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Determinants of Adoption of Fusarium Head Blight Management Techniques in Wheat

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Fusarium head blight (FHB), commonly known as scab, is a disease affecting all classes of wheat and other small grains. We detect, and estimate the effect of, factors on the choice of number of technologies wheat farmers in North Dakota and Minnesota adopt for scab management. Farm characteristics and availability of technical information about best scab management practices are important variables. Availability of technical information and land ownership increase the odds producers concentrate scab management programs into fewer techniques. Increased wheat acreage on owned land has the opposite effect.

Key words: farm characteristics, fusarium head blight, ownership, poisson process, technology adoption

Fusarium head blight (FHB), commonly known as head scab, is a fungal disease affecting all classes of wheat and other small grains. This fungal disease can rapidly damage a crop within a few weeks of harvest. Physical damage from FHB is multifold: reduced yields; discolored, shriveled kernels; grain contamination with mycotoxins (primarily vomitoxin); and reduction in seed quality, each leading to economic loss. Between 1993 and 2001, estimated total yield loss from FHB was approximately 500 million bushels of wheat and 124 million bushels of barley, with North Dakota and Minnesota incurring over 80% of these losses (Nganje et al., 2004). FHB was a minor problem across most of the United States in 2007 and 2008 (Lilliboe, 2008); however, serious disease outbreaks occurred both years in parts of Nebraska and Kansas. In 2007, FHB damaged about one-third of the wheat grown in Nebraska and was considered by local experts to be the worst outbreak in Nebraska in 22 years (Mengistu et al., 2007). The greatest damage occurred in eastern, south central, and southwestern Nebraska, where there were reports of

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mycotoxin levels high enough to incur elevator dockages of up to $0.036/kg (= $1.00/bu). Epidemics continued in 2009, with soft red winter wheat greatly impacted in the southeast and mid-south in 2009 (Lilleboe, 2009). Adoption of FHB management technologies remains a persistent need, since severe cases of FHB continue to occasionally occur in the Upper Great Plains of the United States and elsewhere in that nation (Lilleboe, 2010). A comprehensive summary of the frequency and magnitude of epidemics in the United States has recently been provided (McMullen, et al., 2012).

Genetic, chemical, cultural and biological methods are available to manage FHB damage. Conventional FHB damage management practices include planting varieties that have resistance to FHB; cultural practices, such as crop rotations within the same crop field or planting varieties with a range of flowering dates; and chemical applications, such as fungicides (McMullen, Jones, and Gallenberg, 1997). Multiple studies (Champeil et al., 2004; Yuen and Schoneweis, 2007; McMullen et al., 2008) indicate adopting a combination of FHB management methods during the same season can reduce the incidence of diseased grain.

A farmer's decision about the number of techniques to adopt from a portfolio of FHB damage management strategies depends on several factors. For instance, as shown in McMullen, et al. (2012), local conditions matter. In addition, Jorgensen et al. (2008) indicate farmers may rely on experience or advice as sources of information when making decisions about disease control on wheat. A recent survey of wheat growers in North Dakota and Minnesota shows a variety of combinations of FHB damage management techniques being used and multiple sources for that management information (Ransom, McKee and McMullen, 2010). Hence, although communication about FHB damage management strategies by Cooperative Extension Service personnel, professional sources, and peers does occur, a gap exists in our understanding about what influences affect the adoption of FHB damage management practices.

In this paper, we assess how farm characteristics, farmer human capital, and farm location affect the number of FHB damage management techniques selected by a farmer for use. Specifically, we detect and estimate the effect of these factors on the choice of the number of technologies wheat farmers in North Dakota and Minnesota adopt for FHB damage management. This analysis provides insights into the role played by social and farm-specific factors in the FHB management portfolio adoption. We find that farm structure, levels of farmer human capital, and farm location affect the likelihood a given number of FHB management techniques are adopted.

Theoretical Background

In this paper, we classify factors affecting farm technology adoption as related to farm structure, farming environment, and human capital. Count data are used to observe characteristics of FHB management technique adoption. In so doing, we assume adoption of one technology does not affect the likelihood another is adopted. We also assume farmers adopt FHB management technologies up to the point where the benefit of the next adoption is equal to its associated costs; adopting more technologies only has value when it generates at least as much profits as the costs associated with the technology and if the farmer is aware of how to obtain those benefits from the technology. A farmer is assumed to be an adopter of only one combination of techniques. We also assume that any given FHB management technique cannot be partially adopted; that is, a farmer cannot somehow choose to obtain a partial ability to use a given technique. Each technique can be practiced more or less proficiently, but this is different from attempting to use the technique.

Many studies exist in which a farmer's agricultural production technology adoption decision is considered a dichotomous variable. In these studies, the level of adoption is measured and the determinants of adoption are detected and measured statistically. When a portfolio of choices is considered, however, it is the adoption of the combination of technologies, together with any existing complementarities, that matters.

Instead of explicitly considering the complementarities of the various technologies employed, an alternative is to merely consider the observed number of technologies adopted, with the count serving as a measure of the complexity of FHB management strategies desired by a farmer (Lohr and Park, 2002; Park and Lohr, 2005; Sharma, Bailey and Fraser, 2011). Hence, adoption of one or more technologies can be related to information diffusion rather than the sequence in which previous technologies were adopted.

Traditional farm production functions in microeconomics consider the quantity of land used when technology adoption considerations are made. Feder (1980) demonstrates that adoption of a production technique should be considered in light of its output effect, which is a function of the quantity of land used. In particular, Feder (1980) shows that differences in technology adoption were related to differences in farm size. Just and Zilberman (1983) conclude farm size and land allocation play a major role in the technology adoption decision. Feder (1982) modeled the adoption of interrelated technologies and showed that variations in returns to farm scale affect technology adoption decisions. Just et al. (1980) show that a minimum scale of farm may be required in order to even attempt to adopt a technology. A relationship between farm size and use of specific technologies on targeted crops is shown in other research (Traxler and Falck-Zepeda, 1995; Fernandez-Cornejo, Beach, and Huang, 1994). We expect constant returns to scale will hold in FHB management in wheat production. Farmers with larger operations, in terms of acreage, will be able to reduce long-run average costs associated with fungicide application, crop rotation, alternate planting dates, and planting multiple plant varieties by virtue of having more acreage over which to spread the fixed and variable costs of technology adoption. Numerous studies also describe the interaction between land and labor, which we assume has relevance to our study.

The economic threshold concept suggests rational farmers will not adopt FHB management techniques until the cost of adopting the technique is at least equal to the increased crop value derived from applying the technique. Direct, physical benefits of FHB management include increased yields and decreased incidence of vomitoxin (Pirgozliev et al., 2008; Paul et al., 2010). Financial benefits include increased profitability for both the individual farmer and neighboring farmers. Both physical and economic benefits are considered in this study.

Ownership is a key feature of farm structure, but not necessarily a determinant for adopting disease management strategies whose benefits last one season. Asset ownership is an important feature in discussions about adopting technologies in developing regions, where land and water management technologies may be shunned when insecure property rights exist (Shiferaw, Olello and Reddy, 2009). In the developed world, contracts more or less completely spell out the obligations and benefits of asset use. Studies (Prazan and Dumbrovsky, 2011; Posthumus and Morris, 2010; Prager and Posthumus, 2010) indicate land ownership is an important feature for adopting long-term output management strategies, such as soil conservation practices, and that unassigned, or incompletely assigned, property rights reduce the incentive for land managers to adopt risky technologies. Lichtenberg et al. (2010) show that land ownership generates more incentives to adopt technologies than does land rental. Since the most valued benefits of FHB management occur during the seasonal life cycle of the wheat or barley plant, we do not expect land ownership to directly affect the number of FHB management strategies employed. Alternatively, if FHB management practices are capitalized into land values, farmers who own greater fractions of the land they cultivate may have different FHB management preferences from those who rent their land.

The relationship between human capital and technology adoption has been well-studied. Griliches (1957) shows adoption of hybrid corn varieties was related to the ability of farmers to perceive the enhanced profitability of these over native varieties of corn. Wozniak (1993) empirically measures the relationship between technology adoption and information acquisition. He concludes that information aids the process of early adoption of technology, as well as late adoption, and that information obtained from multiple sources has a complementary effect on technique adoption decisions. An interesting observation in Wozniak's study is that information from public and private sources is adopted by different audiences. Highly technical information from the Cooperative Extension Service could be of use to highly educated and larger scale operators who can process the information on their own. In contrast, private information providers might disseminate "partially processed technical information" to their clientele.

Schooling, age, and off-farm experience, as well as returns to scale affect the joint adoption of complementary technologies (Huffman and Mercier, 1991). Dorfman (1996) concludes farmer and farm characteristics can be used to target technology adoption education programs by Cooperative Extension personnel or other agencies. Foster and Rosenzweig (1995) conclude learning from technical sources and from peers affects the technology adoption decision by farmers, suggesting a role for both the Cooperative Extension Service and farm organizations in disseminating information about new technologies. The importance of learning from community is reinforced by Abdulai and Huffman (2005) who show that the likelihood of technology adoption depends on the proximity of a farm to that of other farms where the same technology is used and contact with Cooperative Extension personnel.

Finally, physical features of the farming environment affect technology adoption. Differences in climate and soil conditions affect FHB incidence. Xu (2003) indicates climactic conditions, including heat and moisture, affect overall FHB incidence and the likelihood of one fungal strain being prevalent in a given area. Gilbert and Tekauz (2000) and Dill-Macky and Jones (2000) observe field conditions and crop rotation patterns affect Fusarium levels. Finally, Miller et al. (1998) conclude the cropping history of a cultivated field and nearby farm fields, as well as the susceptibility of plant variety chosen by the farmer influence FHB incidence. Also, McMullen, et al. (2012) show the prevalence of FHB varies by region and over time. These conditions suggest demand for FHB management inputs vary within a given geographic area.

Methods

Behavioral and empirical models

We assumed farmers maximize wheat production profits, π_i, while managing FHB subject to a production constraint, $Y_i \leq f_i(X_i)$, employing a set of FHB management inputs X_i. Each farmer faces output prices P and input costs w. Profit obtained from adopting the i^{th} FHB management practice is defined as:

$$\pi_i(X_i) = Pf_i(X_i) - wX_i - C_i, \qquad (1)$$

where C_i are the fixed costs of using FHB management technique i. Farmers assess the benefits from each FHB management input. They adopt the technology if perceived benefits from that technology are at least equal to its associated expenses (Hellerstein and Mendelsohn, 1993). The portfolio of FHB management inputs comprises the farmer's FHB management system. Hence, the question of interest is what factors affect the complexity of the FHB management system, X_i, as measured by the number of FHB techniques adopted by the farmer.

The dependent variable of our analysis, X_i, was measured by the count of the number of FHB management techniques adopted by the farmer. For example, the observation was equal to one if that was the total number of FHB management technologies adopted by the farmer. Since a count is an indivisible quantity, statistical methods which estimate a continuous value for a dependent variable are inappropriate. A variety of models are used to measure discrete dependent variables including the Poisson (Hellerstein and Mendelsohn, 1993; Isgin, 2008), the negative binomial (Lohr and Park, 2002; Park and Lohr, 2005), or a probit or logit model (Huffman and Mercier 1991; D'Souza et al., 1993; Fernandez-Cornejo, Beach, and Huang, 1994; Kasenge, Taylor and Bonabana-Wabbi, 2006; Mauceri et al., 2007).

We assumed the number of FHB management techniques adopted by the farmer occurs as a Poisson process. Each producer is assumed to adopt a number of technologies at a constant rate, μ, over time, but we allow the intensity of adoption to vary across farmers as a function of covariates z. In other words, the number of adopted FHB management techniques, x_i, is assumed to be conditionally distributed on a k-dimensional vector of covariates, $z_i' = [z_{1i},\ldots,z_{ki}]$, and parameters β such that $E[x_i|z_i]=$ variance$[x_i|z_i]=\mu(z_i, \beta)$. Under this assumption, the distribution of x_i, given x_i, is Poisson: $Pr(X_i = x_i|z_i) = \frac{\mu_i^{x_i}\exp(-\mu_i)}{x_i!}, x_i = 0,1,\ldots,n$. Using this formulation, we compared the effect of the independent variables at different levels of FHB management technique adoption intensity. We further assumed x_i varies over the N observations as a linear function of observed characteristics, $\boldsymbol{z}_i$, and unobserved characteristics, ε_i. Finally, in order to assure adoption of a nonnegative number of FHB management techniques, we assumed the linear relationship to be $E[x_i|z_i]=$ variance$[x_i|z_i]=\exp(z_i'\boldsymbol{\beta})$ In this model, $\boldsymbol{x}_i$ is comprised of farm-level observations of farm structure, farmer human capital and the physical location of the farm.

Then the regression model is $\log(x_i) = E(x_i|\boldsymbol{z}_i) + \varepsilon$

$$\log(x_i) = (\boldsymbol{z}_i'\boldsymbol{\beta}) + \varepsilon \qquad (2)$$

where $E(\varepsilon|z) = 0$, by assumption and will implicitly be heteroskedastic. The log transformation was taken in order to estimate the vector $\boldsymbol{\beta}$ is found by maximizing the likelihood function. Estimates are generated using SAS, PROC GENMOD.

It is common for the $E[x_i|z_i]=$ variance$[x_i|z_i]$ assumption to be violated in cross section data. Cameron and Trivedi (1998) indicate that when the variance is unequal to the mean, the Poisson regression model parameter estimates remain valid since the means are still estimated consistently. A test for equidispersion revealed that the variance was less than the mean. To correct for this condition, common practice is to adjust the standard errors. Hence, our standard errors were modified to be robust for underdispersion.

Data Description

Observations of the variables in our theoretical framework were obtained from a postal questionnaire sent to North Dakota and Minnesota wheat growers (Appendix 1). The questionnaire was sent to 5150 wheat producers in North Dakota and Minnesota U.S. The sample of producers was drawn from the National Agricultural Statistics Service (NASS) list of North Dakota and Minnesota wheat producers with at least 100 acres of wheat who reside in areas of North Dakota and Minnesota where FHB is considered likely to occur.

Table 1. Sample Statistics of Variables Used in Estimated Model

Variable	Mean	Minimum	Maximum	Standard Deviation
Wheatyield	1.949	0.000	5.000	1.192
Extension	5.325	0.000	15.000	4.036
Empl	6.455	1.000	25.000	5.226
Benefits	2.634	0.000	3.000	0.658
Ownership	2.355	1.000	4.000	0.913
Oldpubs	1.546	0.000	11.667	3.112
Farmorg	0.500	0.000	1.000	0.500
Degree	0.785	0.000	1.000	0.411
Twoyrinfo	0.110	0.000	1.000	0.313
Fouryrinfo	0.035	0.000	1.000	0.185
Region 1	0.108	0.000	1.000	0.310
Region 2	0.100	0.000	1.000	0.300
Region 3	0.121	0.000	1.000	0.327
Region 4	0.137	0.000	1.000	0.344
Region 5	0.151	0.000	1.000	0.358
Region 6	0.078	0.000	1.000	0.269
Region 7	0.303	0.000	1.000	0.460

Responses were received from producers in the following counties: Clay, Kittson, Mahnomen, Marshal, Norman, Penning, Polk, Traverse, and Wilkin (Minnesota); Barnes, Cass, Cavalier, Grand Forks, Griggs, Nelson, Pembina, Ramsey, Ransom, Richland, Sargent, Steele, Stutsman, Traill, and Walsh (North Dakota). NASS mailed the questionnaires to the producers. Respondents mailed completed questionnaires directly to the NASS North Dakota Field Office. All completed questionnaires, with no identifying information, were given to the authors at North Dakota State University. We received 1092 responses; 503 were usable for estimating our statistical model. Table 1 shows sample statistics from the 503 responses for the variables used in the statistical model.

Tables 2, 3 and 4 summarize some of our observations about FHB management technique adoption. Technique (3) (rotate crops) was the most commonly used FHB damage management technique among North Dakota and Minnesota wheat farmers who responded to the survey (Table 2). Despite the popularity of the technique, it was generally used with other techniques. Table 3 shows that 60% of respondents use two or more FHB management techniques. Survey respondents adopted an average of 2.6 techniques, but responses ranged between zero (0.2% of responses) and five techniques (9.4% of responses). The most common combination of techniques involved rotating crops, growing resistant varieties, and applying fungicide (Table 4). The other 23 observed combinations of techniques were much less frequently observed, suggesting general agreement on effective treatment programs. We observed that the selection of FHB management techniques is correlated in some cases. The Pearson correlation coefficient was statistically significant and positive for techniques (1) and (4), (1) and (5), (2) and (4), and statistically significant and negative for techniques (2) and (3). In no case was the magnitude of the correlation great; the largest value of any combination was less than 0.16, supporting our assumption of independence of technique adoption decisions.

Table 2. Distribution of FHB Damage Management Technique Adoption

Technique	Frequency
(1) Grow resistant varieties	5%
(2) Apply a recommended fungicide at heading	12%
(3) Rotate so that I never grow wheat immediately following another small grain or corn crop	52%
(4) Grow varieties that differ in flowering dates	11%
(5) Stagger planting dates so that not all fields flower on the same date	22%

Table 3. Frequency of FHB Management Techniques Adopted per Respondent

Number of Techniques	Frequency
0	0%
1	9%
2	30%
3	41%
4	11%
5	9%

Table 4. Five Most Frequently Adopted FHB Management Technique Combinations

Technique Combination	Marginal Frequency	Cumulative Frequency
1, 2, 3	26%	26%
1, 3	13%	40%
1, 2	8%	48%
1, 2, 3, 4, 5	8%	56%
2, 3	6%	62%

We also observed a variety of farm sizes, farming environments, and amounts of human capital possessed by farmers. In this sample, 21% of farms were larger than 5000 acres, 8% were less than 1000 acres; the mode response was 1000-2000 acres (35% of respondents). The most common fraction of land planted as wheat was 25% and 50% (77% of respondents). The most common wheat acreage planted during this period was less than 500 acres (38%of respondents), but 37% of respondents reported planting 500 to 1000 acres. Respondents indicated the fraction of cultivated land they own, with most owning less than half of their cultivated land.

The number of farm employees also varied. The largest group of respondents (46%) indicated they worked full time, hiring occasional help during key times. On the other hand, 27% of respondents indicated they hired two or more full time persons on a permanent basis.

Respondents anticipated a variety of benefits from using FHB management techniques; more than one could be selected. The most common was increased yield (91%). Eighty-six percent anticipated increased profitability from using these practices, and 74% anticipated fewer sale discounts at the elevator due to vomitoxin. A minority was interested in preventing spread to other farms (22%) and about 13% either did not think the benefits justified the costs of using these techniques or were unaware of effective FHB management practices.

Respondents obtained their information about FHB management from a variety of sources. Sixty-nine percent used Cooperative Extension resources at least once every three years; 64% used some sort of professional resources; and 49% used both. We asked respondents to rank the relative importance Cooperative Extension, professional, and other sources of information on FHB management techniques. Five hundred and three respondents provided these rankings. The average ranking for Cooperative Extension resources was highest in 72% of the responses; professional resources were ranked highest by 20% of the respondents. "Crop consultants" was ranked the most important single source of information on FHB management. Publications prepared by the Cooperative Extension service and Cooperative Extension meetings featuring FHB management techniques were the second and third most important sources on information. Forty-four percent of the respondents were members of farm organizations providing information about best practices for raising wheat.

About 36% of responding producers completed a four-year college degree or more, and 50% of these obtained a degree in an agriculture related field. The largest group of respondents, 33%, had a two-year degree; 30% had completed high school or its equivalent.

Respondents identified the county in which they principally plant wheat. Responses were obtained from all the selected counties. Sixty-four percent of responses were from North Dakota.

The Dependent Variable

Following Lohr and Park (2002), we constructed a dependent variable: the number of adopted FHB management practices. The observed value is based on response to the question "Which of the following do you consistently practice in order to reduce the amount of damage by FHB?" Respondents selected from five techniques for managing FHB. These were (1) "grow resistant varieties," (2) "apply a recommended fungicide at heading," (3) "rotate so that I never grow wheat immediately following another small grain or corn crop," (4) "grow varieties that differ in flowering dates," and (5) "stagger planting dates so that not all fields flower on the same date." Respondents were free to select as many techniques as they believed applied to their situation. We left the meaning of the term "consistently" to the respondent's interpretation. The question was unaccompanied by statements suggesting or indicating the most effective combination of management techniques. Also, no statements about the most effective number of management techniques were made. Hence, any combination of one, two, three, four, or five techniques was regarded as equally feasible for FHB damage management in this study.

The Independent Variables

According to our theoretical framework, a portion of the FHB management technique adoption decision is related to the fixed costs of managing FHB. The fixed costs of adoption include obtaining information, purchasing associated equipment and materials, and time spent either personally using the technology or the associated costs of having someone else use the technology on their farm. We constructed variables indicating the total farmed acreage, average annual wheat acreage, and fraction of total acres farmed as wheat.

To detect the importance of land ownership to the FHB management technique adoption decision, we observed the fraction of cultivated land that was owned by any given farmer. The variable ownership (1=yes; 0=no) is the observed response.

The economic benefits anticipated by the farmer from adopting FHB management techniques were also observed. We observed whether farmers anticipate any of the following benefits from using FHB damage management techniques: increased yield, increased profitability, decreased mycotoxin, prevention of FHB diffusion to neighboring farms, or no benefits at all. Given our constant returns to scale assumption, we considered that benefits will be more important to respondents if they have greater wheat acreage. The variable wheatyield is the interaction of whether a farmer anticipates an increased yield benefit (1=yes; 0=no) and the average annual wheat acreage of the farmer (Table 1). This variable has a nonzero value when a wheat farmer indicates an anticipated increased wheat yield when adopting FHB management techniques.

We also assumed the size of the farm workforce employed on the farm affects the number of FHB management techniques adopted. Employees on the farm may be directly hired by the farmer, hence we inquired as to the number of employees on the farm. Alternatively, temporary employment may be obtained on the farm by specialty service providers, such as fungicide applicators or crop advisors. We observed whether farmers use these services. We also considered whether the effect of hiring employees depends on farm size. The variable empl is the interaction of the observed total acreage and a response to the question "how many employees do you have on your farm?" Hence, the largest values for this variable indicate three or more employees on five thousand or more farmed acres.

We observed a variety of influences on the human capital used to execute the FHB management technique adopted. It may be that information sources that are the most familiar to the farmers have the most influence on adoption. We asked respondents to indicate their level of use of three categories of information sources: professional groups which provide expertise on FHB management practices, Cooperative Extension resources providing similar information, and a variety of other information sources which may provide FHB management expertise. We asked respondents to rank the importance of a variety of activities where respondents had direct contact with Cooperative Extension, professional, or other sources of information about FHB management practices. The variables extension, professional, and other are the average rank (1 being most important, 15 is least) of the activities associated with each source of information. We also asked whether the respondent was a member (1=yes, 0=no) of a farm organization that provides information about wheat husbandry; the variable farmorg contains the response.

We also observed whether education in general affects the FHB technique adoption. The variable degree is the response to the question "what is your highest level of education?" with possible answers ranging from high school diploma (or equivalent) to having completed graduate studies. Correlation analysis can be used to suggest whether use of specific sources of information is related to education level. The dummy variables twoyrinfo and fouryrinfo interact two-year degree and four-year degree holders with specific internet sources of information about FHB management practices (FHB risk or management listserv messages to their cell phone, and viewing information to assess FHB risk or management on Youtube, respectively). Hence, a value of one for the dummy variables twoyrinfo indicates a two-year college graduate considers cell phone messages about FHB management activities important. A value of one for the dummy variable fouryrinfo indicates a four-year college graduate considers Youtube videos about FHB management important. We also considered the value of professional sources of information to non-degree holders. Oldpubs is the interaction of non-degree holders with ranking publications from private companies about FHB management activities as important. Hence, a high value of oldpubs would indicate a respondent with no college education ranks publications from professional sources as highly important when compared with other professional and Cooperative Extension sources.

Lastly, our theoretical framework asserts variations in physical characteristics in farming operations, as related to climate and soil quality, will affect the choice of FHB management techniques. The regions in North Dakota and Minnesota where FHB is likely to occur cover much of each state's geography. As a result, variations in climate, crop production practices, and support infrastructure for various FHB management techniques occur. To proxy for these variations, we observed the geographic region where farmers cultivate most of their land. Regions are observed as groups of counties. The first six regions are clusters of counties adjacent to the Red River, which forms the border of North Dakota and Minnesota. Region 1 is Pembina and Walsh counties; region 2 is Grand Forks and Traill counties; region 3 is Cass and Richland counties; region 4 is Marshall and Kittson counties; region 5 is Polk, Pennington and Norman counties; region 6 is Clay, Wilkin and Traverse counties. Region 7 is comprised of all other counties observed in North Dakota (Barnes, Cavalier, Griggs, Nelson, Ramsey, Ransom, Sargent, Steele, and Stutsman). Each region is represented in the statistical model by a dummy variable. Region 7 is dropped from the regression; its associated observations are used to estimate the intercept for the model (Suits, 1957).

Results

Statistical analysis of the relationship between the number of FHB management techniques adopted and the determinants of adoption showed that, relative to no techniques being adopted, farm size attributes, farm environment, human capital possessed by farmers, expectation of benefits from technique use, and geographic location are significant determinants of the technique adoption decision. We first tested

The coefficients on farm structure-related variables show whether farm size, land use, and land ownership affect the number of FHB management techniques adopted. The variable wheatyield is the interaction of average annual wheat acreage and an anticipated increase in wheat yield from using FHB damage management techniques. The estimated coefficient was positive and significant. The interpretation of this variable is as follows. The log increase in the number of FHB management techniques is 0.10, or approximately one technique, if a farmer were to increase their average annual wheat acreage from a range of between 500 and 1000 to between 1001 and 1500 acres. We noted that, in terms of the estimated slope coefficients, the importance of wheatyield was relatively small in our sample - human capital sources and geographic location mattered more to the FHB management technology adoption decision. This result suggests education efforts are more important than acreage endowments in determining the adoption of FHB management practices. We also noted that farm size, measured as total acreage farmed or total wheat acreage farmed, by itself, does not significantly affect how many techniques are adopted; only when combined with the expectation of benefits does farm size matter in our sample. Note, however, that anticipated benefits alone also affect the FHB management technique adoption decision; the estimated coefficient of benefits is positive and significant. This intuitive result could simply mean that farmers are strongly rational economic agents, all else equal, when determining which techniques to adopt.

We found that land ownership has no significant effect on the number of management techniques selected; the variable ownership is not significant. This is consistent with how the benefits of using management techniques are consumed: management techniques are chosen, applied, and their benefits realized, within a single season. We were unable to find any combination of variables involving land ownership that are significant or improve the fit statistics of the model. This implies existing land rental agreements may adequately share the risk of loss from FHB incidence between owners and users of the land.

The farm environment affects the number of FHB management techniques farmers adopt; the variable empl was negative and significant. The interpretation of this variable is as follows. The change in the log number of FHB management techniques is -0.01, or an increase of slightly less than one technique, if a farmer were to increase their total acreage from a range of between 1000 and 2000 to between 2001 and 3000 acres. Alternatively, the change in the log number of FHB management techniques is slightly less than one technique if a farmer were to hire one more full time person. This indicates operating on greater acreage, having more employees, or both, tends to substitute for FHB management techniques and does so at an increasing rate as acreage or labor force grows.

Table 5. Estimated Results of Poisson Model

Parameter	Estimate	Standard Error	
Intercept (Region7)	-0.94	0.187	***
Region1	-0.012	0.043	
Region2	0.211	0.049	***
Region3	-0.021	0.049	
Region4	-0.027	0.047	
Region5	0.078	0.042	*
Region6	-0.053	0.082	
$D_{wheatyield}$	0.098	0.025	***
Extension	0.008	0.004	**
Empl	-0.011	0.006	**
$D_{benefits}$	0.196	0.043	***
Ownership	-0.008	0.015	
$D_{oldpubs}$	0.027	0.023	
$D_{farmorg}$	-0.084	0.04	**
D_{degree}	0.224	0.168	
$D_{twoyrinfo}$	0.161	0.039	***
$D_{fouryrinfo}$	0.132	0.057	**

*Note: ***, **, * denote significance at the 1%, 5%, and 10% levels, respectively.*

We observed that a number of factors related to farmer human capital affect the number of FHB management techniques a farmer adopts. We tested whether education level affects the number of adopted techniques in at least three ways. First, we observed differences in respondent education level. Second, we observed that farmers with different levels of education ranked the same sources of information differently. Third, we observed differences in preference for the mode of information distribution in the data.

First, we observed education level alone does not affect the number of FHB management techniques farmers adopt. The variable degree refers to the level of education completed. The estimated coefficient was not significant. In addition, earning an agriculture-related degree was not statistically significant.

Second, we did not observe any significant relationship between farmers without any college education and the effect of information from Cooperative Extension, professional sources, or media sources on how many FHB management techniques are adopted. The estimated coefficient of the dummy variable oldpubs was positive, but statistically insignificant. No other considerations of farmer education level and information sources had greater significance.

Third, we observed that the mode of information delivery affects the FHB technique adoption decision differently for farmers who have completed two years of college than those who have completed four years of college. Farmers who had completed two years of school had significantly greater adoption of FHB management techniques when they receive information about FHB risk or FHB management through listserv messages to their cell phone. We note the magnitude of the variable twoyrinfo is in the middle range of any estimated effect regressors. Farmers who had completed four years of college adopted about one more technique when they received information about FHB risk or FHB management through YouTube, as demonstrated by the statistical significance of the dummy variable fouryrinfo. Therefore, based on our results from the twoyrinfo and fouryrinfo variables, we assert the mechanism whereby education affects the FHB management technique adoption decision is related to how college education affects preferences for how the information is received from the source.

Participating in farm organizations that promote best practices for raising wheat affects FHB management practice adoption. The dummy variable farmorg was negative and significant. The estimated coefficient of the variable can be interpreted as follows. The log change in number of adopted FHB management techniques is -0.08, or an increase of less than one technique, if the farmer joins a farm organization that promotes best practices for wheat production. Given that these organizations use professional, Cooperative Extension, and media sources for their identifying best practices for raising wheat, the apparent effect of these organizations on adoption behavior is to complement the original source of the information by encouraging FHB management technique adoption.

The perceived importance of the information source also affects the number of FHB management techniques adopted. When asked to rank the importance of FHB management information from the Cooperative Extension, professional or media sources the average respondent ranked Cooperative Extension highest. Average rankings of these sources were 5.3, 8.4 and 9.2, respectively (1 being most important, 15 is least). Fifty-six percent of respondents had attended field days that discussed or demonstrated FHB management control strategies. Also, 51% had attended Cooperative Extension meetings discussing FHB control at least every other year. The estimated change in the log of adopted FHB management techniques is 0.01. Although this is the regressor with the smallest positive effect, we found no significant effect from professional or media sources. We note that if a portion of the information provided by professional or media sources comes from Cooperative Extension, the economic and statistical significance of information sources other than Cooperative Extension should be expected to be relatively low.

Finally, we observed geography affects the number of FHB management techniques adopted. The regional dummy variables represent clusters of North Dakota and Minnesota counties adjacent to the Red River (regions 1-6) and elsewhere in eastern North Dakota (region 7). Region 7 was dropped from the regression and the associated observations were used to estimate the model intercept. The intercept is negative and statistically significant. The region 2 and region 5 coefficients were positive; indicating that, on average, farmers will adopt more techniques in these regions relative to farmers elsewhere in North Dakota. Furthermore, the counties in regions 2 (Grand Forks and Traill counties, North Dakota) and 5 (Polk, Pennington, and Norman counties, Minnesota) are contiguous, reinforcing the geographic heterogeneity of factors affecting the FHB management technique decision.

Summary and Conclusions

A variety of environmental, farm structure, and farm input factors affect the complexity of an FHB management program. We found that farm size has no direct effect on technique adoption, but becomes relevant when expected management benefits are clearly perceived. Hence, economies of scale alone are insufficient to affect FHB technique adoption; the economic benefits must be clearly perceived by the private farmer within their own operations. We also found that the farmer does not capitalize the benefits of adoption, indicating that land ownership is unlikely to affect the number of FHB management techniques adopted. This suggests that current farm lease agreements may adequately allocate this risk between owners and cultivators. It also suggests that consolidations of wheat farms alone will not have a negative effect on FHB management efforts.

The mix of farm inputs matters in the selection of FHB management techniques used, but our sample suggested this is most strongly the case for large acreage farms; greater numbers of employees tends to increase the number of techniques adopted, all else equal. This suggests the presence of economies of scope in FHB management—having more employees that can perform more tasks tends to increase the complexity of the FHB management program adopted by a farmer.

Human capital is also an important determinant of the complexity of FHB management programs. Although educational attainment alone is not a significant determinant of the number of techniques adopted, it does affect the preferred information source and the preferred mode of obtaining information about FHB risk and management. Farmers recognize information from the Cooperative Extension Service as a significant determinant of their FHB management choices, as well as membership in farm organizations that discuss best practices for raising wheat. At a minimum these results indicate an important role for education programs about FHB risk and management as well as the importance of farmers finding forums for exchanging information about how they have made their FHB management decisions. The fact that the Cooperative Extension service and the farm organization variables are significant, while the professional variable is not, suggests there are public good attributes to selecting FHB management techniques and may justify continued investment in these resources.

Environmental factors affect the complexity of FHB management programs. Wheat growers in portions of the Red River Valley will adopt more FHB management techniques than those outside the Valley. The variety of soil and climate conditions in areas within and outside the Valley must be considered when selecting FHB management techniques. More generally, this indicates that farmers must be aware of local environmental characteristics when consuming information about plant disease management techniques.

Appendix 1

Questionnaire for adoption of Fusarium head blight (Scab) control practices in wheat
Please circle the letter of your best answer, unless specified otherwise.

1. How many total acres do you farm?
   a. <1000
   b. 1000-2000
   c. 2001-3000
   d. 3001- 5000
   e. > 5000
2. What percent of the land that you cultivate do you own?
   a. 0-25%
   b. 26-50%
   c. 51-75%
   d. >75%
3. What has been your average annual wheat acreage during the past five years?
   a. Less than 500 acres
   b. 500-1000 acres
   c. 1001-1500 acres
   d. 1501-2000 acres
   e. More than 2000 acres
4. What fraction of the acres which you farmed in the last five years has been planted as wheat?
   a. 0%
   b. 25-50%
   c. 50-75%
   d. >75%
5. In what county do you principally grow wheat? ______________________
6. In the past five years, how frequently has Fusarium head blight (Scab) been a problem on your farm?
   a. Once in 5 years
   b. Twice in 5 years
   c. Three times in 5 years
   d. Four times in 5 years
   e. Every year
   f. Never

7. Which of the following do you consistently practice in order to reduce the amount of damage by scab? (select all that apply)
    a. Grow resistant varieties.
    b. Apply a recommended fungicide at heading.
    c. Rotate so that I never grow wheat following another small grain or corn crop.
    d. Grow varieties that differ in flowering dates.
    e. Stagger planting dates so that not all fields flower on the same date.
8. What benefits do you expect from scab prevention *practices*? (select all that apply)
    a. Increased yield
    b. Increased profitability
    c. Reduced levels of DON so less discounts at the elevator
    d. Prevention of spread of disease to neighboring farms
    e. Do not think the benefits of current practices justifies the cost
    f. Unaware of any effective control practices
9. Which best describes your use of fungicides to control scab?
    a. I spray every year, all varieties regardless of the level of resistance of my varieties or environmental conditions.
    b. I spray only the most susceptible varieties every year and the more tolerant varieties when conditions seem very conducive to scab development.
    c. I spray only when the weather seems conducive to scab development.
    d. I spray when the Scab Prediction Model indicates that there is a high risk of scab infection.
    e. I spray only when my crop consultant suggests that I should spray.
    f. I spray only when my agriculture retailer suggests that I should spray.
10. Do you hire a custom applicator when you apply fungicide for scab control?
    a. Always
    b. Never
    c. Sometimes to allow for more coverage
    d. Only when conditions are not favorable for a ground application, then I hire a plane.
    e. I have never applied fungicide for scab control
11. Have you attended field days which discussed or demonstrated FHB management control strategies?
    a. Yes
    b. No

12. How often do you attend a meeting sponsored by the extension service where scab control is discussed at least as part of the agenda (ie. Best of the Best, or County Crop Improvement meetings, etc.)?
    a. More than 1 a year
    b. Every year
    c. Every other year
    d. Once in three years
    e. Hardly ever
13. Please rank the following sources of information about scab development on small grains and its control (1 being the most important, 15 the least important):

		Rank
a.	Extension meetings	____
b.	Field days at research/extension centers	____
c.	Publications prepared by the extension service	____
d.	Publications provided by private companies	____
e.	Meetings organized by private companies	____
f.	Searches from the internet	____
g.	Farm newspapers and magazines	____
h.	Radio programs and advertisements	____
i.	Other farmers	____
j.	Grain buyers	____
k.	Television programs or advertisements	____
l.	Local farm supply dealers/ employees at elevators	____
m.	Crop consultants	____
n.	Websites on the internet	____
o.	Crop protection company sales representatives	____

14. If available, would you use any of the following electronic technologies to assess information on risk or management of scab? (Select all that apply)
    a. Internet blog
    b. Twitter
    c. Facebook
    d. YouTube
    e. Listserv message to your cell phone
    f. None of the above
15. Are you a member of a farm organization which provides information about best practices for raising wheat?
    a. Yes
    b. No
16. Do you employ a crop consultant to provide advice on any farm operation?
    a. Yes
    b. No

17. How many employees do you have on your farm?
    a. I only farm part-time
    b. Just myself (full-time) and occasional help during key times.
    c. One full-time person other than myself during the summer months.
    d. Two full-time persons.
    e. Three or more full-time persons.
18. Describe the speed of your internet connection.
    a. I do not have a computer connected to the internet.
    b. I have a computer with a dial-up connection.
    c. I have a high-speed internet connection.
19. I use my internet connection to do the following (circle all that apply).
    a. E-mail
    b. Regular searches for information about farming practices.
    c. I visit extension and product websites for information on varieties and pesticides.
    d. I visit extension site to obtain copies of extension bulletins.
    e. I visit company websites to obtain information about their products.
    f. I regularly view the scab prediction website during the critical period of the growing season to help me determine if I should spray.
20. What is your highest level of education?
    a. High school diploma or equivalent
    b. Two-years of college
    c. Four-year degree
    d. Graduate level course or degree
21. If you obtained a college degree, was your major in an agriculture-related discipline?
    Yes _______ No _______
22. What is your age?
    a. 18-30
    b. 31-40
    c. 41-50
    d. 51-60
    e. 61 or older
23. How many years have you been farming?
    a. 0-10
    b. 11-20
    c. 21-30
    d. 31-40
    e. 41-50
    f. More than 50 years

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