599
Parameter 2	1.2975	2.2916	7.7696	2.1975
Parameter 3	30.37	10.538	12.921	23.444
Parameter 4	141.42	155.88	221.28	153.78
Min	11.75	30.38	14.95	24.15
Max	150.58	140.69	202.65	149.58
DON				
Distribution	Log Normal	Inv. Gaussian	Log Normal	Inv. Gaussian
Parameter 1	1.1036	0.40382	0.83072	0.5344
Parameter 2	2.7992	0.049171	3.307	0.072728
Parameter 3	Shift -0.016028	Shift -0.011808	Shift -0.0055116	Shift -0.017145
Parameter 4				
Min	0	0	0	0
Max	8.84	7.01	13.91	7.01
Correlation Between Yields and DON	.181	.292	.229	.215

Appendix Table C6. Marginal Yield Effects Relative to the Intercept by Class

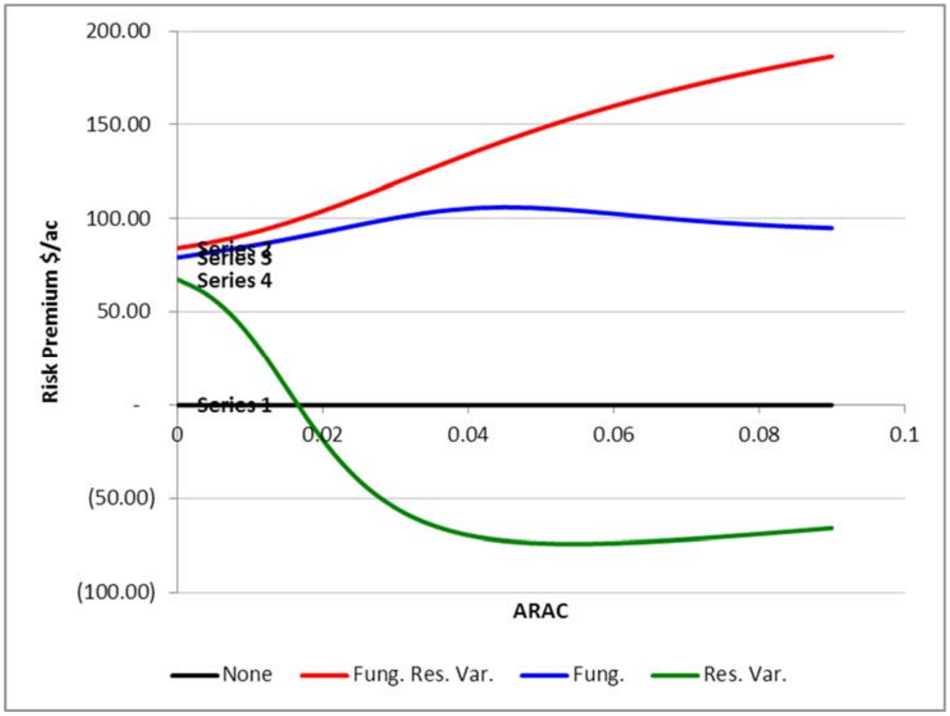
	HRS	SRW	HRW
Intercept			
Fungicide	3.76	3.76	3.76
Resistance	-1.24	-1.24	-1.24
Arcsine Severity	-0.80	-0.80	-0.80
LN Don	-11.32	-11.32	-11.32
Arcsine Severity HRS	-31.50		
Arcsine Severity SRW		4.00	
Arcsine Severity HRW			-18.12
LN DON HRW			10.36
Location	-19.29	6.1	-19.29

Appendix Table C7. Certainty Equivalents by Wheat Class, Malting Barley and Strategy.

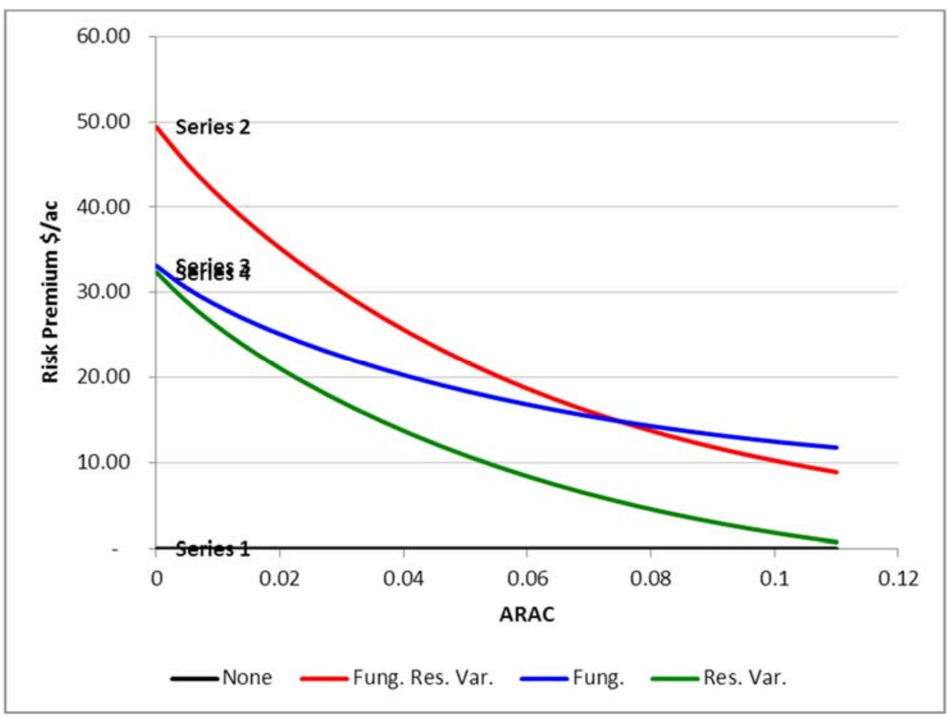
HRS					SRW				
ARAC	None	Fung.Mod . Res.Var.	Fung.	Mod. Res.Var.	ARAC	None	Fung.Mod. Res.Var.	Fung.	Mod. Res.Var.
0	57.42	141.69	136.64	124.96	0	-104.00	-54.60	-70.87	-71.61
0.0038	50.77	137.40	132.25	111.04	0.0046	-106.77	-61.38	-76.09	-77.63
0.0075	44.07	133.74	127.87	92.27	0.0092	-109.31	-67.34	-80.57	-82.91
0.0113	37.25	130.59	123.52	67.92	0.0138	-111.67	-72.74	-84.60	-87.68
0.0150	30.26	127.87	119.20	39.59	0.0183	-113.87	-77.72	-88.27	-92.05
0.0188	23.09	125.48	114.88	10.97	0.0229	-115.95	-82.35	-91.66	-96.10
0.0225	15.74	123.38	110.51	-14.74	0.0275	-117.91	-86.67	-94.81	-99.88
0.0263	8.31	121.51	106.03	-36.40	0.0321	-119.77	-90.72	-97.77	-103.41
0.0300	0.88	119.83	101.36	-54.19	0.0367	-121.54	-94.52	-100.56	-106.74
0.0338	-6.45	118.31	96.41	-68.78	0.0413	-123.23	-98.11	-103.19	-109.88
0.0375	-13.56	116.93	91.09	-80.84	0.0458	-124.85	-101.48	-105.68	-112.84
0.0413	-20.39	115.65	85.36	-90.91	0.0504	-126.40	-104.66	-108.04	-115.63
0.0450	-26.89	114.48	79.23	-99.42	0.0550	-127.88	-107.65	-110.28	-118.28
0.0488	-33.05	113.39	72.80	-106.70	0.0596	-129.30	-110.47	-112.40	-120.78
0.0525	-38.86	112.37	66.20	-112.98	0.0642	-130.66	-113.13	-114.42	-123.14
0.0563	-44.34	111.41	59.60	-118.46	0.0688	-131.96	-115.63	-116.33	-125.38
0.0600	-49.50	110.52	53.15	-123.27	0.0733	-133.20	-117.99	-118.14	-127.49
0.0638	-54.37	109.67	46.96	-127.53	0.0779	-134.40	-120.20	-119.86	-129.48
0.0675	-58.96	108.87	41.09	-131.33	0.0825	-135.54	-122.29	-121.49	-131.36
0.0713	-63.30	108.10	35.59	-134.74	0.0871	-136.62	-124.25	-123.03	-133.13
0.0750	-67.40	107.37	30.45	-137.82	0.0917	-137.67	-126.09	-124.49	-134.81
0.0788	-71.29	106.68	25.67	-140.61	0.0963	-138.66	-127.83	-125.87	-136.39
0.0825	-74.97	106.02	21.22	-143.15	0.1008	-139.61	-129.47	-127.18	-137.88
0.0863	-78.46	105.38	17.09	-145.47	0.1054	-140.52	-131.01	-128.42	-139.29
0.0900	-81.77	104.76	13.25	-147.60	0.1100	-141.38	-132.46	-129.59	-140.62

Appendix Table C7. (continued). Certainty Equivalents by Wheat Class, Malting Barley and Strategy.

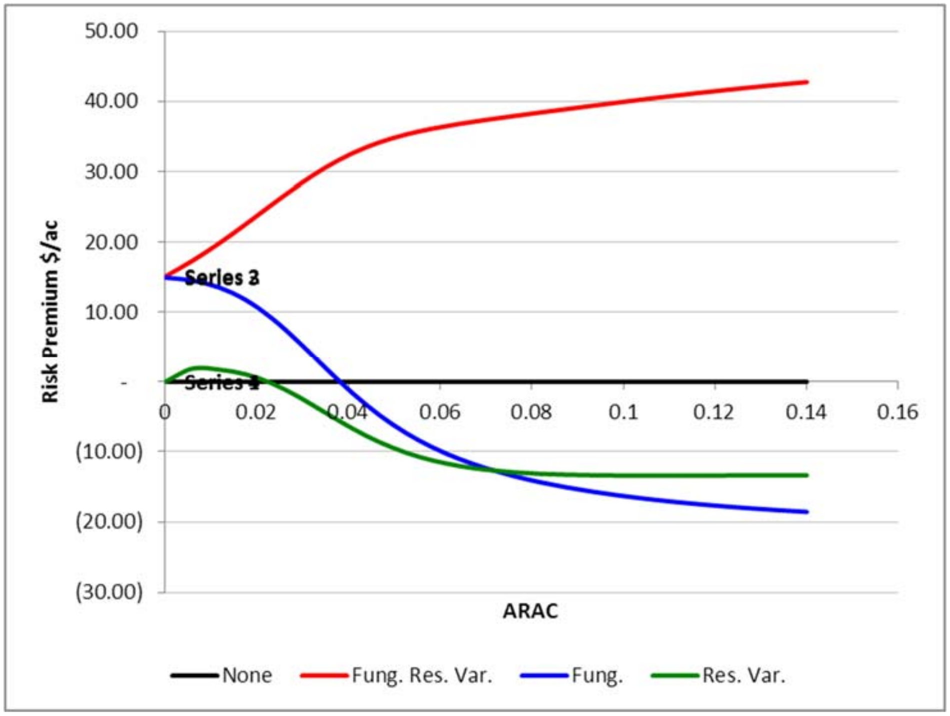
Malting Barley					HRW				
ARAC	None	Fung.Mod. Res.Var.	Fung.	Mod. Res. Var.	ARAC	None	Fung.Mod. Res.Var.	Fung	Mod. Res.Var
0	138.47	164.55	161.96	141.82	0	0	27.91	43.01	42.84
0.0010	130.42	157.77	153.20	134.13	0.0021	0.0058	23.74	41.04	38.26
0.0019	122.64	151.05	144.69	126.66	0.0042	0.0117	18.92	38.73	32.46
0.0029	115.17	144.42	136.44	119.46	0.0063	0.0175	13.44	35.98	25.20
0.0038	108.04	137.91	128.47	112.55	0.0083	0.0233	7.33	32.71	16.42
0.0048	101.28	131.55	120.80	105.94	0.0104	0.0292	0.72	28.85	6.40
0.0058	94.88	125.38	113.43	99.64	0.0125	0.0350	-6.19	24.40	-4.24
0.0067	88.84	119.40	106.37	93.65	0.0146	0.0408	-13.15	19.45	-14.78
0.0077	83.16	113.64	99.60	87.97	0.0167	0.0467	-19.96	14.18	-24.70
0.0086	77.82	108.09	93.14	82.59	0.0188	0.0525	-26.46	8.82	-33.77
0.0096	72.80	102.78	86.96	77.49	0.0208	0.0583	-32.54	3.58	-41.92
0.0105	68.09	97.68	81.06	72.67	0.0229	0.0642	-38.18	-1.39	-49.20
0.0115	63.65	92.82	75.43	68.10	0.0250	0.0700	-43.36	-6.00	-55.71
0.0125	59.48	88.17	70.06	63.78	0.0271	0.0758	-48.11	-10.23	-61.55
0.0134	55.56	83.74	64.93	59.69	0.0292	0.0817	-52.47	-14.07	-66.79
0.0144	51.86	79.52	60.03	55.82	0.0313	0.0875	-56.46	-17.56	-71.53
0.0153	48.37	75.49	55.36	52.14	0.0333	0.0933	-60.12	-20.73	-75.83
0.0163	45.07	71.66	50.89	48.65	0.0354	0.0992	-63.49	-23.62	-79.74
0.0173	41.94	68.00	46.61	45.34	0.0375	0.1050	-66.59	-26.25	-83.31
0.0182	38.98	64.51	42.52	42.19	0.0396	0.1108	-69.45	-28.66	-86.58
0.0192	36.16	61.18	38.61	39.19	0.0417	0.1167	-72.10	-30.88	-89.59
0.0201	33.49	58.01	34.86	36.33	0.0438	0.1225	-74.55	-32.92	-92.37
0.0211	30.94	54.97	31.26	33.60	0.0458	0.1283	-76.83	-34.81	-94.93
0.0220	28.51	52.08	27.81	30.99	0.0479	0.1342	-78.96	-36.56	-97.31
0.0230	26.19	49.31	24.50	28.50	0.0500	0.1400	-80.94	-38.19	-99.52



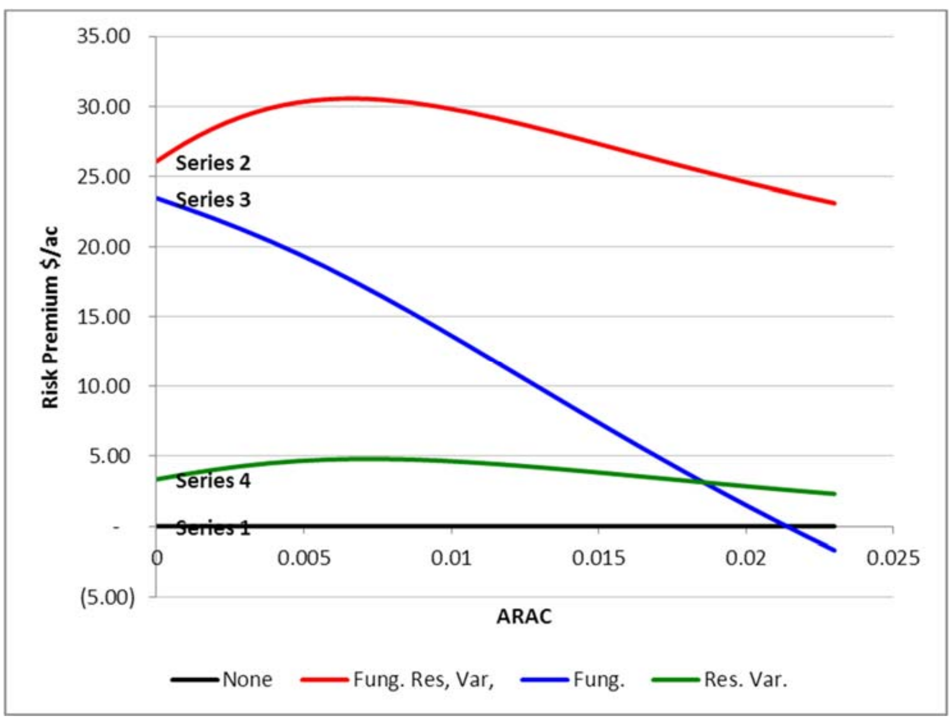
Appendix Figure C1. Risk Premiums for HRS relative to No Fungicide and No MR Varieties, by Strategy.



Appendix Figure C2. Risk Premiums for SRW relative to No Fungicide and No MR Varieties, by Strategy.



Appendix Figure C3. Risk Premiums for HRW relative to No Fungicide and No MR Varieties, by Strategy. (new risk premiums (truncated))



Appendix Figure C4. Risk Premiums for Malting Barley relative to No Fungicide and No MR Varieties, by Strategy.

Appendix D: Regression Coefficients on Yield Loss

Table D1. Regression Coefficients by State and CRDs

Durum Yield Equation Parameter Estimates					
State / CRD	**Intercept**	**Trend**	**Temperature**	**Precipitation**	**R2**
ND - NC	98.817	0.32251	-1.4729	0.70589	0.4058
	(3.332)	(1.625)	(-2.887)	(1.356)	
ND - NE	84.35	0.36631	-1.1761	0.82275	0.3615
	(2.798)	(1.829)	(-2.275)	(1.475)	
ND - C	82.668	0.46442	-1.2943	1.3865	0.5387
	(2.616)	(2.263)	(-2.449)	(2.693)	
ND - EC	94.682	0.85496	-1.3889	0.87211	0.4673
	(2.348)	(3.360)	(-2.033)	(1.567)	
ND - SE	65.407	0.5025	-0.89617	0.83324	0.3908
	(1.750)	(2.420)	(-1.459)	(1.771)	
MN - NW	61.129	0.6421	-0.82059	1.4907	0.4763
	(1.416)	(2.678)	(-1.145)	(2.387)	
MN - WC **	35.806	0.42769	-0.39002	1.2589	0.4217
	(1.044)	(2.674)	(-0.7170)	(3.084)	
MT-NC	13.19	0.36	-0.27	2.3	0.4224
	(0.28)	(1.65)	(-0.33)	(2.62)	
MT-C	24.07	0.95	-1.02	1.94	0.4168
	(0.37)	(2.94)	(-0.83)	(1.89)	
MT-SE	-23.96	-0.6	1.15	0.9	0.5131
	(-0.91)	(-3.87)	(2.36)	(2.44)	
Hard Wheat Yield Equation Parameter Estimates					
State / CRD	**Intercept**	**Trend**	**Temperature**	**Precipitation**	**R2**
ND - NC	94.227	0.32133	-1.4173	0.64874	0.4029
	(3.305)	(1.685)	(-2.890)	(1.297)	
ND - NE	85.402	0.5673	-1.0613	0.47697	0.3101
	(2.285)	(2.337)	(-1.698)	(0.7834)	
ND -C	75.725	0.33886	-1.0997	1.0742	0.4323
	(2.423)	(1.669)	(-2.103)	(2.110)	
ND -EC	93.574	0.63324	-1.2613	0.60845	0.3619
	(2.415)	(2.590)	(-1.922)	(1.138)	
ND-SE	78.095	0.40425	-1.0025	0.26589	0.2333
	(1.935)	(1.803)	(-1.511)	(0.5233)	
MN-NW	70.111	0.72676	-0.88439	1.0175	0.4083
	(1.522)	(2.842)	(-1.157)	(1.528)	
MN-WC	46.37	0.61307	-0.54676	1.2211	0.3581
	(0.9857)	(2.788)	(-0.7331)	(2.189)	
MN-C	-26.752	0.20103	0.91152	0.46975	0.1508
	(-0.4797)	(0.6544)	(1.017)	(0.9343)	
SD-NC	79.998	0.36576	-1.134	0.58488	0.3396
	(1.714)	(1.710)	(-1.571)	(0.8920)	
SD-NE	36.78	0.47997	-0.47984	1.2704	0.3232
	(0.8842)	(2.576)	(-0.7205)	(2.563)	
SD-C	84.557	0.32151	-1.1035	-0.047464	0.291
	(-1.702)	(-1.289)	(-1.452)	(-0.079)	

MT-NW	15.75	0.47	0.24	1.18	0.3412
	(0.33)	(2.24)	(0.25)	(1.99)	
MT-NC	-14.82	0.15	0.24	2.98	0.4983
	(-0.35)	(0.77)	(0.32)	(3.74)	
MT-C	-9.43	0.03	0.35	1.99	0.3827
	(-0.24)	(0.16)	(0.47)	(3.20)	
MT-SW	38.92	0.27	-0.19	1.83	0.4406
	(0.95)	(1.50)	(-0.23)	(2.96)	
MT-SC	18.46	0.4	-0.29	1.56	0.2882
	(0.34)	(1.62)	(-0.29)	(1.83)	
MT-SE	40.42	0.05	-0.4	0.5	0.1593
	(1.43)	(0.30)	(-0.77)	(1.26)	
NE-NW	32	0.25	-0.25	0.96	0.4073
	(0.85)	(1.54)	(-0.39)	(2.26)	
NE-N	-43.8	0.92	0.8	0.71	0.7359
	(-1.37)	(5.37)	(1.42)	(2.11)	
NE-C	64.95	0.72	-0.82	0.07	0.3849
	(1.57)	(3.33)	(-1.14)	(0.23)	
NE-SW	19.82	0.39	-0.06	1.03	0.3494
	(0.40)	(1.65)	(-0.07)	(2.09)	
NE-S	-14.47	0.09	0.86	0.25	0.0599
	(-0.24)	(0.31)	(0.86)	(0.56)	
NE-SE	77.33	0.51	-0.69	-0.63	0.4135
	(1.78)	(2.31)	(-1.00)	(-1.93)	
KS-NW	-51.27	0.14	1.1	1.46	0.1573
	(-0.65)	(0.40)	(0.87)	(1.82)	
KS-WC	-27.91	-0.13	0.96	0.53	0.0845
	(-0.41)	(-0.39)	(0.89)	(1.05)	
KS-C	107.52	-0.02	-0.79	-0.99	0.1797
	(1.40)	(-0.06)	(-0.68)	(0.073)	
KS-NE	-52.41	0.17	1.43	-0.12	0.1345
	(-0.57)	(0.42)	(1.02)	(-0.13)	
KS-EC	108.99	0.29	-0.87	-1.42	0.3898
	(1.46)	(0.96)	(-0.78)	(-2.87)	
KS-SE	66.9	0.34	-0.33	-0.93	0.3186
	(0.96)	(1.09)	(-0.31)	(-2.55)	

Soft Wheat Yield Equation Parameter Estimates

State / CRD	Intercept	Trend	Temperature	Precipitation	R2
IL - W	56.233	1.2241	-0.24502	-0.58471	0.6816
	(1.279)	(4.483)	(-0.3298)	(-1.742)	
IL - WSW	75.505	0.93293	-0.4845	-0.61913	0.6284
	(1.783)	(3.799)	(-0.6918)	(-1.884)	
IL - ESE	35.662	0.85432	0.21217	-0.73802	0.6479
	(0.8517)	(3.77)	(0.3069)	(-2.286)	
IL - SW	80.715	0.80986	-0.55467	-0.83165	0.6176
	（1.86）	（3.643）	(-0.7916)	(-2.814)	
IL - SE	-2.2713	0.79954	0.7623	-0.62178	0.5553
	(-0.04404)	（3.272）	（0.9269）	(-1.910)	
IN - NE **	70.906	0.89601	-0.57457	-0.17975	0.6339

	（2.351）	（6.03）	(-1.111)	(-0.4213)	
IN - C **	90.46	1.0548	-0.7959	-0.36563	0.7873
	（3.339）	（9.376）	(-1.763)	(-1.292)	
IN - SW	29.112	0.76875	0.22551	-0.39652	0.4521
	（0.5295）	（3.081）	（0.2547）	(-1.101)	
IN - SC **	42.918	0.66552	-0.16107	-0.073021	0.4488
	（1.015）	（3.651）	(-0.2327)	(-0.2520)	
IN - SE	33.704	0.90967	0.013917	-0.25987	0.6554
	（0.7634）	（4.818）	（0.01932）	(-0.8592)	
KY - PUR **	4.975	0.74822	0.46648	-0.27356	0.5624
	（0.0909）	（2.577）	（0.5423）	(-1.060)	
KY - MW	63.983	0.6774	-0.40115	-0.37702	0.4075
	（0.8769）	（2.169）	(-0.3477)	(-0.8993)	
MI - C	46.362	0.7124	-0.33776	0.51998	0.3094
	（1.105）	（2.529）	(-0.4099)	（0.9605）	
MI - EC	33.645	1.3381	-0.087447	0.79063	0.6995
	（0.9666）	（5.78）	(-0.1301)	（1.771）	
MI - SW	57.557	0.88435	-0.52123	0.093666	0.4865
	（1.543）	（3.208）	(-0.7884)	（0.1458）	
MI - SC	76.68	0.88382	-0.8258	0.013682	0.4688
	（1.805）	（3.181）	(-1.081)	（0.02038）	
MI - SE	54.808	0.99427	-0.46167	0.36915	0.6047
	（1.64）	（4.657）	(-0.7414)	（0.6588）	
MO - NE **	76.348	0.74045	-0.58409	-0.51745	0.3678
	（1.543）	（2.953）	(-0.7318)	(-1.294)	
MO - E	42.048	0.54152	-0.005345	-0.47311	0.4246
	（0.9438）	（2.516）	(-0.007128)	(-1.783)	
MO - SW	95.491	0.48229	-0.96776	-0.43828	0.4027
	（2.16）	（2.27）	(-1.333)	(-1.645)	
MO - SC	38.84	0.58563	-0.10129	-0.38543	0.4907
	（1.002）	（3.128）	(-0.1553)	(-1.670)	
MO - SE **	53.13	0.18257	0.0076974	-0.89689	0.3791
	（1.803）	（0.8101）	（0.01441）	(-2.865)	
OH - NW **	11.227	0.88812	0.42239	0.55772	0.5406
	（0.258）	（4.883）	（0.5589）	（0.899）	
OH - NC **	14.405	0.95953	0.41396	0.0062829	0.6824
	（0.4492）	（6.564）	（0.71990）	（0.01602）	
OH - NE **	0.68114	0.88102	0.60395	-0.077001	0.7398
	（0.02670）	（8.242）	（1.282）	(-0.2230)	
OH - WC **	30.901	0.92016	0.24147	-0.29203	0.6805
	（0.9204）	（6.548）	（0.4161）	(-0.9234)	
OH - C **	17.405	1.0137	0.4663	-0.5433	0.8358
	（0.6465）	（11.11）	（1.031）	(-2.278)	
AR-NW	159.31	0.4	-1.91	-0.6	0.4039
	（3.41）	（2.94）	（-2.82）	（-1.77）	
AR-NC	10.49	0.16	1.81	-4.82	0.4081
	（0.12）	（0.95）	（1.21）	（-2.68）	

AR-C	-25.43 （-0.48）	0.01 （0.05）	1.09 （1.40）	-0.19 （-0.87）	0.2206
AR-SW	76.94 （1.07）	1.02 （4.65）	-0.84 （-0.79）	-0.38 （-1.29）	0.5925
AR-SC	-118.51 （-0.87）	0.24 （0.99）	1.96 （1.05）	0.7 （1.13）	0.254
AR-SE	70.18 （1.17）	0.64 （3.95）	-0.47 （-0.58）	-0.41 （-1.58）	0.5261
GA-NW	-14.44 （-0.11）	1.08 （3.02）	0.4 （0.20）	0.001 （0.00）	0.3776
GA-NC	-30.88 （-0.25）	0.51 （1.54）	0.63 （0.34）	0.34 （0.89）	0.1818
GA-C	122.22 （1.22）	0.26 （1.16）	-1.27 （-0.91）	0.16 （0.56）	0.1721
GA-SW	48.94 （0.52）	0.26 （1.35）	-0.13 （-0.11）	0.09 （0.39）	0.102
GA-SC	122.15 （1.19）	0.43 （2.00）	-1.32 （-0.94）	0.19 （0.73）	0.2633
GA-SE	126.33 （1.03）	0.87 （3.22）	-1.59 （-0.94）	0.06 （0.17）	0.3997
OR-NW	9.22 (0.12)	1.4 (5.14)	0.69 (0.51)	-0.08 (-0.21)	0.5954
OR-NC	47.07 (0.59)	-0.6 (-2.05)	-0.07 (-0.05)	3.5 (2.86)	0.4223
OR-SW	-70.33 (-0.73)	-1.3 (-3.05)	3.42 (1.93)	0.31 (0.20)	0.4188
OR-SE	34.5 (0.52)	0.06 (0.22)	1.15 (1.02)	1.22 (1.28)	0.0891
LA-NW	-300.42 (-3.71)	0.6 (4.24)	4.43 (3.88)	0.31 (1.57)	0.771
LA-NC	-117.96 (-1.05)	0.69 (3.85)	1.81 (1.14)	0.59 (2.31)	0.5645
LA-C	-263.43 (-2.45)	0.8 (4.01)	3.92 (2.65)	-0.03 (-0.14)	0.7412
LA-SW	-383.12 (-3.53)	0.11 (0.63)	5.76 (3.86)	-0.14 (-0.71)	0.5802
LA-SC	-206.25 (-1.94)	0.33 (1.77)	3.32 (2.28)	-0.19 (-1.09)	0.5754
MD-W	140.51 (2.15)	-0.46 (-2.45)	-1.45 (-1.18)	0.01 (1.80)	0.317
MD-NC	66.68 (1.26)	0.51 (2.58)	-0.004 (-0.00)	-1.18 (-3.46)	0.5472
MD-S	102.64 (1.41)	0.17 (0.85)	-0.64 (-0.55)	-0.75 (-2.36)	0.2792
MD-LES	75.81 (0.70)	0.52 (1.46)	-0.4 (-0.24)	-0.33 (-0.52)	0.1404
NY-N	94.34 (1.17)	0.7 (2.47)	-1.05 (-0.70)	-0.62 (-0.87)	0.2592

NY-C	-13.47	0.39	1.28	-0.8	0.6182
	(-0.49)	(2.94)	(2.45)	(-2.82)	
NY-SW	-62.17	0.58	1.9	-0.24	0.5398
	(-1.41)	(2.88)	(2.22)	(-0.62)	
NY-S	45.41	0.18	0.21	-0.68	0.2529
	(1.16)	(0.94)	(0.28)	(-2.32)	
NY-SE	-72.48	-0.18	2.19	0.59	0.2279
	(-1.33)	(-0.66)	(2.06)	(1.31)	
NC-NM	64.6	0.59	-0.49	-0.36	0.1842
	(0.68)	(1.84)	(-0.31)	(-1.04)	
NC-WM	-42.26	0.38	1.06	0.25	0.1414
	(-0.38)	(1.28)	(0.63)	(0.48)	
NC-CP	143.02	0.85	-1.7	-0.56	0.3631
	(1.38)	(3.10)	(-1.09)	(1.34)	
NC-NC	113.38	0.91	-1.21	-0.48	0.3447
	(0.95)	(2.95)	(-0.68)	(-1.19)	
NC-CC	84.55	0.7	-0.82	-0.16	0.2585
	(0.75)	(2.48)	(-0.50)	(-0.37)	
NC-SC	49.93	0.52	-0.35	0.04	0.1299
	(0.38)	(1.62)	(-0.19)	(0.08)	
VA-N	26.31	0.67	0.42	-0.9	0.4219
	(0.33)	(2.49)	(0.33)	(-1.75)	
VA-C	208.14	0.24	-2.19	-0.95	0.3109
	(2.62)	(0.96)	(-1.72)	(-2.53)	
VA-SW	142.11	0.97	-1.49	-1.06	0.4677
	(1.68)	(3.30)	(-1.08)	(-1.69)	
VA-S	56.51	0.3	-0.07	-0.84	0.3553
	(0.83)	(1.38)	(-0.06)	(-2.62)	
VA-SE	119.68	0.58	-1.05	-0.64	0.2572
	(1.42)	(2.17)	(-0.81)	(-1.28)	
PA-NW	97.52	0.32	-0.98	-0.41	0.2869
	(3.19)	(2.41)	(-1.72)	(-1.68)	
PA-NC	63.36	0.89	-0.68	-0.35	0.7046
	(1.97)	(5.94)	(-1.08)	(-1.31)	
PA-C	37.25	0.85	-0.06	-0.61	0.7006
	(1.08)	(5.64)	(-0.09)	(-2.55)	
PA-SW	95.84	0.62	-1.15	-0.27	0.3551
	(1.93)	(3.15)	(-1.29)	(-0.57)	
PA-SC	46.19	0.77	-0.05	-0.72	0.5796
	(0.95)	(3.92)	(-0.06)	(-2.35)	
PA-SE	5.62	0.93	0.56	-0.49	0.6206

Barely Yield Equation Parameter Estimates

State / CRD	Intercept	Trend	Temp Deviation	Precip Deviation	Precipitation Deviation squared	R2
ND - NC**	25.87*	0.72*	-3.89*	4.1*	-2.65*	0.71
	(9.06)	(5.64)	(-3.31)	(3.72)	(-2.47)	
ND - NE	24.43*	1.15*	-3.41*	3.26*	-2.31	0.75
	(8.48)	(9)	(-2.47)	(2.72)	(-1.65)	

ND - C	21.28*	0.93*	-4.56*	5.37*	-1.27	0.69
	(7.73)	(7.02)	(-3.44)	(4.25)	(-1.34)	
ND - EC	27.2*	1.17*	-3.57*	2.96*	-2.27	0.76
	(10.01)	(9.09)	(-2.67)	(2.33)	(-2.14)	
ND - SE	26.43*	0.92*	-2.87*	5.49*	-3.6	0.7
	(9.66)	(7.01)	(-2.07)	(3.56)	(-3.83)	
MN - NW	12.51	0.94	5.15	0.65	-0.44	0.66
	(1.59)	(1.03)	(2.92)	(2.28)	(-5.62)	
MN - WC	19.93	0.76	3.49	1.78	-0.4	0.69
	(2.73)	(3.83)	(4.71)	(1.79)	(-5.3)	
MN - C	21.45	0.37	2.94	1.52	-0.08	0.48
	(3.17)	(3.5)	(3.45)	(1.67)	(-2.79)	
MD-W	91.24	-0.17	-0.46	-0.02	0	0.0515
	(0.68)	(-0.39)	(-0.19)	(-0.34)	(0.32)	
MD-NC	19.12	0.23	0.52	2.65	-0.09	0.3699
	(0.28)	(0.96)	(0.46)	(0.57)	(-0.78)	
MD-S	-27.08	0.12	1.24	1.52	-0.04	0.0583
	(-0.19)	(0.32)	(0.57)	(0.25)	(-0.24)	
MD-LES	-31.64	0.54	0.91	2.74	-0.07	0.163
	(-0.20)	(1.25)	(0.45)	(0.37)	(-0.40)	
NY-N	29.31	-0.23	1	-2.28	0.08	0.1954
	(0.54)	(-1.38)	(1.16)	(-0.64)	(0.76)	
NY-C	86.14	-0.42	0.24	-4.27	0.15	0.677
	(3.65)	(-4.76)	(0.70)	(-2.35)	(2.63)	
NY-SW	-40.21	-0.57	0.43	12.44	-0.37	0.3194
	(-0.57)	(-2.25)	(0.42)	(2.22)	(-2.26)	
NY-S	101.13	0.13	-0.51	-3.44	0.09	0.1074
	(1.83)	(0.62)	(-0.59)	(-1.15)	(1.22)	
NY-SE	34.25	-0.13	0.77	-3.22	0.1	0.1468
	(0.48)	(-0.41)	(0.72)	(-0.68)	(0.81)	
VA-N	92.09	0.4	-1.02	3.98	-0.14	0.2418
	(0.81)	(1.06)	(-0.57)	(0.68)	(-0.91)	
VA-C	109.62	0.22	-1.09	2.92	-0.08	0.2239
	(1.14)	(0.72)	(-0.73)	(1.00)	(-1.27)	
VA-SW	8.59	0.22	0.58	1.63	-0.05	0.1786
	(0.08)	(0.83)	(0.46)	(0.20)	(-0.29)	
VA-S	173.03	-0.08	-1.29	-1.78	0.03	0.1251
	(1.72)	(-0.25)	(-0.82)	(-0.58)	(0.39)	
VA-SE	105.47	-0.07	-0.76	1.82	-0.05	0.0309
	(0.81)	(-0.22)	(-0.48)	(0.25)	(-0.28)	