AN ECONOMIC ANALYSIS OF FOLIAR FUNGICIDES USED IN NORTHEAST TEXAS WHEAT PRODUCTION

A Thesis

by

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ABSTRACT

AN ECONOMIC ANALYSIS OF FOLIAR FUNGICIDES USED IN NORTHEAST TEXAS WHEAT PRODUCTION

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Texas A&M University-Commerce, 2013

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Fungal diseases are the number one biotic reason for crops losses around the world and have a significant impact on yield and quality in wheat (*Triticum aestivum L.*) production. Up to 42% yield loss caused by fungal diseases can be prevented by applying foliar fungicides to winter wheat. The U.S. is the world's largest wheat producing and exporting country. Texas ranks 8th among the major U.S. wheat producing states and most of its wheat is grown in the High Plains region in Texas.

The Texas A&M AgriLife Extension Representative in Commerce, TX conducted a two year study to evaluate the response of four soft red winter wheat varieties (Magnolia, Terral LA 841, Pioneer 25R47, and Coker 9553) to a foliar fungicide application treatment (tebuconazole). The experiments were conducted in Northeast Texas, in Royce City, in the town of Howe, and in the city of Leonard during 2011 and 2012. Each treatment was replicated six times in a randomized complete block design.

The main objective of the study was to evaluate the economic impact of tebuconazole in wheat production. Statistical Analysis System (SAS) was used to analyze yield and net return. Additionally, a Tukey's means separation test was used to performed means comparisons between treatments at 5% significance level. The profitability of obtaining net returns from a single fungicide application was conducted by implementing a Bayesian inference method. A sensitivity analysis was used to evaluate the economic effects of spraying and non-spraying tebuconazole at varying wheat prices and fungicide cost.

No fungal diseases were found during the two years that were evaluated. In 2011 low levels of barley yellow dwarf, a viral disease, were detected at the Howe location. In 2011, there was not a significant effect of tebuconazole treatment on the overall yield response compared to the control group. In 2012 there was a significant difference of an 8.6% increase on yield from the tebuconazole treatments over the control group, which may be attributed the higher precipitation level in 2012 than in 2011. Excitingly, during the two years of the study, 66% of the observations resulted in positive net returns from fungicide applications. In addition, it was found that high net yields do not necessarily mean high probabilities of obtaining net returns from fungicide applications. However, the probability of breaking even from fungicide use is positively correlated to the yield magnitude (i.e., the variety's capacity to produce yield) and the variety's partial resistance to leaf and stripe rust.

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INTRODUCTION

At the beginning of the 21st century, the United States (U.S.) wheat production started facing some challenges related to foreign competition and fewer alternative crops eligible for government programs. Despite these challenges, wheat production is still important since the U.S. is the world's largest wheat producer and exporter. According to the 2007 Census of Agriculture, Texas ranked as the 8th largest wheat producing state in the U.S. with wheat being the third largest revenue-generating crop planted behind forages and cotton in the state of Texas (USDA, 2007).

The wheat industry is affected by economic, environmental and biological factors such as fungal diseases which often cause most of the losses on wheat yield returns. Among the many biological factors, fungal diseases are the number one cause of wheat losses around the world. Fungal diseases have a high impact on the crop's yield and quality and thus, affect economics (McGrath, 2004). Thus, universities, farm associations and organizations, and many government agencies and offices are constantly conducting research on wheat cultivars and foliar fungicides with the main objective of improving economic returns. However, there are few studies that evaluate foliar fungicide applications in wheat production from a micro-economic point of view. The author is unaware of any micro-economic study on foliar fungicides in Northeast Texas.

1.1 World and U.S. Wheat Production

According to the United States Department of Agriculture (USDA, 2012), the U.S. is the world's largest wheat producer with a production value around $14.37 billion in 2011; only exceeded occasionally by China, the European Union, and India. According to the same source, during the last 10 years, wheat has been ranked as the third largest (acreage) crop planted in the country, only behind corn and soybean.

According to the 2007 Census of Agriculture (USDA, 2007), the top five states in terms of their value of agricultural products sold and their share, are California (11.4 %), Texas (7.1 %), Iowa (6.9 %), Nebraska (5.2 %) and Kansas (4.8 %). The top five industries with the highest net cash income are grains and oilseeds, milk, poultry and eggs, fruits and nuts, and nursery and greenhouse. Of $300 billion sold on agricultural products in 2007, crops accounted for 48.33% while grains and oilseeds for 26% (USDA, 2007).

Richardson, Outlaw and Raulston (2006) estimated the impact of the wheat industry on the U.S. economy. They reported that in 2005, the wheat industry generated 198,370 jobs nationwide and the total impact of the industry on the U.S. economy was $20.6 billion.

According to the USDA (2012), the economic return of wheat relative to other crops is decreasing, and the possibility of planting alternative crops under government programs is increasing. As a result, the U.S. wheat harvested area has dropped to nearly 30 million acres, which is about one-third of the 1981 record high level.

Despite those challenges, wheat prices have been increasing from $6.78 in 2007/2008 to $7.24/bushel in 2011/2012 (Figure 1.1). In addition, the 2012 U.S. wheat production projections from the National Agricultural Statistics Services (NASS, 2012) survey are estimated to be 1.67 billion bushels, up to 12 % from 2011. In 2012, wheat yield is expected to average 47.7 bushels per acre, 1.5 bushels more than 2011 (NASS, 2012).

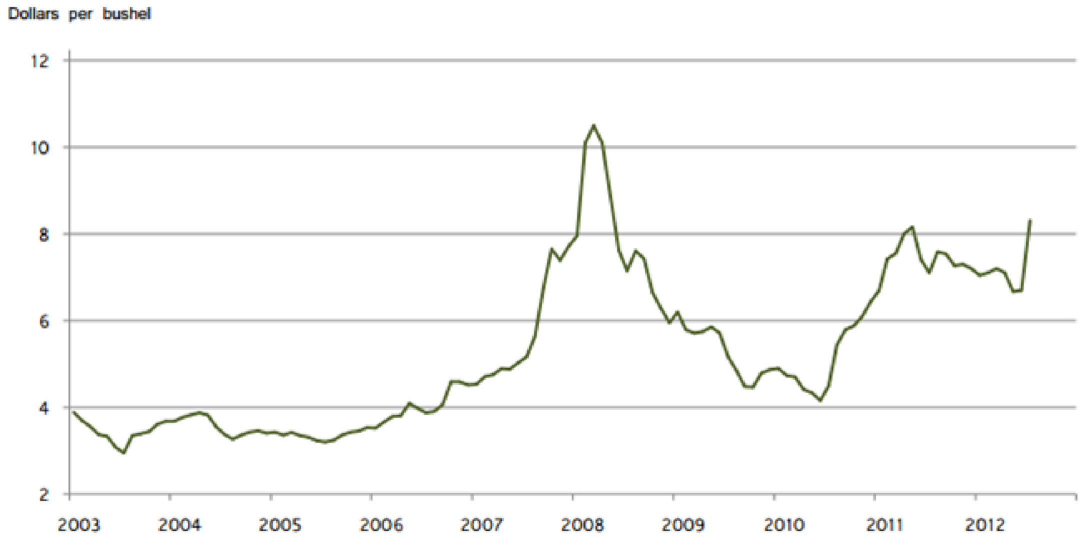
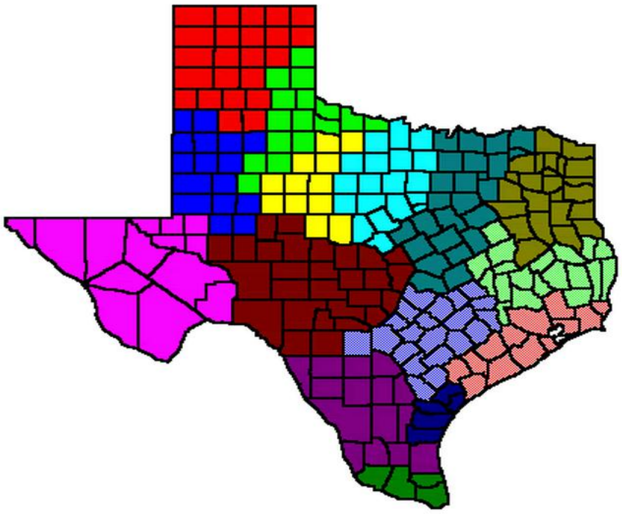


Figure 1.1. United States Prices for Wheat by Month, 2003-2012

Source: Agricultural Prices. USDA (2012, p. 12).

1.2 Texas Wheat Production

According to the 2007 Census of Agriculture, Texas ranked 8th among the major wheat producing states in the U.S. with more than 1.9 million acres in production (USDA, 2007). Currently, wheat is the third most planted crop behind forages and cotton in Texas. In 2012, the state of Texas planted 5,800,000 acres of wheat, which corresponds to 10.35 % of the total wheat area planted in the U.S. The High Plains region of Texas is where most of the wheat is grown (Figure 1.2). In 2005, the wheat industry generated 11,273 jobs in Texas that contributed with $658.8 million to the state economy (Richardson, Outlaw and Raulston, 2006).



Key	Code	Numeric Name	Geographic Name
■	11	District 1-North	Northern High Plains
■	12	District 1-South	Southern High Plains
■	21	District 2-North	Northern Low Plains
■	22	District 2-South	Southern Low Plains
■	30	District 3	Cross Timbers
■	40	District 4	Blacklands
■	51	District 5-North	North East Texas
▨	52	District 5-South	South East Texas
■	60	District 6	Trans-Pecos
■	70	District 7	Edwards Plateau
▨	81	District 8-North	South Central
■	82	District 8-South	Coastal Bend
▨	90	District 9	Upper Coast
■	96	District 10-North	South Texas
■	97	District 10-South	Lower Valley

Figure 1.2. Texas Agricultural Statistical Districts

Source: USDA (2012).

Reports from the last survey conducted by NASS (2012) in July 2012 showed that Texas wheat producers are expecting to harvest 91.5 million bushels in 2012, which represent an increase of 85 % compared with that of 2011 but down 28 % from 2010 (Figure 3.1). Production in the Northern High Plains is anticipated to be 29.6 million bushels, up 62 % from 2011. Winter wheat production in the Blacklands is estimated at 25.6 million bushels, up 53 % from 2011. Production in the Low Plains is projected at 20.0 million bushels, up from 7.0 million bushels in 2011.

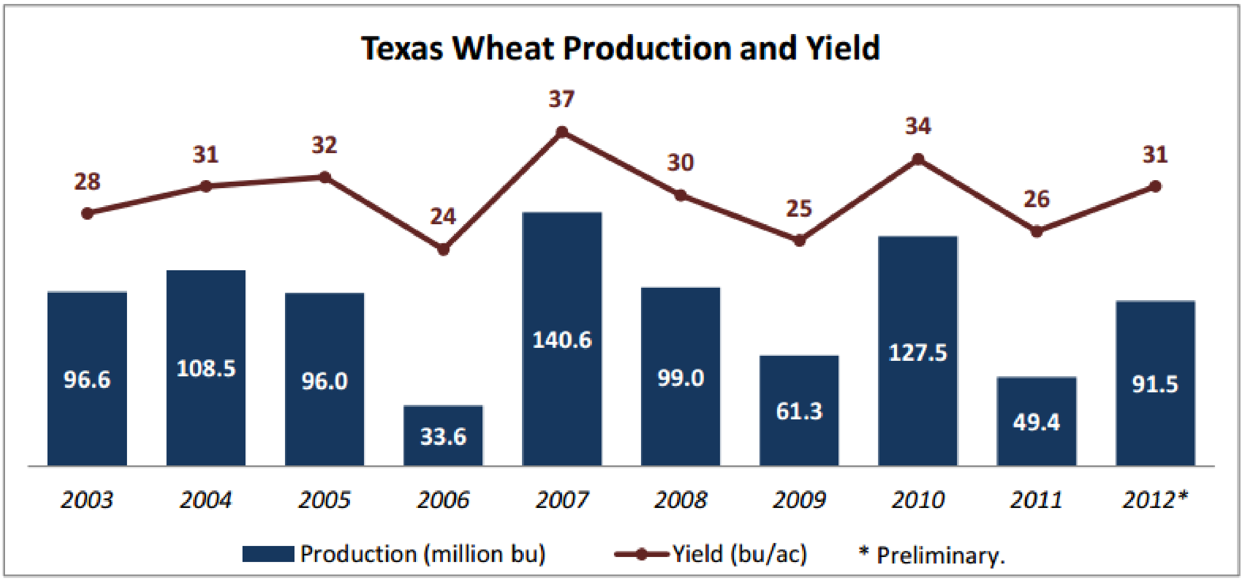


Figure 1.3. Texas Wheat Production and Yield, 2003-2012

Source: USDA (2012, p. 1).

1.3 World Wheat Trade

The U. S. is the world's leading wheat exporter (ERS, 2012). The U. S., Canada, Australia, the EU-27, the former Soviet Union (including three major wheat exporters: Russia, Ukraine, and Kazakhstan), and Argentina usually account for about 90 % of world wheat exports (USDA, 2012).

According to ERS (2012), the diversity of exporting countries in the world provides a significant stability to world wheat trade and prices. Population growth is another important factor that provides stability to wheat world trade. The population growth in Egypt, Algeria, Iraq, Brazil, Mexico, Indonesia, Nigeria, and other developing countries will be the driving force of future expansion of world wheat trade (USDA, 2012).

1.4 U.S. Wheat Trade

According to the ERS (2012), by producing 10% of world's wheat (1993/94-2007/08 average), the U.S. is consistently the world's biggest wheat exporter. However, in the last 10 years, the U.S. wheat exports have exceeded 30 million MT[1] only twice. The U.S. wheat exports reached a peak in 2007/08, when they were 34 million MT, accounting for the 30 % of the world's wheat exports that year (Figure 4.1). This was the largest increase in wheat production for the U.S. over the last 20 years (USDA, 2012).

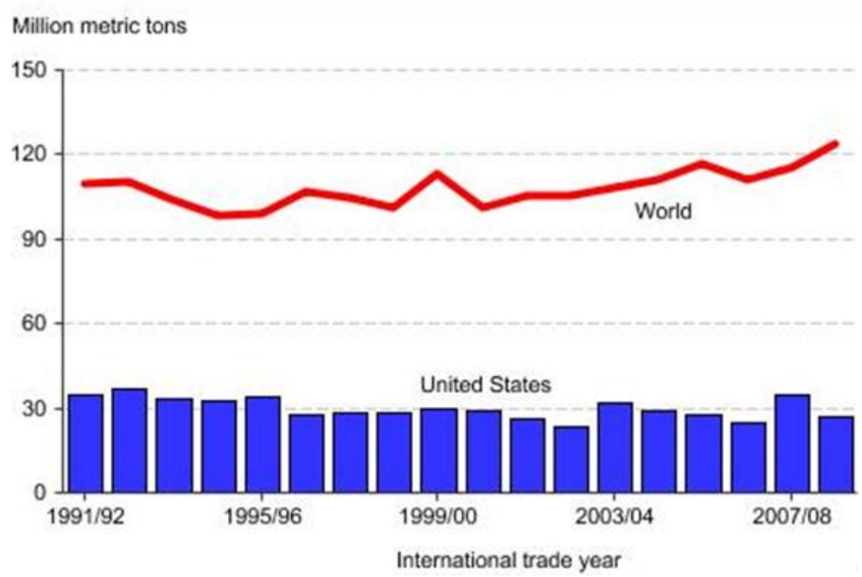


Figure 1.4. World Wheat Trade and U.S. Exports

Source: USDA (2012).

According to the ERS (2012), U.S. wheat exports grew at the expense of other exporting countries in 2007/08 due to the depreciation of the U.S. dollar with respect to other major world currencies. The U.S. dollar's fall in value, reduced the price for U.S. wheat compared to that

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[1] Metric tons.

produced by other countries. This fall boosted U.S. exports in 2007/08, and lowered exports by other major wheat producers. In previous years, increased planting flexibility in U.S. farm legislation and low returns relative to competing crops had led to a decline in U.S. wheat area, limiting wheat export potential (ERS, 2012).

1.5 Fungal Diseases in Wheat

According to McGrath (2004), diseases are the major source of crop damage. They can be caused by a number of pathogenic organisms; however, fungi are the number one biotic reason of crop losses around the world. Fungal diseases have a significant economic impact on yield and quality in wheat production, for this reason managing these diseases is an essential component of the production system for most of the crops.

The most prevailing foliar diseases of winter wheat in the U.S. are leaf rust (*Puccinia triticina*), powdery mildew (*Blumeria graminis* f. sp. *graminis*), tan spot (*Pyrenophora tritici-repentis*; anamorph: *Drechslera tritici-repentis*), Septoria tritici blotch (*Mycosphaerella graminicola*; anamorph: *Septoria tritici*), spot blotch (*Cochliobolus sativus*; anamorph: *Bipolaris sorokiniana*), and Stagonospora nodorum blotch (*Phaeosphaeria nodorum*; anamorph: *Stagonospora nodorum*). Stripe rust (*Puccinia striiformis* f. sp. *tritici*) and stem rust (*Puccinia graminis* f. sp. *tritici*) also occur, but are less common (Wegulo et al., 2011).

Leaf rust and stem rust are the most frequent wheat diseases and occur every year in the wheat producing regions of the U.S. (Kolmer, 2007). Yield losses of up to 60% due to stripe rust have been documented in experimental fields but it can also cause 100% of losses (Chen, 2011).

According to Osborne (2009), besides fungicide applications, plant diseases in wheat are best managed by integrating a number of control practices such as crop rotation, use of resistant cultivars, time of planting, level of fertilization, micro-climate modification, and sanitation. Hershman (2012) showed that the use of seed treatment and foliar fungicides are usually necessary to maximize wheat profitability in Kentucky.

1.6 Foliar Fungicides in Wheat

A fungicide is a specific type of pesticide which is used to control fungal diseases (McGrath, 2004). In North America, besides Chlorothalonil, foliar fungicides in wheat belong to two major classes with a broad spectrum of activity against fungal pathogens. These are the strobilurins and triazoles. Fungicides in both classes are used as foliar fungicides and seed treatment (Wegulo et al., 2011).

There are three main reasons to use fungicides: control the disease during the establishment and development of the wheat crop, increase productivity and reduce leaf and seed damage, and to improve the storage life and quality of harvested products (McGrath, 2004). Fungicides are commonly applied as dust, granules, gas, and most commonly as a liquid. Fungicides are applied to seed, bulbs, and roots of transplants, soil, foliage, plant trunk, and air in enclosed areas such as greenhouses and covered soil, harvested products and, as a dip or spray in the packinghouse (McGrath, 2004).

To be effective, most fungicides need to be applied before disease occurs or at the appearance of the first symptoms. In general, fungicides primarily protect plants from getting infected and just few fungicides are effective in plants that have been already infected (McGrath, 2004). O’Brien (2007) conducted a study in Kansas and showed that potential average wheat yield losses of 30% are common when leaf rust is not controlled at flowering.

Timing of application is very important. Fungicides are generally applied to winter wheat 1 or 2 times per season. The first application is often during stem elongation stage. The second application is to control early season s such as tan spot, and to protect the flag leaf (Wegulo et al., 2011). Fungicides can best protect these critical growth stages from fungal disease when applied between the full emergence of the flag leaf and anthesis (flowering). Fungicide applications made before flag leaf emergence generally result in less disease control on the upper leaves during grain development and smaller yield benefits (De wolf et al., 2012).

Usually, leaf diseases are managed by a combination of genetic resistance and crop rotation; however, foliar fungicides may be needed when these practices fail to keep diseases at low levels (Osborne, 2009). The yield response of wheat to foliar fungicides is highly variable. This response is influenced by many factors, including a cultivar's genetic resistance to disease, the amount of disease present in a field, yield potential of the crop, and weather conditions (De wolf et al., 2012).

According to McGrath (2004) the use of excess fungicide may lead to a fungicide resistant fungus. This resistance usually occurs with fungicides that have a single-site mode of action compared to those with multi-site modes of action. Most of the fungicides developed today have a single-site mode of action, which is associated with lower potential for negative impact on the environment.

1.7 Economic Impact of Foliar Fungicides Used in Wheat

Fungicide prices influence the decision of spraying or not spraying. However, when the disease severity is low, crop yield is usually not impacted. The benefits from fungicide applications in crop production are reflected in the returns of up to three times the cost involved (McGrath, 2004).

According to Wegulo et al. (2009), various studies have demonstrated yield increases in winter wheat due to fungicide applications in the U.S. Most of these studies showed that up to 42% yield loss was prevented by applying foliar fungicides to winter wheat. An economic analysis of fungicide use from 1995-2007 in winter wheat in Southern Sweden showed that the use of a fungicide was more profitable by getting a mean net return of $27 per ha (Wiik and Rosenqvist, 2009).

There is a misconception that fungicides are used to get a “yield bump” but most crop scientists agree that fungicides simply protect yield potential. When disease severity has the potential to reduce crop yields, then fungicide applications may help protect the crop from potential losses. On the other hand, if disease severity is low and there is minimal yield loss, then applying a fungicide will not result in either a yield or economic advantage (Hershman, 2012).

In the Northern Texas Blacklands, Swart and Jones (2011) evaluated the response of the most common commercial soft red winter wheat cultivars to a foliar fungicide (Tebuconazole). Swart and Jones (2011) found a positive return in all the cultivars evaluated in this trial. Using projected 2011 grain and fungicide prices, they obtained returns of $1.51 to $10.93 for every dollar invested. In the same study they also emphasized that there are a number of factors that farmers should consider before making a fungicide spray decision, including yield potential, wheat price, fungicide cost, and disease pressure.

1.8 Purpose of the Study

The general objective of this research is to evaluate the economic impact of fungicide applications in wheat production. This study will assist farmers to be more economically efficient in their use of fungicide applications to control for wheat foliar fungal diseases.

1.9 Specific Objectives

The specific objectives of this study are:

- To analyze the effect of foliar fungicide applications on yield response from Northeast Texas wheat production.
- To analyze the effect of foliar fungicide applications on the economic net returns from Northeast Texas wheat production.
- To determine the probability of obtaining economic net returns from foliar fungicides in wheat production from Northeast Texas.
- To determine the feasibility and profitability of spraying tebuconazole and non-spraying to control wheat fungal diseases in Northeast Texas

Chapter 2

LITERATURE REVIEW

This chapter summarizes relevant studies on the effect of foliar fungicides in wheat production. Each summary reviews the background, methodology, economic model, statistical analysis and the main findings. The studies have been grouped into different sections to better explain the impact of those studies' results in the development and the analysis of this present study. Section 2.1 discusses the economic impact of applying fungicides in winter wheat and section 2.2 discusses yield response to foliar fungicides and some factors that influenced wheat yields.

The results from the different studies vary mainly depending on the location where the experiment was done. These variations are also influenced by environmental, economic and cultural factors. In general, this chapter summarizes the main findings from previous studies on the economics of applying fungicides in winter wheat that relate to the results from this study.

2.1 Economic Impact of Foliar Fungicides in Wheat

Wegulo et al. (2011) and Wiik and Rosenqvist (2010) demonstrated that the application of fungicides to control fungal diseases in winter wheat is economically profitable. However, Wegulo et al. (2011) found that net returns can be negative if fungicides are applied when disease severity is low. The results from Wiik and Rosenqvist (2010) supported this statement by showing a negative mean net return when disease severity rates were low. Both studies conclude that weather plays an important role when evaluating fungicides efficacy to control for winter wheat diseases.

Wegulo et al. (2011) evaluated the economic impact of fungicide applications on net returns to control for foliar fungal diseases in winter wheat. The experiment was developed in

2006 and 2007 in Nebraska at four different locations (Mead, Clay Center, North Platte, and Sidney) in both years. The main objective was to evaluate the effects of fungicide and fungicide application timings on foliar fungal disease severity, yield increase and net return in winter wheat. Wegulo et al. (2011) evaluated the effect of five fungicides (azoxystrobin + propiconazole, pyraclostrobin, propiconazole, azoxystrobin and trifloxystrobin + propiconazole) in winter wheat. The fungicide treatments were applied at different rates 24 hours after inoculation of the fungus (*Pyrenophora tritici-repentis, Mycosphaerella graminicola, Blumeria. graminis forma specialis tritici, and Puccinia triticina*). According to Wegulo et al., (2011) wheat responds best to fungicides at certain growth stages (GS) of plant development. Therefore fungicides were also applied at different growth stages using Zadoks scale.[2] In 2006, fungicides were applied at GS 31 (first node on stem detectable). In 2007, fungicides were applied at GS 37 (flag leaf visible), GS 31 and GS 39 (ligule/collar of flag leaf just visible) (Wegulo et al., 2011).

Wegulo et al. (2011) obtained the average wheat prices from the United States Department of Agriculture (USDA), Agricultural Marketing Service. They computed the average of fungicide application and the average of fungicide application costs by surveying local retailers, chemical manufacturers and commercial applicators. These prices and costs were used to calculate net returns from fungicide treatments.

The authors estimated net returns from fungicide applications by the formula,

$$Rn = Yi\,P - (Fc + Ac),$$

where Rn represent the net returns from fungicide applications ($/ha); Yi is yield increase from fungicide applications (kg/ha) which was obtained by subtracting yield in the check treatment

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[2] The Zadoks scale is a cereal development growth stage scale from 10 (one leaf) to 92 (grains are ripe). It is internationally recognized in agricultural research.

from the yield in the fungicide treatments; *P* is the wheat price ($/kg); *Fc* is the fungicide cost ($/ha); and *Ac* is the fungicide application costs ($/ha).

Wegulo et al. (2011) determined the overall effect of fungicide and fungicide application timing on disease severity, yield increase, and net return by subjecting the means from each location to an analysis of variance using the SAS GLM procedure. The authors compared treatments means by using Fisher's least significant difference test at *P* = 0.05. Additionally, a linear regression analysis was used to describe the relationships between disease severity and yield increase, between disease severity and net return, and between yield increase and net return. Wegulo et al. (2011) used disease severity and yield increase as independent variables, and yield increase and net return as dependent variables.

According to Wegulo et al. (2011), the effect of application timing on net return was not significant for any fungicide in 2006. Net returns were at least two times the total cost ($2 return on $1 investment) in 4 out of 60 or 6.7% of treatments in 2006 and 51 out of 60 or 85% of treatments in 2007. However, in 2007, net returns were significant for the fungicides Headline, Quilt, and Tilt. When Wegulo et al. (2011) averaged net returns across fungicides, GS 39 application timing generally resulted in higher net returns than the GS 31 application timing. The probability of a positive net return was 0.63 in 2006 and 1.00 in 2007 (Wegulo et al., 2011).

The regression analysis from Wegulo et al. (2011) showed that there is a significant, linear inverse relationship between disease severity and yield increase. This implies that higher yield increases were realized in plots with lower disease severity and vice versa. In addition, disease severity explained 56% of the variation in yield increase.

Wegulo et al. (2011) also indicated that foliar fungicide applications to winter wheat can be profitable in years with moderate to high disease severity. However, a net loss can result if fungicides are applied in years with low disease severity. Additionally, the probability of obtaining positive net returns in wheat production also depends on other factors. Such factors include weather conditions favorable to disease development, the specific diseases which are present, the level of disease intensity, efficacy of the fungicide applied in controlling each specific disease, fungicide and fungicide application cost and rates, fungicide application timing, cultivar resistance, cultural practices and the price of wheat.

Wiik and Rosenqvist (2010) conducted an economic evaluation of fungicide application in Southern Sweden that was based on results from untreated plots and fungicide treated plots in trials in farmers' fields from 1983 to 2007. The authors simultaneously evaluated different scenarios with varying grain prices and costs of fungicide treatments. The main objective of the study was to examine the profitability of a single fungicide treatment (Amistar) at GS 45(before the heading stage)[3] and at GS 61(after heading stage) in winter wheat production.

Wiik and Rosenqvist (2010) used net return to model the profitability of applying fungicides in winter wheat. The equations for the economic model were:

$$(1) \qquad U = [(Y - D) * N] - (cF + cS),$$

$$(2) \qquad N = Z - (cP + cK + cH + cT + cA).$$

In equation 1, U is the net return (€/ha), Y is the yield increase (kg/ha), D is the yield loss due to wheel damage caused by spraying (kg/ha), N is the net value per kg (€/kg), cF and cS (€/ha) are the costs of fungicide and spraying, respectively in €/ha, and € denotes the Euro currency. In equation 2, Z is grain price per kg (€/kg), and cP, cK, cH, cT and cA are the costs per kg of phosphorus losses from the field (€/kg), potassium losses from the field (€/kg), harvest (€/kg), transportation (€/kg), and artificial drying (€/kg), respectively.

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[3] The heading stage begins when the tip of the spike (i.e., the head) can be seen emerging from the flag leaf sheath, and it ends when the head has completely emerged.

Wiik and Rosenqvist (2010) calculated the net return for 21 scenarios, using three groups of seven scenarios to evaluate different grain prices, €10/dt, €20/dt and €30/dt (dt=100kg). Four different fungicide prices (€0/ha, €30/ha, €40/ha or €60/ha), three costs of spraying (€0/ha, €6/ha or €12/ha) and three costs of damage from spraying (€0/ha, €4/ha or €8/ha) were used in the calculations. They employed an analysis of variance and a regression analysis as a statistical method to analyze the results. Additionally, they used boxplots to compare distribution between fungicide treatments. The Student Newman Keuls (SNK) test and Tukey's multiple range tests were used to compare means (Wiik and Rosenqvist, 2010).

Wiik and Rosenqvist (2010) found that wheat grain price had the largest impact on the net return from fungicide treatments. The cost of the fungicides had the second largest impact on net return. They also reported that the mean net return from fungicide use was no more than €12/ha over the 25 year period. In addition, the mean maximum net return was reached by using a mean dose of Amistar between 0.55 and 0.66 L/ha. Furthermore, the mean net return was negative in 10 out of 25 years analyzed. Less than 50% of the net return scenarios were profitable to treat in 11years.

Wiik and Rosenqvist (2010) concluded that in general, there was an increase of the overall net return from applying a single fungicide treatment at GS 45 to 61 for controlling fungal diseases in Southern Sweden wheat production from 1983 to 2007. Compared to the earlier (1983-1994) part of the study, the returns were higher (mean net return of €21/ha compared to €3/ha) than in the latter (1995-2007) part of the study, especially due to more cost-effective fungicides becoming available (Amistar). Finally Wiik and Rosenqvist (2010) recommended evaluating scenarios of high infection pressure disease that was not evaluated in their study. They also mentioned that a stronger fungicide treatment than the original one used in their study may be needed.

Wegulo et al. (2011) did not find significant differences on net returns when evaluating the effect of application timing for any fungicide in 2006. In contrast, Wiik and Rosenqvist (2010) reported that wheat responds best to fungicides at certain stages of plant development. They found a significant increase of the overall net return in GS 45 and GS 61 stage of application timing in treatments where the fungicides were used to control fungal diseases in wheat.

Wegulo et al. (2011) and Wiik and Rosenqvist (2010) used a net return analysis to evaluate the profitability of applying fungicides in wheat. Both studies analyzed the data by performing an analysis of variance and a regression analysis to determine the relationships and variability between variables. Wegulo et al. (2011) compared the treatment means by using Fisher's least significant difference test while Wiik and Rosenqvist (2010) used a Student Newman Keuls (SNK) test and a Tukey's multiple range test at $P = 0.05$ to compare means. The methodology and the findings from Wegulo et al. (2011) and Wiik and Rosenqvist (2010) will be used as a guide to conduct the profitability analysis in this study.

2.2 Yield Response to Foliar Fungicides in Wheat

Several studies have found positive effects of fungicides on wheat yields when they are applied to control fungal diseases (Tadesse, Ayalew, and Badebo, 2010; Wegulo et al., 2011; Wiik and Rosenqvist, 2010; Reid and Swart, 2004; Orum, Pinnschmidt and Jorgensen, 2006). Tadesse, Ayalew, and Badebo (2010) reported grain losses of up to 29% when wheat was not treated with fungicides. Additionally, Reid and Swart (2004) observed yield increases of 34% to 41% in treated plots compared to untreated plots. However, fungicides will have a different effect on wheat yields depending on the disease severity (Tadesse, Ayalew, and Badebo, 2010; Wegulo et al., 2011; Wiik and Rosenqvist, 2010; Reid and Swart 2004) and the diseases infection level. The latter will vary between years according to the weather conditions (Tadesse, Ayalew, and Badebo, 2010; Wegulo et al., 2011; Wiik and Rosenqvist, 2010).

Reid and Swart (2004) evaluated the response of soft red winter wheat to different foliar fungicide applications for the control of stripe rust (*Puccinia striiformis*). The experiment was carried out in field trial plots near Royse City in Northern Texas in 2003. Stripe rust has caused significant damage and loss of yield in the Northern Texas Blacklands.

The fungicides evaluated in this study were Tilt®, Quilt®, Stratego®, Headline®, Quadris®, and Folicur®. These fungicides were applied in a single application at different rates when wheat was in Feekes scale growth stage 9.[4] Agripro Patton was used as the selected wheat cultivar to determine the impact of stripe rust because this cultivar is highly susceptible to stripe rust, but resistant to leaf rust (*Puccinia recondita*). Visual leaf disease ratings, grain yields, and bushel weights (i.e., test weights) were used as measures to evaluate the efficacy of the fungicide treatments. The data was analyzed through an analysis of variance and Newman Keuls Multiple Comparison Test (0.05) was used to compare the means from yield returns (Reid and Swart, 2004).

Reid and Swart (2004) reported yield increases of 34% to 41% over untreated plots when wheat was treated with foliar fungicides. The yield produced from the fungicide treated plots averaged 3 pounds higher than that of the untreated plots. Additionally, seed size increased from

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[4] The Feekes scale ranges from 1 (one leaf) to 11.4 (ripe for cutting). It identifies the growth and the development stages of cereal crops and is widely used in the United States.

29% to 34% over the untreated plots. Thus, the yield response to fungicide paralleled seed size. There were no differences between fungicide treatments and type of fungicides.

Furthermore, Reid and Swart (2004) found that disease infection in all of the fungicide treatments was significantly less than in the untreated plots. The fungicides Folicur, Tilt, Quilt, Quadris, and Stratego showed slightly lower visual leaf infection levels than Headline. However, Headline showed significantly better results from the treatments than the untreated check. Finally, Reid and Swart (2004) concluded that the use of fungicides to control stripe rust in soft red winter wheat widely impacts yield increase in the Northern Texas Blacklands.

Wegulo et al. (2011) developed a study to quantify yield increases from fungicide applications to control foliar fungal diseases in winter wheat in Nebraska. The study was developed in five regions from that state in 2006 and 2007 and five fungicides at different rates were evaluated. One of their objectives was to analyze the effect of weather variation on disease severity.

Wegulo et al. (2011) reported very low disease severity in 2006 compared to 2007. Since the average temperature was similar in both years, the difference in disease severity between 2006 and 2007 was attributed to moisture. Plus, lack of adequate moisture during the grain filling period in 2006 also affected the yield obtained from the plots. They emphasized that the variation in weather from year to year had a significant impact on disease severity but also on the overall yield obtained in those years.

Wegulo et al. (2011) in the same study also estimated the effects of fungicides and fungicide application timing on disease severity. They chose to evaluate a single fungicide treatment just before and during heading (spike has emerged) because it had given the greatest yield increase in studies on treatment strategies performed in previous studies from Wiik (2009).

They reported that the effects of fungicides and fungicide application timings in 2006 and 2007 resulted in low yield increase. Additionally, non-significant differences were found among fungicides and application timings in 2006 and 2007. They concluded that there were no significant differences among fungicides in their efficacy in controlling disease in both application timings in both years.

Similar to Reid and Swart (2004), Wegulo et al. (2011) found no significant differences on yield returns among the type of fungicides. Additionally, Wegulo et al. (2011) did not find statistical differences between fungicide application timings. Both studies (Wegulo et al., 2011; Reid and Swart, 2004) attributed these results to the level of disease infection which strongly fluctuated due to changes in weather conditions among the years of their studies. These findings will help to explain the results from fungicide treatments and the effect of disease severity in this present study.

Tadesse, Ayalew, and Badebo (2010) evaluated the effect of fungicide on the development of wheat stem rust and yield in bread wheat cultivars. The experiment was developed under rainfall conditions during 2005 and 2006 at two locations in Bale highlands of Ethiopia. The main objective was to evaluate the response of three bread wheat cultivars which vary in reaction to stem rust to fungicide applications at two different locations in Ethiopia.

Three wheat cultivars (Sirbo, Maddawalabu, and FH4-2-11) were evaluated at both locations. The fungicide used was propiconazole (Tilt® 250 EC) which was applied at 0.5 L/ ha every 7, 14, 21 and 28 days in each cultivar. Stem rust severity was recorded using the modified Cobb's scale (Tadesse, Ayalew, and Badebo, 2010).[5]

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[5] Scale to measure disease severity ratings from 1 to 100 and was developed by Peterson et al. (1948).

In this study, the analysis of stem rust severity were represented by the area under the disease progress curve (AUDPC), the rate of disease increase yield, and the yield components (number of heads per acre, number of seeds per head, and the weight of the individual seeds). This data were evaluated by doing an analysis of variance using IRRISTAT software. A least significant difference (LSD 0.05) was employed to compare treatment means (Tadesse, Ayalew, and Badebo, 2010).

Tadesse, Ayalew, and Badebo (2010) also reported that a thousand kernel weight (TKW) of the cultivars increased significantly in response to the fungicide treatments. Additionally, they observed that there were differences in the level of stem rust severity at the locations evaluated between 2005 and 2006. Most of these differences were related to the lower temperature condition recorded in 2005.

Tadesse, Ayalew, and Badebo (2010) concluded that the rates of infection of stem rust on the cultivars evaluated were significantly reduced by the fungicide sprays. Also, they reported that grain yield was significantly increased by fungicide sprays on the cultivars of Sirbo and Maddawalabu except for Sinana in 2005. Unsprayed plots resulted in relative yield losses of up to 29% due to leaf rust infestation. Finally, they emphasized that weather conditions played an important role in the development of the disease in this study.

Tadesse, Ayalew, and Badebo (2010), reported that the differences on yield from fungicide applications were attributed to changes in temperature conditions. In contrast to this study, Wegulo et al. (2011) reported that the differences they found among fungicide treatments are related to the variation in moisture from year to year. These findings emphasized the importance of taking into account all the weather variables to analyze the final results from this present study.

Wiik and Rosenqvist (2010) carried out a fungicide application study to control winter wheat fungal diseases in Southern Sweden. One of the main objectives was to evaluate the effect of fungicide applications on yield increase in wheat production. To address this objective, they compared the results from untreated plots and fungicide treated plots to a single fungicide treatment at growth stages (GS) 45 to 61. This study was developed on farm field's trials from 1993 to 2007 using cultivars and fungicides available at that time. The study focused its research in evaluating the effect of the fungicides in controlling the main diseases that negatively affect winter wheat production in Southern Sweden such as leaf blotch, powdery mildew and brown rust and yellow rust. An analysis of variance, student Newman Keuls (SNK test) and Tukey multiple range test were used to compare the results from the plots (Wiik and Rosenqvist, 2010).

According to Wiik and Rosenqvist (2010) a fungicide treatment is habitually required, but in some years the normal dose recommended can be reduced. Many fungicides are very potent and a dose reduction usually does not impair the efficacy and resulting yield increase greatly due to the non-linear shape of the dose response curve. The fungicides evaluated in this present study were generally applied at normal doses recommended according to the fungicide label.

Wiik and Rosenqvist (2010) found that leaf blotch diseases, powdery mildew, brown rust and yellow rust were effectively controlled by fungicides. These results were similar to the ones from previous studies from Wiik et al. (2010) in Southern Sweden. A half dose of Tilt Top (0.5 L) resulted in only about 15% less yield increase compared to the recommended dose established on the label. The efficacy against leaf blotch diseases, brown rust, yellow rust and mildew was 82%, 90%, 84% and 78% respectively.

Wiik and Rosenqvist (2010) reported that by using an optimum dose of Amistar (0.66 L/ha) compared with a recommended standard dose (0.8 L/ha) during 1995-2007, the farmer would have gained €24/ha which is €3/ha more than the usual average (€21/ha). However, the dose that allowed reaching the maximum yield increase was achieved by using 0.9 L/ha Amistar. The optimal fungicide dose strongly fluctuates due to differences in disease intensity between years.

Wiik and Rosenqvist (2010) concluded that best results in yield increases from fungicide treatments were observed from a single fungicide application at GS 45 to 61. This result was achieved each year during the period 1983 to 2007. On average, the yield increase per year ranged between 3 and 19 dt/ha. They explained that the effect of fungicide applications on yield increase in wheat production is influenced not only by climate changes over time but also changes in controllable factors (fungicide and cultivar choice, crop rotation, techniques) and uncontrollable factors (emerging and new diseases, price relations).

Orum, Pinnschmidt and Jorgensen (2006) conducted a 5 year study to develop a model for fungicide applications in winter wheat in seven different regions of Denmark. The main objective was to analyze the impact of cultivars, fungicide application strategies, and dose effect on yield, as well as the economic risk of applying fungicides to winter wheat. The model considered dose response functions for fungicides controlling rust, mildew and *Septoria* diseases, cultivars' resistance classes, and fungicide strategies with respect to timing, active ingredients, and doses.

The yield gain $f(x)$ from a single fungicide dose x was calculated as,

$$f(x) = (1 - R)M(1 - \exp(\alpha x^{\beta})),$$

where α and β are the dose response parameters, M is the potential yield gain (from using fungicides), and R describes how much the yield gain is reduced by healthy cultivars. To control the effect of fungicides when they are applied in more than one period, the yield gains were added up by using the minimum survival method (Pavely et al., 2003).

Orum, Pinnschmidt and Jorgensen (2006) reported that the general yield gain from using Septoria fungicides varied from 0 to 25 hg (Hectokilogram) per ha. In 20% of the trials, the general yield gain exceeded 15 hg per ha and in 90% of the trials, the yield gain exceeded 3 to 4 hg per ha. A potential yield gain from mildew and rust fungicides merely occurred in 60% and 40% of the trials, respectively.

Orum, Pinnschmidt and Jorgensen (2006) concluded that the highest net yield gains were obtained from the most susceptible cultivars while the highest net yield and highest stability were found in the more robust cultivars.[6] The potential yield gain also varied from region to region. Agronomic practices such as crop rotation, soil quality and disease severity registered in the different field may explain the variances between regions.

Besides weather conditions analyzed in some studies (Tadesse, Ayalew, and Badebo, 2010; Wegulo et al., 2011), wheat cultivar, disease severity, fungicide doses, timing or wheat growth scale of application and agronomic practices are also important variables to consider when evaluating yield response to fungicide applications in wheat (Tadesse, Ayalew, and Badebo, 2010; Wiik and Rosenqvist, 2010).

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[6] Vigorous. Healthy wheat plants.

2.3 Profitability of Fungicide Treatment Use

Bestor (2011) analyzed the effects of foliar fungicides on Septoria Brown Spot and soybean yield in Iowa. The goals of this research were to determine the effect of growth stage applications of fungicides and insecticides compared with integrated pest management practices and to evaluate the economic benefits from applying fungicides alone. The experiment was developed at 13 locations conducted at three to five Iowa State University farms across Iowa, during three years (2008, 2009 and 2010).

Data on disease severity and yield response were analyzed using the GLM procedure in SAS. Means comparisons were calculated using Fisher's protected Least Significant Difference (LSD). The economic analysis was done through a Bayesian inference method that calculated the probability of obtaining positive net returns from fungicide treatments compared to the non-treated experimental units in this study. Besides determining the probability of break even, Bestor (2011) also evaluated the probability of receiving a 50% return on investment.

The author found that although fungicides reduced Septoria Brown Spot severity, they did not always impact yield. Greater yields were reported with tank mix applications of an insecticide and fungicide, however the addition of a fungicide did not always increase yield compared to the used of insecticide alone. The overall probability of making a net return on a fungicide application ranged from 0.01 to 0.99 and increased as grain price parameters were increased, Bestor (2011).

Bestor (2011) concluded that even when grain prices are high and returns are likely, the risk of fungicide resistance development is a concern. Consequently, increase in yield returns do not always mean profitable net returns from fungicides. This research recommends the use of resistant cultivars and crop rotations, in combination with chemicals as an effective way to manage foliar disease in Iowa.

Munkvold et al. (2001) developed a study to evaluate the probability for profitable fungicide use against gray leaf spot in hybrid maize. The objective of this study was to assess the profitability of fungicide applications for gray leaf spot control. The research was conducted in Iowa, in10 field experiments during 1995, 1996, and 1997 under conditions of natural disease infection.

Munkvold et al. (2001) analyzed yield response of two hybrids of maize to one or two applications of propiconazole. Disease severity and yield ratings were recorded and data were analyzed by an analysis of variance using the general linear models procedure of the SAS statistical software (SAS Institute, Cary, NC), mean separation was performed with Duncan's multiple range test at 5%. Linear correlation analyses were also performed to describe the relationship between disease severity ratings and yield.

The probability of achieving a positive net return with one or two propiconazole applications was done by using a Bayesian inference method. This analysis was based on the mean yields and standard deviations for treated and untreated plots, the price of grain, and the costs of the fungicide applications. Additionally to obtain the probability of returns equaling or exceeding costs, the probability of net return equaling or exceeding $25/ha was calculated to demonstrate a profit level a producer might as a criterion to justify a fungicide application (Munkvold et al., 2001).

The findings from this study showed that fungicide applications with propiconazole or mancozeb significantly reduced gray leaf spot severity. The highest yields tended to occur with two applications of propiconazole, but this treatment was commonly not significantly different from the single propiconazole application. Significant correlations were observed between gray leaf spot severity and yield (Munkvold et al., 2001).

The economic analysis showed that for one application, the probability of getting positive net returns ranged from approximately 0.06 to more than 0.99, and exceeded 0.50 in six of nine scenarios (specific experiment/hybrid). The highest probabilities occurred in the 1995 experiments with the most susceptible hybrid. Probabilities were almost always higher for a single application of propiconazole than for two applications (Munkvold et al., 2001).

Munkvold et al. (2001) concluded that a single application of propiconazole frequently can be profitable for gray leaf spot management in Iowa. However, the use of fungicide in corn production should be considered only for the more susceptible hybrids. Finally, they emphasized that the use of probabilities to calculate positive net returns was more informative than mean separation when evaluating the economic benefits from fungicide applications.

Esker and Conley (2012) analyzed the probability of yield response and breaking even for soybean seed treatments. The main objectives of this study were to quantify the effects of seed on early season plant population and seed yield. In addition, they evaluated the probability that yield response covered the cost of the seed treatment.

Experimental trials were conducted from 2009 to 2010 at nine different locations in Wisconsin. In each experiment, Esker and Conley (2012) compared the effect of mefenoxam + fludioxonil (ApronMaxx), and mefenoxam + fludioxonil+ thiamethoxam (CruiserMaxx) and no soybean seed treatments. Treatments were evaluated on four soybean cultivars run under a wide array of production situations in Wisconsin.

Yield ratings were analyzed by using a PROC MIXED statistical analysis in SAS. Means comparisons were based on a Fisher’s protected LSD at 5% significant level. The Bayesian economic analysis was done to quantify the probability that a seed treatment would be cost effective, meaning that the cost of the product was covered by an expected relative increase in yield that was measured as a percentage increase from fungicide applications. The Bayesian analysis considered a combination of seed treatment price, grain sell price, and actual yield (Esker and Conley, 2012).

Esker and Conley (2012) reported differences in early season plant populations due to cultivar and seed treatment and that seed yield was affected by a cultivar and seed treatment interaction. In addition, there was evidence of differences in response of cultivar and seed treatment across years. Finally, they emphasized that seed treatments can be a cost effective component of soybean production and that several factors such as weather and seed cultivar must be considered.

De Bruin et al. (2010) evaluated that probability of yield response to inoculants in field with a history of soybean production. The objective of this study was to determine yield response and probability of an economic return from inoculants in fields with a recent history of soybean production. Fifty-one inoculant products were evaluated in 73 experiments conducted in Indiana, Iowa, Minnesota, Nebraska and Wisconsin between 2000 and 2008.

Environments (specific combination of each year and each location) were generated to evaluate the effect of inoculants in yield responses of soybean. Yield response data from each environment were subjected to analysis of variance using the PROC MIXED in SAS. Least Square means were obtained from each treatment and the untreated control (De Bruin et al., 2010).

The economic analysis done by implementing a Bayesian inference method that was based on a relative yield response estimate that was calculated for each product as a ratio of the yield produced from the inoculant product divided by the yield produced by the untreated control, then multiplied by 100, and presented as a percentage. It also considered seed price and inoculant cost to calculate net return from yield estimates. The SAS Probit function was used to calculate the probability of achieving positive net returns from the use of inoculants in soybean fields (De Bruin et al., 2010).

Results showed that inoculants were similar and did not produce a yield response relative to an untreated control different from zero at 63 environments tested. From the economic analysis, De Bruin et al. (2010) found that no state included in this analysis gave a high probability of a yield response or positive net return on investment. Based on their results, De Bruin et al. (2010) concluded that the use of soybean inoculants in fields with a history of a soybean is not recommended regardless of price or easiness of application.

In summary, fungal diseases are one of the most important reasons for crop losses around the world (Chen, 2011). They have a significant impact on yield and quality in wheat production (McGrath, 2004 and Wegulo et al., 2009). Leaf rust and stripe rust are the most frequent annual diseases that affect the U.S. wheat production (Kolmer, 2007). According to Hershman (2012), McGrath (2004) and Wegulo et al. (2009) the use of fungicides are usually necessary to maximize profits in wheat. Several studies (De Bruin et al., 2010; Esker and Conley, 2012; Bestor et al., 2011 and Munkvold et al., 2001) have implemented Bayesian inference methods to analyze the probability of obtaining net returns from fungicide applications in wheat. In this study, the literature review from this chapter will be used to support the discussions and conclusions from chapters 3 to 5.

Chapter 3

METHOD OF PROCEDURE

The response of four wheat cultivars to the fungicide tebuconazole was evaluated at three different locations in the Northeast Texas Blacklands during 2 years (2011 and 2012). Non-irrigated field trials were conducted by the Texas A&M AgriLife Extension Representative in Commerce, TX under natural disease infection conditions. Similar management practices (planting dimensions, fertilization treatment, fungicide treatment rate, equipment and method of application, harvesting and weighing) were used on all field trials.

The main objectives of this study are 1) to estimate the effect of fungicide applications on the overall yield and net economic returns from Northeast Texas wheat production, 2) to determine the probability for profitable tebuconazole usage and, 3) to analyze net return increases from fungicide spraying by using a sensitivity net return analysis.

3.1 Data

Field trials were conducted at three locations in Northeast Texas: 1) Howe location 2) Leonard location and 3) Royse City. Royse City is located at 32°58′27″N, 96°19′58″W and at an elevation of 167 m. Howe is located at 33°30′18″N, 96°36′51″W, and at an elevation of 256 m. Leonard is located at 33°22′59″N, 96°14′43″W, and at an elevation of 219 m.

Weather data was downloaded from the National Weather Service Forecast Office (2013). The following weather data is based on the months from the most common fungal disease infection season, which are February, March and April. Mean monthly rainfall is 86 millimeters in Royse City, 89 millimeters in Howe location, and 95 millimeters in Leonard location. The monthly mean minimum and maximum temperatures in Royse City are 8 ^{o}C and

20 ^{o}C, respectively. The monthly mean minimum and maximum temperatures in Howe location are 7 ^{o}C and 18 ^{o}C, respectively. The monthly mean minimum and maximum temperatures in Leonard location are 11 ^{o}C and 16 ^{o}C, respectively. Total precipitation data for each location was recorded from the nearest station located at Grenville, Texas (Table 3.1).

Table 3.1 Planting Dates, Harvesting Dates, and Total Precipitation during the Winter Wheat Growing Season at each Location

Year	Locations	Planting Date	Harvesting Date	Total Precipitation (mm)
2011	Howe	October 29, 2010	June 7, 2011	361
2011	Leonard	November 10, 2010	June 2, 2011	314
2011	Royse City	November 19, 2010	May 31, 2011	369
2012	Howe	November 2, 2011	May 22, 2012	537
2012	Leonard	October 31, 2011	June 6, 2012	556
2012	Royse City	November 1, 2011	May 17, 2012	537

Source: Year, location, planting, and harvesting date were provided by the Texas A&M AgriLife Extension Representative in Commerce, TX. Precipitation data were obtained from the National Weather Service Forecast Office (2013).

The soil types in all three locations are either Houston Black Clay (calcareous clays and marls) or Leson Clay (alkaline shale and clays). Both soil types are very deep, moderately well drained, and very slowly permeable soils. Those characteristics are considered as the typical soils types where wheat is grown in Northeast Texas. The four wheat cultivars tested were Magnolia, Terral LA 841, Pioneer 25R47, and Coker 9553. These cultivars were chosen because they are locally adapted and partially resistant to both leaf and stripe rust. The seeding rate was 100.88 kg/ha.

Fungicide treatments consisted in the application of 0 or 280 g/ha of tebuconazole. The application was done when the plants were approximately at Feekes Growth stage 10.[7] The plots were sprayed with a CO_2 powered backpack sprayer equipped with a three-nozzle boom with 8002VS stainless steel tips 48 cm apart. The fungicide was diluted in 93 liters of water per hectare with 8002VS tapered, flat-fan nozzles at 30 pounds per square inch (p.s.i.) and was applied over the top and directly to the foliage. Each trial was replicated six times in a randomized complete block design. Each plot was 1.22 meters wide and 6.06 meters long and a row spacing of 5.24 centimeters. Conditions at the time of fungicide application are summarized in Table 2.

Table 3.2 Harvesting, Location, Application Dates, and Weather Conditions at the Time of Tebuconazole Application

Year Harvested	Location	Application Date	Weather Conditions at Application Time		
			Wind (kmph)	Temperature (^oC)	Relative Humidity (%)
2011	Howe	4/1/2011	6.4	18.3	61.6
2011	Leonard	3/8/2011	8.0	12.1	61.6
2011	Royse City	3/27/2011	6.4	18.3	61.6
2012	Howe	3/29/2012	4.8	27.5	51.8
2012	Leonard	3/28/2012	6.4	24.4	61.0
2012	Royse City	3/28/2012	8.0	20.0	87.0

Source: Year, location, planting date, harvesting date and weather conditions were provided by the Texas A&M AgriLife Extension Representative in Commerce, TX. Weather conditions at the time of application were obtained from the National Weather Service Forecast Office (2013).

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[7] Feekes growth stages are discussed on Chapter 2.

3.3 Disease Severity Assessment

Each experimental unit was evaluated one month after the tebuconazole application treatment by the Texas A&M AgriLife Extension Representative in Commerce, TX. Ten plants per plot (subsamples) were randomly selected for disease assessment. Flag leaves on each plant were visually assessed for disease severity. It was rated as a percent of infection or leaf damage from any fungus pathogen present in the leaves.

3.4 Harvesting and Weighing

The harvest was done by the Texas A&M AgriLife Extension Representative located in Commerce, TX with a research Kincaid combine (Kincaid Manufacturing, Haven, Kansas). Grain yield in bushels per acre was recorded at the end of the experiment and converted to kg/ha. After weighing the grain and correcting to 13% moisture, yield was calculated and reported in bushels/acre. Samples were analyzed at the Agronomy Lab of Texas A&M University-Commerce in Commerce, TX.

3. 5 Estimated Costs and Wheat Prices

Wheat prices per bushel were obtained from the planning cost projections developed by the Department of Agricultural Economics, Texas A&M University and Crop Production Services (Texas A&M AgriLife Extension Service, 2013). Tebuconazole price and application cost in $/acre were obtained from fungicide companies in Northeast Texas. Tebuconazole cost (application included) did not change over the two years of this study. Wheat price and fungicide costs were then converted to $/kg and $/ha, respectively. Direct and fixed costs were not used in this research due to the objective of asses the net returns from fungicide application.

3. 6 Statistical Analyses

Effects of tebuconazole application on disease severity, net returns and wheat yields response were evaluated by an analysis of variance using the GLM procedure in SAS, Statistical Software (SAS Institute, Cary, NC) version 9.3. Multiple linear models were developed to test treatment interactions with location, cultivar, year and block. Tukey means separation test at 5% significance level was used to perform means comparisons between sprayed and unsprayed treatments for final disease severity ratings, yield response and net yield from tebuconazole usage. Differences in yield between the sprayed and unsprayed treatments were used to analyze wheat yield response and net returns from tebuconazole treatments.

When evaluating fungicide treatment effects in wheat production; Wegulo et al. (2011) compared the disease severity ratings, net returns and wheat yield means from different treatments by using Fisher's least significant difference test while Wiik and Rosenqvist (2010) used Tukey test at *P* = 0.05 to compare means. In this study, a Tukey multiple range test was use to minimize chances of type I error, which occur when mean comparison are developed. In addition, Tukey test is used when working with variables in which the units of measure are required to have big magnitudes in order to show statistical differences, such as yield.

The linear model used was a randomized complete block design. Thus,

$Y_{ijklmn} = \mu + \alpha_i + \beta_j + \gamma_k + \delta_l + \lambda_m + \alpha\gamma_{ik} + \varepsilon_{ijklmn},$

where, μ is the overall yield mean were the treatment was applied, α_i is the effect due to the ith treatment, β_j represent the effect from the jth block, γ_k is the effect from the kth cultivar, δ_l is the effect from the lth location, λ_m is the effect from the mth year, $\alpha\gamma_{ik}$ represents the interaction effect of the ith level of treatment depending on the kth level of cultivar and ε_{ij} is the error term assuming that errors in observed yields are independently normally distributed with $\mu = 0$ and constant variance σ^2.

3.7 Profitability Analysis

The profitability analysis was based on a Bayesian inference method. The Bayesian method is used to determine the probability of achieving positive net returns from a single tebuconazole application. This economic analysis is widely accepted and had been previously employed by Bestor et al. (2011), Munkvold et al. (2001), De Bruin et al. (2010), and Esker and Conley (2012).

Bestor et al. (2011) and Munkvold et al. (2001) implemented a similar methodology to determine the probability of profitable fungicide applications. However, Munkvold et al. (2001) analyzed effects of fungicides in hybrid maize while the study from Bestor et al. (2011) was based on soybean production. Different from Bestor et al. (2011) and Munkvold et al. (2001), this study works with soft red winter wheat.

De Bruin et al. (2010) and Esker and Conley (2012) analyzed the probability of profitable yield response in soybean. However, Esker and Conley (2012) studied the economic effect of seed fungicide treatments and De Bruin et al. (2010) studied the profits from inoculant (ensure nitrogen fixation) use to enhance yield. As opposed to De Bruin et al. (2010) and Esker and Conley (2012), this study analyzed the profitability of foliar tebuconazole applications in wheat production.

In order to obtain the probability of profitable net returns from inoculants or fungicides, De Bruin et al. (2010) and Esker and Conley (2012) employed a percentage cost relative yield in their Bayesian analysis method. In contrast, Bestor et al. (2011) and Munkvold et al. (2001) used a yield difference needed to reach a specified net return in their model. Similar to Bestor et al. (2011) and Munkvold et al. (2001), this study works with yield response estimates from fungicide applications and also works with wheat price, and fungicide treatment cost (application cost included) as the main variables to determine net returns from fungicide usage in winter wheat.

The probability of breaking even, getting 25% and 50% of net returns on fungicide investments was evaluated under two different scenarios of wheat prices ($0.25/kg and $0.30/kg) and a single tebuconazole treatment price ($17.29/ha). Only one fungicide treatment price was used due to minor significant changes observed on tebuconazole cost reported by local suppliers across the years. In order to calculate the probability of getting positive net returns, estimated yield differences (β_0) in kg/ha needed to offset the cost of fungicide treatment was obtained from the different wheat prices; fungicide cost scenarios and actual yield observed from this experiment.

LSMEANS (Least Square Means) was used to obtain mean estimates from each variable in the model. Then, treatment means were used to calculate net returns (*Rn*) in $/ha by using the following equation:

(1) $Rn = ((Y_f - Y_c) * P) - (C_f + C_a)$,

where $\left(\Delta_y = Y_f - Y_c\right)$ is the yield response difference (kg/ha), Y_f is the observed yield (kg/ha) from tebuconazole treatment, Y_c is the observed yield (kg/ha) from the untreated plots, P is wheat price ($/kg), $(Y_f - Y_c) * P$ is the gross net return from tebuconazole applications, C_f is the fungicide cost ($/ha), and C_a is the cost of fungicide applications ($/ha). Net returns (*Rn*) in $/ha from a single tebuconazole application is the difference between gross net return and costs.

In order to analyze the probability of achieving profits from the fungicide applications, expected net return *(ERn)* in \$/ha are used. *ERn* is defined as the amount of profits that the growers would like to obtain to justify tebuconazole applications. This amount can vary depending on each grower criterion. In this study, *ERn* is considered to be 0% (breaking even), 25% and 50% of net return on the fungicide investment. These percentages were arbitrarily selected and they represent returns on investments that growers may find attractive.

A new yield difference $\beta_0 = Y_f - Y_c$ in kg/ha is obtained by replacing the original net return (*Rn*) with the new expected net return (*ERn*) (see Equation 2). The new yield difference (β_0) represents the yield response difference needed to offset the cost of tebuconazole application. Thus, β_0 is calculated by applying the net return (*Rn*) equation,

$$(2)\ \beta_0 = \frac{ER_n + (C_f + C_a)}{P}.$$

Several yield differences (β_0) can be calculated according to the net returns that the grower is expecting to get from spaying. The new estimated yield differences (β_0) for each net return scenario (net returns larger than 0%, 25% or 50% of the investment in tebuconazole) were calculated by plugging the expected net return (ER_n) in the following equations:

For breaking even on the investment in tebuconazole (0% net returns),

$$(3)\ \beta_0 = \frac{0 + (C_f + C_a)}{P}.$$

For achieving net returns of 25% of the investment in tebuconazole,

$$(4)\ \beta_0 = \frac{0.25 * (C_f + C_a) + (C_f + C_a)}{P}.$$

For achieving net returns of 50% of the investment in tebuconazole,

$$(5)\ \beta_0 = \frac{0.5 * (C_f + C_a) + (C_f + C_a)}{P}.$$

Following Bestor et al. (2011) and Munkvold et al. (2001), the probability (*PT*) that tebuconazole treatments resulted in a yield difference larger than the estimated yield difference needed to offset the cost of tebuconazole (β_0) was calculated from the observed yield difference between the treated and untreated plots $(Y_f - Y_c)$ and their observed standard deviation (S) which calculated from a pooled variance in yield (Sp^2). Yield differences (β_0) are standardized and are assumed to have a student's *t* distribution (see Equation 6). Similar to Box and Tiago (1973), the degrees of freedom (df_e) are determined from the number of observations of tebuconazole treatments (n_t) and the number of observations in the control group (*nc*) or untreated experimental units. Thus,

$$(6)\ \ T(\beta_0) = \frac{\beta_0 - (Y_f - Y_c)}{sp^2(1/\mathrm{n}_\mathrm{t} + 1/\mathrm{n}_\mathrm{c})^{1/2}}\ .$$

Following Box and Tiago (1973), the pooled variance (Sp^2) is computed from the variance of the observed yield from the treated plot $(S_1{}^2)$, the variance of the observed yield from the control plot $(S_2{}^2)$, the number of observations in the treated plot (n_t), and the number of observations in the control plot (n_c). That is,

$$(7)\ \ S_P{}^2 = \frac{(n_t - 1)\cdot S_1{}^2 + (n_c - 1)\cdot S_2{}^2}{(n_t - 1) + (n_c - 1)}\ .$$

The variances from treated and untreated observations ($S_1{}^2$ and $S_2{}^2$) are estimated as,

$$(8)\ \ S_i{}^2 = \frac{\sum_{i=1}^{n} \left(Yi - \overline{Y}\right)^2}{n\ -1}\ ; \qquad i\ = 1,2.$$

The pooled variance is then used to calculate the standard deviation as,

$$(9)\ \ S = \sqrt{\frac{(n_t - 1)\cdot S_1{}^2 + (n_c - 1)\cdot S_2{}^2}{(n_t - 1) + (n_c - 1)}}\ .$$

The probability that net returns from a tebuconazole treatment (*P*T) will at least break even (*Rn* >

0), be 25% larger than the investment on tebuconazole ($Rn > 0.25*(C_f + C_a)$) or be 50% larger than the investment on tebuconazole ($Rn > 0.50*(C_f + C_a)$) is estimated as

(10) $PT = 1 - Prob\ t[\,t(\beta_0)\,,\, df_e]$.

This method allows growers to determine the probability of breaking even under different wheat prices and the estimated production costs scenarios. However, the probability of breaking even may not be attractive for the grower to consider applying fungicides. For this reason, this study also determines the probability of achieving net returns of 25% and 50% of investments on tebuconazole. By taking these probabilities under consideration, wheat growers can make better decisions about applying or not applying tebuconazole in partially resistant wheat cultivars to control foliar fungal disease infestations.

3.8 Net Return Sensitivity Analysis

A sensitivity analysis on net returns is also performed in this study. It considers two scenarios (an optimistic scenario and a pessimistic scenario). The sensitivity analysis uses lower and higher wheat prices ($/kg) and fungicide treatment costs (including the fungicide application cost). The yield increase (kg/ha) needed to break even for each interaction of wheat price and fungicide cost was evaluated in the sensitivity analysis.

The optimistic scenario is estimated under low fungicide cost treatments. Four fungicide costs ($15.561/ha, $13.832/ha, $12.103/ha, and $10.374/ha) which are subsequently 10% lower than the original fungicide cost of $17.29/ha were considered. In addition, four wheat prices ($/0.275/kg, $0.30/kg, $0.325/kg, and $0.35/kg) which are subsequently 10% higher than the original wheat price average of $0.25/kg were also considered.

The pessimistic scenario considers four fungicide treatments costs ($19.019/ha, $20.748/ha, $22.477/ha, and $24.206/ha), each one subsequently 10% more expensive than the regular cost of $17.27/ha. In the same scenario, wheat prices are subsequently reduced by 10% of the original average price of $0.25/kg. That is, four wheat prices are considered ($0.225/ha, $0.2/ha, $0.175/ha, and $0.15/ha).

Average yield increases from the different scenarios were obtained from methods previously implemented by Wegulo et al., (1997). Thus,

$$(11)\quad \left(Y_f - Y_c\right) = \frac{\left(C_f + C_a\right)}{P}.$$

where, Y_f is the observed yield (kg/ha) from tebuconazole treatment, Y_c is the observed yield (kg/ha) from the untreated plots. Yield increases $(Y_f - Y_c)$ resulted from dividing the cost of fungicide (C_f) in $/ha and the cost of fungicide application (C_a) in $/ha by the wheat price ($P$) in $/kg. The average yield increase was plugged in equation (1) to obtain the different net returns from the varying scenarios of wheat prices and fungicide cost used for the sensitivity analysis.

A sensitivity analysis on yield increases was also performed by using the same varying wheat prices and fungicide costs on the sensitivity analysis on net returns. The objective of this analysis is to find the break even yield in kg/ha needed to offset the cost of fungicides at different wheat prices. As well as the changes in yield increase when fungicides cost change. Yield increases for this analysis were obtained by applying equation 10.

Chapter 4

RESULTS AND DISCUSSION

This chapter discusses and reports the main findings from the wheat trial experiments, where the tebuconazole application treatments were evaluated to control foliar fungal diseases in soft red winter wheat production in Northeast Texas. A disease severity analysis is conducted in section 4.1, in which no fungal diseases were found at any time at all locations. However the viral disease barley yellow dwarf was found at one single location in 2011. This viral disease was analyzed to evaluate its effect on the final wheat yields obtained that year. In this analysis, no statistical significant differences ($P>0.05$) of viral infections were found between the tebuconazole treatment and the control group. However, significant differences ($P<0.05$) on viral infection (%) among the cultivars evaluated were found at the Howe location. At this location, wheat plants were infected with barley yellow dwarf at low rates. In this study, the effects of cultivar, location, year and their interaction on the average wheat yield and net return from tebuconazole treatments were evaluated for the two years of study. As explained in Chapter 3, four cultivars and three locations (Tables 3.1 and 3.2) were considered in 2011 and 2012.

Fungicide application was found to have a statistical significant effect ($P<0.05$) on the overall yield (Section 4.2) and net returns (Section 4.3). There was a significant effect ($P<0.0001$) of the interaction between year and fungicide treatment on the overall yield and net returns response. This means that the overall yield and net returns were affected differently by the level of fungicide treatment each year. To provide a more in depth analysis of the effect of fungicide applications on yield and net returns among years, each year was analyzed separately. This study also analyzed the number of observations that resulted in positive net returns from fungicide applications. This study found that during the two years of study, 66% of the observations resulted in positive net returns from fungicide applications (see Table 4.23).

A profitability analysis is developed in Section 4.4 and was done by calculating probabilities for breaking even and getting returns of 25% and 50% on the tebuconazole investments. Probabilities of making positive net returns from fungicide applications were obtained by year, location and cultivar, as well as the combination of those variables. Results showed that the probability of obtaining net return of 50% on the tebuconazole investment is lower than the probability of obtaining a net return of 25%, which is also lower than the probability of breaking even.

A sensitivity analysis on net returns and yield increase are reported in Section 4.5. The net return sensitivity analysis estimates the net returns that are needed to break even when tebuconazole is applied. The sensitivity analysis estimates the increase in yield that is needed to offset the cost of applying the fungicide. Scenarios of increasing or decreasing wheat prices and fungicide cost were evaluated in each sensitivity analyses. As it was expected, better net returns where observed when wheat prices were high and fungicide cost were as low as possible.

4.1. Disease Severity

None of the most common foliar fungal diseases in Northeast Texas were found at all locations during the two years of the study. Barley yellow dwarf, which is a viral disease, was found at the Howe location in 2011, but at very low levels of infection for that year. At the Howe location, the average of barley yellow dwarf infection in the control plots was 1.42% while it was 1.31% in the treated plots (see Table 4.1). That is, the average viral infection was 7.1% lower in the treated plots than the untreated plots (Table 4.1).

Table 4.1. Levels of Barley Yellow Dwarf Infection (%) from the Non-Treated and the Treated Experiments with Tebuconazole at the Howe Location, Averaged across Four Cultivars in 2011

Level of Treatment	N	Yield (kg/ha)		Barley Yellow Dwarf Infection (%)	
		Mean	Std. Dev.	Mean	Std. Dev.
Control	24	5,143.98	527.52	1.42	0.52
Treatment	24	5,257.28	542.08	1.31	0.44

Table 4.2 reports the results from conducting an analysis of variance for barley yellow dwarf infection among cultivars at the Howe location in 2011. The analysis of variance was done using PROC GLM in SAS.[8] In this study, no significance differences on barley yellow dwarf severity were found between the treated and the non-treated plots among cultivars (P = 0.3012). In addition, barley yellow dwarf severity of infection was not found to be statistically different between the treated and the non-treated plots with tebuconazole (P = 0.3345) at the Howe location. However, there were statistical differences on barley yellow dwarf infection among cultivars (P=0.001).

Table 4.2. ANOVA for Barley Yellow Dwarf Infection (%) at the Howe Location, Averaged across Four Cultivars in 2011

Source	DF	Type III SS	Mean Square	F Value	Pr > F
Treatment	1	0.13	0.13	0.95	0.3345
Cultivar	3	4.77	1.59	11.64	<0.0001
Treatment*Cultivar	3	0.52	0.17	1.26	0.3012

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[8] Additional information about the ANOVA source and coefficient of variation results for barley yellow dwarf disease severity at the Howe location is provided in Appendix A, Table A.1.

Table 4.3 reports mean separation from the Tukey's Studentized Range Honestly Significant Difference (HSD) test for barley yellow dwarf viral infection (%) at the Howe location in 2011. The Tukey’s mean separation test was conducted using the PROC GLM procedure in SAS. This test is used to observe the percentage of infection on barley yellow dwarf infection among cultivars at the Howe location in 2011. Results from this test showed that there were differences on barley yellow dwarf disease infection (%) among cultivars. The cultivar Pioneer 25R47 and Magnolia were found statistically similar between each other on viral disease level of infection (%). However they were different from Terral LA841 and Coker 9553, same that showed to be not statistically different between each other.

Table 4.3. Barley Yellow Dwarf Disease Infection (%) per Cultivar at the Howe Location in 2011

Cultivar	N	Mean (%)*
Pioneer 25R47	12	1.79a
Magnolia	12	1.54a
Terral LA841	12	1.08b
Coker 9553	12	1.04b

*Means with the same letter are not statistically different at α=0.05 significance level.

Table 4.4 reports the results from conducting an analysis of variance for barley yellow dwarf infection and the overall yield among cultivars in evaluation at the Howe location in 2011. The analysis of variance was performed using PROC GLM in SAS. This analysis was done to evaluate how the viral disease barley yellow dwarf affects the overall yield mean. Coker 9553 showed the highest overall yield (5646.26 kg/ha) in the presence of barley yellow dwarf and the lowest viral infection level among the rest of cultivars in this study (Table 4.4).

Table 4.4. ANOVA for Barley Yellow Dwarf Disease Infection (%) and Overall Yield (kg/ha) per Cultivar at the Howe Location in 2011

Cultivar	N	Overall Yield (kg/ha)		Barley Yellow Dwarf Infection (%)	
		Mean	Std. Dev.	Mean	Std. Dev.
Coker 9553	12	5,646.26	340.98	1.04	0.14
Magnolia	12	5,013.74	387.13	1.54	0.50
Pioneer 25R47	12	4,633.61	260.46	1.79	0.45
Terral AL841	12	5,508.88	408.85	1.08	0.29

4.2 Yield Analysis

This present study also evaluated the effects of cultivar, location, and year on the average wheat yield response to tebuconazole application. Table 4.5 reports the results from conducting an analysis of variance for wheat yield (kg/ha) among all cultivars and locations during 2011 and 2012. This analysis of variance was performed using PROC GLM in SAS. The main objective of this analysis was to evaluate the overall wheat yield average response to tebuconazole applications. These results indicated statistically significant differences ($P<0.05$) on mean yield (kg/ha) among the two years of study (Table 4.5).[9] The interaction between year and treatment effect also showed statistically significant differences ($P<0.05$). This result shows that wheat

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[9] Additional information about the ANOVA source and coefficient of variation results for wheat yield (kg/ha) response to fungicide applications among all locations and cultivars in 2011 and 2012 are provided in Appendix A, Table A.2

yield was affected differently by the level of fungicide treatment during each year of study. In order to provide a more in depth analysis of the effect of fungicide applications on wheat yields among years, each year was analyzed separately (Table 4.6 and 4.11).

Table 4.5. ANOVA for Wheat Yield (kg/ha) Response to Fungicide Applications in 2011 and 2012

Source	DF	Mean Square	F Value	Pr > F
Year	1	90,035,162.00	601.25	<0.0001
Location	2	16,633,801.40	111.08	<0.0001
Location*Year	2	1,045,569.94	6.98	0.0011
Treatment	1	5,907,666.05	39.45	<0.0001
Treatment*Year	1	3,814,899.67	25.48	<0.0001
Location*Treatment	2	997,778.97	6.66	0.0015
Location*Treatment*Year	2	600,384.97	4.01	0.0195
Cultivar	3	5,347,546.25	35.71	<0.0001
Cultivar*Year	3	2,116,317.93	14.13	<0.0001
Location*Cultivar	6	1,516,552.40	10.13	<0.0001
Location*Cultivar*Year	6	2,180,117.92	14.56	<0.0001
Treatment*Cultivar	3	388,173.34	2.59	0.0535
Treatment*Cultivar*Year	3	264,861.34	1.77	0.1540
Location*Treatment*Cultivar	6	196,873.48	1.31	0.2515
Location*Treatment*Cultivar*Year	6	119,835.88	0.80	0.5706
Rep(location)	15	420,479.19	2.81	0.0005

Table 4.6 reports the results from conducting an analysis of variance for wheat yield (kg/ha) among all cultivars and locations for evaluation in 2011. The analysis of variance was performed using PROC GLM in SAS.[10] This analysis evaluated the wheat yield average response to tebuconazole applications during this year. Results showed that in 2011, there was not a significant effect of tebuconazole treatment on the overall yield response compared to the control

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[10] Additional information about the ANOVA source and coefficient of variation results for wheat yield (kg/ha) response to fungicide applications among all locations and cultivars in 2011 is provided in Appendix A, Table A.3

(P=0.3629). Similarly, there was not a significant interaction of tebuconazole treatment among cultivars (P=07941). However, there were significant differences on yield response among cultivars (P<0.0001) and locations (P<0.0001).

This study found statistically significant differences across (P<0.0001) and between cultivar and location (P=0.0034) on the overall yield response in 2011(Table 4.6). Different from this study, Reid and Swart (2004) observed statistically significant yield increases of 34% to 41% in treated plots compared to the untreated plots.

Differences between locations can be related to temperature conditions (Tadesse, Ayalew, and Badebo, 2010). Orum, Pinnschmidt and Jorgensen (2006) also attribute differences in yield observed from region to region to agronomic practices such as crop rotation, soil quality and disease severity registered in the different fields. According to Tadesse, Ayalew, and Badebo (2010), there could be differences between locations when fungicides are used to avoid yield losses from fungal diseases. Most of these differences are related to the lower temperature conditions recorded among years. Therefore yield increase differences from this experiment could be attributed to the amount of rainfall (mm) received during each year, which was greater in 2012 than rainfall average in 2011.

Table 4.6. ANOVA for the Wheat Yield (kg/ha) Response to Fungicide Applications in 2011

Source	DF	F Value	Pr > F
Location	2	93.94	<0.0001
Treatment	1	0.83	0.3629
Location*Treatment	2	0.25	0.7792
Cultivar	3	23.57	<0.0001
Location*Cultivar	6	3.50	0.0034
Treatment*Cultivar	3	0.34	0.7941
Location*Treatment*Cultivar	6	0.62	0.7131
Rep(location)	15	1.31	0.2119

Table 4.7 reports Tukey's HSD means separation test for the overall average yield (kg/ha) per year from all cultivars and locations for evaluation in this study. The Tukey's means separation test was conducted using the PROC GLM procedure in SAS. This test is used to observe the differences in the overall yield from fungicide applications each year. The overall average yield in 2011 is 4,632.10 kg/ha, which is lower than the overall average yield of 5,750.36 kg/ha in 2012 (Table 4.7). In addition, the overall average yield (kg/ha) in 2011 is statistically different from the overall average yield (kg/ha) in 2012 at the 5% significance level.

Table 4.7. Yield (kg/ha) Response to Fungicide Applications per Year, Averaged across Three Locations and Four Cultivars

Year	N	Mean (kg/ha)*
2012	144	5,750.36a
2011	144	4,632.10b

*Means with the same letter are not statistically different at α=0.05 significance level.

Table 4.8 reports Tukey's HSD means separation test for the overall average yield gain (kg/ha) per cultivar from all locations for evaluation in 2011. The Tukey's means separation test was conducted using the PROC GLM procedure in SAS. This test is used to observe the differences in yield from fungicide application among cultivars in 2011. In 2011, the cultivars Coker 9553 and Pioneer 25R47 were found to have yield responses that were statistically different from each other at the 5% significance level ($\alpha = 0.05$). In contrast, the cultivars Magnolia and Terral LA841 showed no significant differences between each other at the 5% significance level (Table 4.8). In addition, Coker 9553 provided the highest average yield of

4,974.75 kg/ha while Pioneer 25R47 provided the lowest average yield response of 4,250.59 kg/ha in 2011.

This study found no effect of fungicide treatments on cultivars' yield. However, differences in yield between cultivars were observed in this study. This result could be attributed to the cultivars' resistance to foliar diseases (strip rust and leaf rust). In fact, the cultivars evaluated in this study were partially resistant to leaf rust and stipe rust, therefore they are expected to be less susceptible to infection with those diseases (Reid and Swart, 2004).

Table 4.8. Yield (kg/ha) Response to Fungicide Applications per Cultivar, Averaged across Locations in 2011

Cultivar	N	Mean (kg/ha)*
Coker 9553	36	4,974.75a
Terral LA841	36	4,698.27b
Magnolia	36	4,604.81b
Pioneer 25R47	36	4,250.59c

*Means with the same letter are not statistically different at α=0.05 significance level.

Table 4.9 reports Tukey's HSD means separation test for the overall average yield gain (kg/ha) per location from all cultivars for evaluation in 2011. The Tukey's means separation test was conducted using the PROC GLM procedure in SAS. This test is used to observe the differences in yield from fungicide application among locations in 2011. In 2011, the yield means at the three locations were statistically different from each other at a 5% significance level. The highest yield was obtained at the Howe location with 5,200.63 kg/ha, followed by Royse City and Leonard location which produced 4,504.9 kg/ha and 4,190.78 kg/ha, respectively (Table 4.9). Similar to this study, Orum, Pinnschmidt and Jorgensen (2006) also found differences on potential yield gain varied from region to region. They attributed these differences to agronomic practices such as crop rotation, soil quality and disease severity registered in the different fields. In this present study, such variables previously mentioned, may also explain the variances between locations, especially crops rotation.

Table 4.9. Yield (kg/ha) Response to Fungicide Applications per Location, Averaged across Four Cultivars in 2011

Location	N	Mean (kg/ha)*
Howe	48	5,200.63a
Royse City	48	4,504.90b
Leonard	48	4,190.78c

*Means with the same letter are not statistically different at α=0.05 significance level.

Table 4.10 reports Tukey's HSD means separation test for the overall average yield gain (kg/ha) for the interaction between all locations and cultivars in 2011. The Tukey’s means separation test was conducted using the PROC GLM procedure in SAS. This test is used to observe the differences in yield among fungicide application levels between locations and cultivars in 2011. There were significant differences in wheat yield among cultivars and locations. The highest yield gain was obtained from the cultivar Coker 9553 at the Howe location.

Table 4.10. Yield (kg/ha) Response to Fungicide Applications for the Interaction between Location and Cultivar in 2011

Level of Location	Level of Cultivar	N	Yield (kg/ha) Mean	Yield (kg/ha) Std. Dev.
Leonard	Coker 9553	12	4,501.33	242.95
Leonard	Magnolia	12	4,152.37	351.65
Leonard	Pioneer 25R47	12	3,862.58	388.31
Leonard	Terral LA841	12	4,246.86	498.02
Royse City	Coker 9553	12	4,776.65	239.26
Royse City	Magnolia	12	4,648.31	396.12
Royse City	Pioneer 25R47	12	4,255.58	329.43
Royse City	Terral LA841	12	4,339.07	464.73
Howe	Coker 9553	12	5,646.26	340.98
Howe	Magnolia	12	5,013.74	387.13
Howe	Pioneer 25R47	12	4,633.61	260.46
Howe	Terral LA841	12	5,508.88	408.85

Table 4.11 reports the results of an analysis of variance for wheat yield (kg/ha) among all cultivars and locations evaluated in 2012. The analysis of variance was developed using PROC GLM in SAS.[11] This analysis evaluated the wheat yield mean response to tebuconazole applications during this year. In 2012, significant ($P<0.05$) effects of tebuconazole treatments on yield response were observed between the treated and the untreated plots. Tebuconazole treatments also had a significant interaction with location and cultivar. The results also showed differences on the wheat yield gain across cultivar and location, as well as the interaction of these last two variables (Table 4.11). This means that there was an effect of tebuconazole treatments levels among the levels of the interactions between cultivars and locations.

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[11] Additional information about the ANOVA source and coefficient of variation results for wheat yield (kg/ha) response to fungicide applications among all locations and cultivars in 2012 is provided in Appendix A, Table A.4

Table 4.11. P>F Values from the ANOVA for the Variable Yield (kg/ha) Response to Fungicide Applications in 2012

Source	DF	Type III SS	Mean Square	F Value	Pr > F
Location	2	9,719,084.22	4,859,542	40.76	<0.0001
Treatment	1	9,608,614.04	9,608,614	80.59	<0.0001
Location*Treatment	2	3,128,082.93	1,564,041	13.12	<0.0001
Cultivar	3	12,740,764.70	4,246,922	35.62	<0.0001
Location*Cultivar	6	19,316,161.80	3,219,360	27.00	<0.0001
Treatment*Cultivar	3	1,818,575.21	606,192	5.08	0.0025
Location*Treatment*Cultivar	6	1,391,781.19	231,964	1.95	0.0802
Rep(location)	15	10,477,517.40	698,501	5.86	<0.0001

Table 4.12 reports Tukey's HSD means separation test for the average yield gain (kg/ha) from all cultivars and locations in 2012. The Tukey’s means separation test was conducted using the PROC GLM procedure in SAS. This test is used to observe the differences in wheat yield between the application and the non-application of fungicide treatments in 2012. Results showed that there were significant differences (P<0.05) between fungicide treated and non-treated plots in the overall mean yield. These differences represent a 8.6% yield increase between the tebuconazole treatment over the control treatment in 2012 (Table 4.12). Similar to our findings, Reid and Swart (2004) reported yield increases of 34% to 41% over untreated plots when wheat was treated with foliar fungicides. Additionally, Wiik and Rosenqvist (2010) also found yield increase in several years of study due to a single fungicide treatment during the period 1983-2007.

Table 4.12. Yield (kg/ha) Response to Fungicide Application Treatments, Averaged across Three Locations and Four Cultivars in 2012

Treatment	N	Mean (kg/ha)*
Treatment	72	6,008.67a
Control	72	5,492.04b

*Means with the same letter are not statistically different at α=0.05 significance level.

Table 4.13 reports Tukey's HSD means separation test per location for the average yield (kg/ha) from all cultivars in 2012. The Tukey’s means separation test was conducted using the PROC GLM procedure in SAS. This test is used to observe the differences in wheat yield in response to tebuconazole treatments among locations in 2012. In 2012, only the Howe location showed statistically significant differences from the other two locations in this study. This location also had the highest average yield response of 6113.62 kg/ha (Table 4.13). Different from 2012, results from 2011 showed significant differences across each location. However, data from both years reported that the greatest yield average gain was obtained from Howe.

Table 4.13. Yield (kg/ha) Response to Fungicide Application per Location, Averaged across Three Locations and Four Cultivars in 2012

Location	N	Mean (kg/ha)*
Howe	48	6,113.62a
Royse City	48	5,616.40b
Leonard	48	5,521.06b

*Means with the same letter are not statistically different at α=0.05 significance level.

Table 4.14 reports Tukey's HSD means separation test per cultivar for the average wheat yield gain (kg/ha) from locations in 2012. The Tukey’s means separation test was conducted using the PROC GLM procedure in SAS. This test is used to observe the differences in wheat yield response to tebuconazole application among cultivars in 2012. In 2012, the highest mean yields were obtained from the cultivar Coker (6215.04 kg/ha), followed by Pioneer 25R47 (5763.93 kg/ha), Magnolia (5619.46 kg/ha) and Terral LA 841 (5403.00 kg/ha). However, yield from Pioneer 25R47 and Magnolia were not significantly different from each other ($P<0.05$) (Table 4.14).

Table 4.14. Yield (kg/ha) Response to Fungicide Applications per Cultivar, Averaged across Three Locations (kg/ha) in 2012

Cultivar	N	Mean (kg/ha)*
Coker 9553	36	6,215.04a
Pioneer 25R47	36	5,763.93b
Magnolia	36	5,619.46b
Terral LA841	36	5,403.00c

*Means with the same letter are not statistically different at $\alpha=0.05$ significance level.

Table 4.15 reports Tukey's HSD means separation test for the average wheat yield gain (kg/ha) among the treatments and cultivars levels evaluated in 2011. The Tukey’s means separation test was conducted using the PROC GLM procedure in SAS. This test is used to observe the differences in wheat yield response to tebuconazole treatments among the levels of cultivars and locations in 2012. Compared to the results from 2012, there was a significant effect ($P<0.05$) of tebuconazole treatment on yields response in 2012. Considering this effect, the cultivar Coker 9553 reached the highest yield at 6,407.75 kg/ha when tebuconazole was applied, which represents a 6% increase compared to the yield from the control treatment (Table 4.15).

Table 4.15. Yield (kg/ha) Response to Fungicide Applications for the Interaction between Fungicide Treatment and Cultivar Levels, Averaged across Three Locations in 2012

Level of Treatment	Level of Cultivar	N	Yield (kg/ha) Mean	Yield (kg/ha) Std. Dev.
Control	Coker 9553	18	6,022.34	550.87
Control	Magnolia	18	5,202.93	571.17
Control	Pioneer 25R47	18	5,643.82	728.17
Control	Terral LA841	18	5,099.09	346.97
Treatment	Coker 9553	18	6,407.75	580.10
Treatment	Magnolia	18	6,035.99	504.97
Treatment	Pioneer 25R47	18	5,884.04	1,052.75
Treatment	Terral LA841	18	5,706.91	588.63

Research from Wiik and Rosenqvist (2010) addressed that the effect of fungicide applications on yield increase in wheat production is influenced by climate changes over time. In this study, yield differences between years could also be influenced by weather such as the amount of precipitation per year, which was higher in 2012 than 2011. Wiik and Rosenqvist (2010) also explained that yield gain can be affected by changes in controllable factors (fungicide and cultivar choice, crop rotation, techniques) and uncontrollable factors (emergence of new diseases and changes in grain prices).

4.3 Net Return Analysis

Table 4.16 reports the results from conducting an analysis of variance for net returns response to fungicide applications. The analysis of variance was developed using PROC GLM in SAS, version 9.3.[12] This analysis evaluated the effect of tebuconazole application among cultivars and

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[12] Additional information about the ANOVA source and coefficient of variation results for wheat net returns (k$/hg) response to fungicide applications among all locations and cultivars in 2011 and 2012 is provided in Appendix A, Table A.5

locations on net returns in 2011 and 2012. Results demonstrated a difference between years (P<0.05), locations (P<0.05) and a significant interaction between them (P<0.05; Table 4.16).

Table 4.16. ANOVA for the Wheat Net Return Response to Fungicide Applications in 2011 and 2012

Source	DF	Type III SS	Mean Square	F Value	Pr > F
Location	2	227,621.00	113,811.00	5.59	0.0048
Cultivar	3	140,849.00	46,949.60	2.31	0.0802
Cultivar*Location	6	143,406.00	23,900.90	1.17	0.3248
Year	1	445,384.00	445,384.00	21.88	<0.0001
Location*Year	2	128,745.00	64,372.60	3.16	0.0459
Cultivar*Year	3	93,470.00	31,156.70	1.53	0.2102
Cultivar*Location*Year	6	85,726.50	14,287.80	0.70	0.6487

Table 4.17 reports Tukey's HSD means separation test for the overall average net return ($/kg) from all cultivars and locations for evaluation in 2011 and 2012. The Tukey’s means separation test was conducted using the PROC GLM procedure in SAS.[13] This test is used to observe the net return differences from fungicide applications in each year of the study. In 2011, the mean net returns were -3.53 $/ha. Net returns in 2012 were considerably lower than net returns in2012, which were $107.7/ha (Table 4.17). Fungal diseases were not found in this study. However, a viral disease was found at very low levels and was observed only at one single location in 2011. Wegulo et al. (2011) and Wiik and Rosenqvist (2010) suggested that net returns can result in loss if fungicides are applied when disease severity rates are low. Therefore, according to Wegulo et al. (2011), negative net returns from fungicide applications were

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[13] Additional information about the ANOVA source and coefficient of variation results for wheat net returns (k$/hg) response to fungicide applications among all locations and cultivars in 2011 are provided in Appendix A, Table A.6

expected. On the other hand, even if we did not observe fungal disease ratings, there still was a positive net return from fungicide applications in 2012.

Table 4.17. Net Return ($/ha) from Fungicide Applications per Year Averaged across Three Locations and Four Cultivars

Year	N	Mean ($/ha)*
2012a	72	107.70
2011b	72	-3.53

*Means with the same letter are not statistically different at α=0.05 significance level.

Table 4.18 reports Tukey's HSD means separation test for the overall average net return ($/kg) per location among all cultivars in 2011 and 2012. The Tukey’s means separation test was conducted using the PROC GLM procedure in SAS. This test is performed to observe the net return differences from fungicide applications at each location on evaluation. Net returns of $108/ha obtained at the Howe location were greater than and significantly different ($P<0.05$) from the Royse City location which were $28.18/ha and the Leonard location which were $19.97/ha (Table 4.18). The net return analysis also coincides with the results obtained from the yield increase analysis, in which the Howe location had the highest yield from the two years of experimental research. Furthermore, both analyses demonstrated to have no significant differences between Royse City and Leonard when analyzing yield increase and net returns from tebuconazole applications.

Table 4.18. Net Return ($/ha) from Fungicide Applications per Location, Averaged across Four Cultivars and Two Years

Location	N	Mean ($/ha)*
Howe	48	108.12a
Royse City	48	28.18b
Leonard	48	19.97b

*Means with the same letter are not statistically different at α=0.05 significance level.

Due to a significant interaction between year and location, data was analyzed by year to observe the effect of tebuconazole applications on net returns between locations among each year. Table 4.19 reports the analysis of variance for net returns ($/kg) among cultivars and locations in 2012. The analysis of variance was developed using PROC GLM in SAS.[14] This analysis was conducted to evaluate the effect of tebuconazole treatments on net returns among cultivars and locations in 2011 and 2012. From the analysis done by year, in 2011, no statistical differences were found between cultivar, location and their interactions.[15] In 2012, differences in both, cultivar and locations were found to be statistically significant (Table 4.19).

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[14] Additional information about the ANOVA source and coefficient of variation results for wheat net returns (k$/hg) response to fungicide applications among all locations and cultivars in 2012 is provided in Appendix A, Table A.6

[15] Additional information about the ANOVA results for wheat net returns (k$/hg) response to fungicide applications among all locations and cultivars in 2011 is provided in Appendix A, Table A.7

Table 4.19. ANOVA for the Variable Net Return ($/ha) Response to Fungicide Applications in 2012

Source	DF	Type III SS	Mean Square	F Value	Pr > F
Location	2	346,376.00	173,188.00	11.43	<0.0001
Cultivar	3	214,873.00	71,624.20	4.73	0.0050
Cultivar*Location	6	157,935.00	26,322.60	1.74	0.1277

Table 4.20 reports Tukey's HSD means separation test per cultivar for the net return average ($/kg) among locations in 2012. The Tukey's means separation test was conducted using the PROC GLM procedure in SAS. This test is performed to observe the differences on net returns response from the effect of tebuconazole application among cultivars in 2012. Net returns from the cultivar Magnolia ($182.8/ha) was similar to Terral LA841 ($133.43/ha) but different from Coker 9553 ($73.92/ha) and Pioneer 25R47 ($40.66/ha). These last two cultivars had no differences on net return means between them. However, Magnolia and Terral LA841, Coker 9553 and Pioneer 25R47 showed similarity on net returns averages from fungicide applications this year (Table 4.20).

Table 4.20. Net Return ($/ha) from Fungicide Applications per Cultivar, Averaged across Three Locations in 2012

Cultivar	N	Mean ($/ha)*
Magnolia	18	182.80a
Terral LA841	18	133.43ab
Coker 9553	18	73.92b
Pioneer 25R47	18	40.66b

*Means with the same letter are not statistically different at α=0.05 significance level.

Table 4.21 reports Tukey's HSD means separation test per location for the net return average ($/kg) among cultivars in 2012. The Tukey’s means separation test was performed using the PROC GLM procedure in SAS. This test is done to observe the effect of tebuconazole applications on net returns between locations in 2012. From the separation mean in 2012, net returns had significant differences between locations in which means were significantly different and higher at Howe ($204.46/ha) than the rest of the locations. Royse City ($73.25/ha) and Leonard ($45.39/ha) had no significant differences on net returns means between each other (Table 4.21).

Table 4.21. Net Return ($/ha) from Fungicide Applications per Location, Averaged across Four Cultivars in 2012

Location	N	Mean ($/h)*
Howe	24	204.46a
Royse City	24	73.25b
Leonard	24	45.39b

*Means with the same letter are not statistically different at α=0.05 significance level.

Table 4.22 reports the number of observations that resulted in positive net returns from fungicide treatments in this study. The analysis was performed among all cultivars and locations evaluated in 2011 and 2012. This analysis was conducted to determine the percentage of observations that resulted in positive net returns from tebuconazole treatments. The numbers of fungicide treatment observations resulting in positive and negative net returns were measured for each combination of cultivar, location and year (Table 4.22).

Table 4.22. Percentage of Tebuconazole Observations that Resulted in Positive Net Returns from Fungicide Treatments, Averaged across 2011 and 2012

Location	Cultivar	Number of Observations					Proportions Rn>0
		2011	2012	Total	Rn>0	Rn<0	
Leonard	Coker 9553	5	4	12	9	3	0.75
	Magnolia	2	4	12	6	6	0.50
	Pioneer 25R47	3	3	12	6	6	0.50
	Terral LA841	2	5	12	7	5	0.58
Royse City	Coker 9553	2	6	12	8	4	0.67
	Magnolia	4	6	12	10	2	0.83
	Pioneer 25R47	3	2	12	5	7	0.42
	Terral LA841	3	6	12	9	3	0.75
Howe	Coker 9553	4	5	12	9	3	0.75
	Magnolia	2	6	12	8	4	0.67
	Pioneer 25R47	4	5	12	9	3	0.75
	Terral LA841	3	6	12	9	3	0.75

Table 4.23 reports the percentage of observations that resulted in positive net returns from fungicide treatments per year. This analysis was done considering all cultivars and locations for evaluation. The objective of this analysis was to observe any difference on net returns depending on each year of study. During the two years, the 66% of the observations between the treated and the untreated plots resulted in positive net returns (see Table 4.23). This proportion was greatly affected by year, due to significant differences between the numbers of observations resulting in positive net returns among each year. In 2011, 37 observations out of 72 (51%) of the experiments treated with fungicides, resulted in positive net returns. Different from 2011, more observations resulted in positive net returns in 2012. The 81% (59 out 72) of observations where fungicide was applied resulted in positive net returns that year (Table 4.23).

Table 4.23. Percentage of Tebuconazole Observations that Resulted in Positive Net Returns from Fungicide Treatments each Year, Averaged across Three Locations and Four Cultivars

		Number of Observations		
Year	Total	Rn>0	Rn<0	Proportions Rn>0
2011	72	37	35	0.51
2012	72	58	14	0.81
Average	144	95	49	0.66

The percentages of observations that resulted in positive net returns at each location are described in Table 4.24. This analysis was done including all cultivars for evaluation across the two years of study. The percentage of entries resulted in positive net returns per location showed similar results to the net return analysis, when making comparison between locations. Thus, from the 48 observation or experimental units evaluated during 2011 and 2012; in Howe 35 (73%) of the observations resulted in positive net returns to the grower. At the same time, Leonard also had the lowest (58%) number of observations with positive net returns from fungicide applications as it was also observed from the net returns analysis.

Table 4.24. Percentage of Tebuconazole Treatments that Resulted in Positive Net Returns per Location, Averaged across Three Cultivars and Two Years

Location	Number of Observations					Proportions Rn>0
	2011	2012	Total	Rn>0	Rn<0	
Leonard	12	16	48	28	20	0.58
Royse City	12	20	48	32	16	0.67
Howe	13	22	48	35	13	0.73

Table 4.25 describes the percentage of the observations that resulted in positive net returns per cultivar. This analysis was done including all locations across the two years of study.

When analyzing the economic effect of tebuconazole treatments, there were significant differences among locations and among cultivars on the proportion of treatments resulting in positive net returns. Coker 9553 resulted in 35 out of 48 observations with positive net returns (72%) across the two years of study. Looking back to the results from the yield analysis, it showed that the highest yield in kg/ha was also found from the cultivar Coker 9553 (Table 4.25).

Table 4.25. Percentage of Tebuconazole Treatments that Resulted in Positive Net Returns per Cultivar, Averaged across Three Locations and Two Years

Cultivar	Number of Observations					Proportions Rn>0
	2011	2012	Total	Rn>0	Rn<0	
Coker 9553	11	15	36	26	10	0.72
Magnolia	8	16	36	24	12	0.67
Pioneer 25R47	10	10	36	20	16	0.56
Terral LA841	8	17	36	25	11	0.69

The percentage of observations that resulted in positive net returns from fungicide applications, during the two years of study, ranged from 42% to 83% (Table 4.22). The overall percentage of positive observations was mostly due to the high number of entries that resulting in negative net returns in 2011. This year also showed negative mean net returns from the net return analysis discussed previously. Similar to our findings, Wiik and Rosenqvist (2010) reported having a negative mean net return during 10 years of study and less than 50% of the entries were profitable to treat in 11years. In addition, Wiik and Rosenqvist (2010) mentioned that wheat price had the largest impact on the net return from fungicide treatments, followed by the cost of the fungicides.

4.4 Profitability Analysis

Table 4.26 reports the probabilities of making a positive net return of 0%, 25%, and 50% on the tebuconazole investment from a single fungicide application in wheat production.[16] This probability analysis was done for the three locations and four cultivars during the two years of study. The probabilities of making net returns of 0% on a single fungicide application of tebuconazole in wheat production ranged from 0.03 to 1 at a price of $0.25/kg and from 0.034 to 1 at $0.30/kg (Table 4.26).

The probability of making 25% net return from fungicide investments was also evaluated and ranged from 0.024 to 1 at a grain price of $0.25/kg and from 0.29 to 1 at a wheat price of $0.30/kg. The lowest probability occurred when the probability of obtaining 50% net returns on investments was calculated and decreased when the wheat price changed from $25/kg to $30/kg. According to Bestor (2011), the overall probability of making a net return on a fungicide application ranged from 0.01 to 0.99 and increased as wheat price increased. In our study, the probability of making net returns decreases as the wheat price increased from $0.25/kg to $0.3/kg.

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[16] The methodology that corresponds to the profitability analysis results presented in this section was discussed in Section 3.7.

Table 4.26. Probability of Making Net Returns of 0%, 25%, and 50% of the Investment on a Single Fungicide Application in Wheat Production, Averaged across Three Locations and Four Cultivars

			Yield Increase from Fungicide Treatments	Net Returns =0% on Investment		Net Returns =25% on Investment		Net Returns =50% on Investment	
Year	Location	Cultivar	(kg/ha)	0.25 ($/kg)	0.30 ($/kg)	0.25 ($/kg)	0.30 ($/kg)	0.25 ($/kg)	0.30 ($/kg)
2011	Leonard	Coker 9553	182.43	0.80	0.82	0.76	0.79	0.72	0.76
		Magnolia	-193.53	0.10	0.11	0.09	0.10	0.07	0.09
		Pioneer 25R47	73.77	0.51	0.53	0.48	0.50	0.45	0.48
		Terral LA841	128.64	0.58	0.59	0.56	0.57	0.53	0.56
	Royse City	Coker 9553	282.00	0.60	0.63	0.56	0.60	0.51	0.56
		Magnolia	463.49	0.70	0.72	0.67	0.69	0.65	0.67
		Pioneer 25R47	-76.15	0.03	0.03	0.02	0.03	0.02	0.02
		Terral LA841	358.12	0.41	0.43	0.39	0.41	0.36	0.39
	Howe	Coker 9553	106.12	0.59	0.61	0.55	0.58	0.52	0.55
		Magnolia	190.28	0.72	0.74	0.70	0.72	0.67	0.70
		Pioneer 25R47	-271.25	0.52	0.55	0.47	0.51	0.43	0.47
		Terral LA841	5.47	0.49	0.51	0.46	0.48	0.43	0.46
2012	Leonard	Coker 9553	526.23	0.75	0.76	0.73	0.75	0.72	0.73
		Magnolia	502.75	0.93	0.93	0.92	0.93	0.91	0.92
		Pioneer 25R47	33.82	0.33	0.34	0.31	0.32	0.29	0.31
		Terral LA841	393.80	0.90	0.91	0.88	0.90	0.87	0.88
	Royse City	Coker 9553	113.61	0.97	0.97	0.96	0.97	0.96	0.96
		Magnolia	201.99	0.99	0.99	0.98	0.98	0.98	0.98
		Pioneer 25R47	75.71	0.45	0.46	0.42	0.44	0.40	0.42
		Terral LA841	61.90	0.99	0.99	0.99	0.99	0.98	0.99
	Howe	Coker 9553	348.02	0.94	0.95	0.93	0.94	0.91	0.93
		Magnolia	1532.94	1.00	1.00	1.00	1.00	1.00	1.00
		Pioneer 25R47	762.99	1.00	1.00	1.00	1.00	1.00	1.00
		Terral LA841	1071.54	1.00	1.00	1.00	1.00	1.00	1.00

Table 4.27 describes the probabilities of making net returns of 0%, 25%, and 50% on investments from a single application of tebuconazole at each location. This probability analysis

was done across cultivars and years. This was conducted to analyze differences on the probabilities when data from each location was considered separately. The highest probability of obtaining positive net returns was observed at the Howe location. Additionally, the highest mean yield increase (kg/ha) between the treated and untreated plots was also obtained at the Howe location (Table 4.27).

The probability of profitable fungicide applications is also linked to the cultivar potential to produce yield, cultivar resistance to fungal disease and the disease level of infection at the time of application (Munkvold et al., 2001). Even if the Howe location was affected by viral infection levels of barley yellow dwarf in 2011, it still demonstrated to have the highest yield response. It is important to consider that levels of infection were very low and that they did not significantly affect the yields.

Table 4.27. Probabilities of Making Net Returns Of 0%, 25%, and 50% of the Investment on a Single Application of Tebuconazole in the Leonard, Royse City and Howe Location, Averaged across Four Cultivars and Two Years

Location	Yield Increase From Fungicide Treatments (kg/ha)	Net Returns =0% on Investment		Net Returns =25% on Investment		Net Returns =50% on Investment	
		0.25 ($/kg)	0.30 ($/kg)	0.25 ($/kg)	0.30 ($/kg)	0.25 ($/kg)	0.30 ($/kg)
Leonard	152.35	0.68	0.71	0.65	0.68	0.61	0.65
Royse City	185.90	0.77	0.79	0.73	0.76	0.70	0.73
Howe	521.09	1.00	1.00	1.00	1.00	1.00	1.00

Table 4.28 reports the probabilities of making net returns of 0%, 25%, and 50% on investments from a single application of tebuconazole in each cultivar. This probability analysis was performed across locations and years. The main purpose of this study was to know if there

were differences on the probabilities of obtaining positive bet returns according to each cultivar. In average, the lowest probability of achieving positive net returns from a single fungicide treatment was observed from the cultivar Pioneer 25R47 and it decreased as wheat price changed from $0.30/kg to $0.25/kg (Table 4.28). This was due to low yields observed in this cultivar from the yield response analysis, where Pioneer 25R47 obtained 4,633.61 kg/ha. This cultivar had the lowest mean yield across the other cultivars for evaluation.

Different from Pioneer 25R47, Coker 9553 obtained the highest yield response from the yield analysis; however the results from the probability analysis did not indicated that Coker 9553 had the highest probability of obtaining positive net returns (Table 4.28). Bestor (2011) indicated that increases in yield do not necessarily mean that the probability to obtain positive net returns would be high and that other factors such as weather conditions and cultivar resistant to fungal disease should be considered.

Leaf rust and stripe rust disease severity infection levels affect the probability of obtaining profits from fungicide applications. According to Bestor (2012), high probabilities of obtaining net returns were observed in plots where disease infection levels were also high. This means that the fungicide will actually help to control the disease infection as opposed to applying it when is not necessary and the cost of the fungicide will just increase production cost. The low probability of net returns from Coker 9553 can be explained by the low viral infection that affected the Howe location in 2011. In this location, Coker 9553 demonstrated low infection levels during that year (1.04%). The highest probability of making net returns greater than 0% on investments were obtained from Magnolia, followed by Terral LA841. Both cultivars demonstrated to have high yield but as high as the yield from the cultivar Coker 9553.

Table 4.28. Probabilities of Making Net Returns of 0%, 25%, and 50% of the Investment on a Single Application of Tebuconazole for Coker 9553, Magnolia, Pioneer 25R47 and Terral LA841

Cultivar	Yield Increase from Fungicide Treatments (kg/ha)	Net Returns =0% on Investment 0.25 ($/kg)	Net Returns =0% on Investment 0.30 ($/kg)	Net Returns =25% on Investment 0.25 ($/kg)	Net Returns =25% on Investment 0.30 ($/kg)	Net Returns =50% on Investment 0.25 ($/kg)	Net Returns =50% on Investment 0.30 ($/kg)
Coker 9553	259.73	0.86	0.88	0.84	0.86	0.82	0.84
Magnolia	449.65	0.99	0.99	0.99	0.99	0.99	0.99
Pioneer 25R47	99.81	0.56	0.58	0.52	0.55	0.49	0.52
Terral LA841	336.58	0.96	0.97	0.95	0.96	0.94	0.95

4.5 Sensitivity Analysis

A sensitivity analysis on net returns was done to investigate the impact of changing wheat prices and fungicide cost (application cost included) on net returns from tebuconazole applications in wheat production (Table 4.29). Also, a sensitivity analysis on yield increases from fungicide application was performed to evaluate changes in yield increases to changing wheat prices and fungicide cost (Table 4.30). The variation in wheat prices and fungicide costs for both studies are based on the most probable scenarios from the observed prices and costs during the two years of study. Wheat price and fungicide cost used as the base line for the sensitivity analysis were $0.25/kg and $0.1729/ha, respectively. A pessimistic and an optimistic scenario were evaluated in each sensitivity analysis. The pessimistic analysis considered scenarios in which wheat prices were decreasing and fungicide prices were increasing. In contrast, the optimistic analysis evaluated scenarios with increasing wheat prices and decreasing fungicide cost.

Table 4.29 reports the net return change ($/ha) from tebuconazole applications under different wheat prices and fungicide cost. This change was calculated based on a yield increase of 286.45 kg/ha which is the mean yield increase response to fungicide applications in the two years of study. The net returns from the baseline wheat price of $0.25/kg and the fungicide cost of $17.29/ha can be observed when both variables have 0% increment. Such net return corresponds to $54.32/ha and from this point. If we moved vertically or horizontally across the table, net returns will constantly changes from a pessimistic to the optimistic scenario. The pessimistic scenario is observed when fungicide cost start going up and decreasing prices on wheat are observed. In this study, the pessimistic scenario ranged from $54.34/kg (base line cost and price) to $18.76/kg when fungicide cost increased 40% and wheat price decreased to 60% of the original price (Table 4.29). The optimistic scenario occurred when fungicide cost decreased and wheat prices increased. This scenario can be observed in a range from $54.32/kg (base line fungicide price and wheat cost) to $89.88/kg, which is reached when fungicide cost drop down to 40% and wheat prices go up by 40% of the original price(Table 4.29).

Table 4. 29. Net Returns Increase ($/ha) from Tebuconazole Applications at Varying Wheat Prices and Fungicide Cost

		Tebuconazole Cost in $/ha (Application Cost Included)								
		24.21	22.48	20.75	19.02	17.29	15.56	13.83	12.10	10.37
Wheat Price Variation in $/kg	0.15	18.76	20.49	22.22	23.95	25.68	27.41	29.13	30.86	32.59
	0.18	25.92	27.65	29.38	31.11	32.84	34.57	36.30	38.02	39.75
	0.20	33.08	34.81	36.54	38.27	40.00	41.73	43.46	45.19	46.92
	0.23	40.24	41.97	43.70	45.43	47.16	48.89	50.62	52.35	54.08
	0.25	47.41	49.13	50.86	52.59	54.32	56.05	57.78	59.51	61.24
	0.28	54.57	56.30	58.02	59.75	61.48	63.21	64.94	66.67	68.40
	0.30	61.73	63.46	65.19	66.91	68.64	70.37	72.10	73.83	75.56
	0.33	68.89	70.62	72.35	74.08	75.80	77.53	79.26	80.99	82.72
	0.35	76.05	77.78	79.51	81.24	82.97	84.69	86.42	88.15	89.88

Table 4.30 reports the yield increase (kg/ha) needed to break even when having different wheat prices and fungicide cost. This analysis was conducted to observe the different scenarios of yield increases needed to offset the cost of fungicide (application included) when wheat prices and fungicide cost are constantly changing in the market. The 0% row and column in wheat price and fungicide cost variation represent the average magnitude of both variables that has been observed in the last two years. At this point, the yield increase needed to offset the cost of fungicide is 69.16 kg/ha and it decreases as fungicide cost decreases and is even lower when wheat prices increase at the same time. For this scenario, the minimum yield increase needed to break even can be found when wheat prices go up to40% more than the original base price and fungicide costs drop down 40%. On the other hand, 161.37 kg/ha is the yield increase needed to break even when fungicide cost increases 40% from the original cost and wheat price decrease 40%.

Table 4.30. Yield Increase (kg/ha) Needed to Break Even at Different Wheat Prices and Fungicide Cost Scenarios

		Tebuconazole Cost in $/ha (Application Cost Included)								
		24.21	22.48	20.75	19.02	17.29	15.56	13.83	12.10	10.37
Wheat Price Variation in $/kg	0.15	161.37	149.85	138.32	126.79	115.27	103.74	92.21	80.69	69.16
	0.18	138.32	128.44	118.56	108.68	98.80	88.92	79.04	69.16	59.28
	0.20	121.03	112.39	103.74	95.10	86.45	77.81	69.16	60.52	51.87
	0.23	107.58	99.90	92.21	84.53	76.84	69.16	61.48	53.79	46.11
	0.25	96.82	89.91	82.99	76.08	69.16	62.24	55.33	48.41	41.50
	0.28	88.02	81.73	75.45	69.16	62.87	56.59	50.30	44.01	37.72
	0.30	80.69	74.92	69.16	63.40	57.63	51.87	46.11	40.34	34.58
	0.33	74.48	69.16	63.84	58.52	53.20	47.88	42.56	37.24	31.92
	0.35	69.16	64.22	59.28	54.34	49.40	44.46	39.52	34.58	29.64

Table 4.31 presents an analysis of the yield increase response (kg/ha) by cultivar to tebuconazole applications. Data for this analysis included all locations during the two years of study. Most of the cultivars for evaluation in this study demonstrated to have the potential to produce the maximum yield increase to break even the cost of fungicide applications in the worst wheat price and fungicide cost scenario. However, the average yield increase from Pioneer 25R47 (99.80 kg/ha) during the two years of study demonstrated to be more susceptible to get the lowest net returns when having constant changes in wheat price and fungicide cost (Table 4.31).

Table 4.31. Yield Increase Response (kg/ha) by Cultivar to Tebuconazole Applications, Averaged across Three Locations

	Yield Increase (kg/ha)		
Cultivar	2011	2012	Average
Coker 9553	134.10	385.40	259.75
Magnolia	66.20	833.10	449.65
Pioneer 25R47	-40.60	240.20	99.80
Terral LA841	65.30	607.80	336.55

In summary, results from this study found that regardless of wheat price and fungicide cost, the economic impact of fungicide applications in wheat production depends mainly on the following factors: cultivar performance, disease potential of damage, the partial cultivar resistance to fungal disease and weather conditions. Yield performance refers to the cultivar potential to produce high or low yields. Choosing a cultivar that produces better yield than others, helps to avoid losses on net returns by harvesting more units per area and consequently to get more income from wheat production. In addition, applying fungicides when there are not fungal disease symptoms do not produce profits, unless the cultivar used is highly susceptible to that specific fungal disease. For this reason, it is important to choose cultivars that are resistant to the most common diseases that could affect wheat production.

Climate conditions in wheat production are very important when making the decision of applying or not applying foliar fungicides. Years with high rainfall conditions, disease severity tends to increase and the need for fungicide applications becomes indispensable. Finally, agronomic practices such as crop rotation, improving soil quality and fertilization should be considered because they have a high influence on yield and can even enhance yields when they are appropriately managed.

Chapter 5

SUMMARY AND CONCLUSION

The United States (U.S.) is the world's largest wheat producer with a production value around $14.37 billion in 2011 (USDA, 2012). Records from the last 10 years revealed that wheat is the 3rd largest crop planted in the U.S.; and therefore, one of the most important commodities for the economy (USDA, 2012). Furthermore, wheat prices have been increasing from $6.78 in 2007/2008 to $7.24/bushel in 2011/2012 (USDA, 2012). Texas ranked 8th among the major wheat producing states in the U.S. with more than 1.9 million acres in production (USDA, 2007). Additionally, wheat ranks as the third most planted crop in this state, behind forages and cotton. Most of the wheat is grown in the High Plains region in Texas.

Even though wheat production has demonstrated to have a successful future in the market, it is facing challenges related to foreign competition and fewer alternative options under government programs. As a result, wheat returns have relatively decreased compared to other crops. In addition, wheat harvested acreage has dropped off nearly 30 million acres or about one-third from its 1981 highest level (USDA, 2012). Since wheat is such an important crop in Texas and the U.S. market, it is important to constantly research techniques that allow wheat growers to obtain higher yields and larger profits in order to compete with other countries in the wheat market.

Fungal diseases are the number one reason for crops losses around the world and have a significant impact on yield and quality in wheat production (McGrath, 2004). The most frequent annual diseases in the wheat producing regions of the U.S. are leaf rust and stem rust (Kolmer, 2007). Studies have reported yield losses of up to 60% due to stripe rust but it can also cause 100% of losses (Chen, 2011). According to Hershman (2012) the use of seed treatments and foliar fungicides are usually necessary to maximize profits. In order to be effective, most fungicides need to be applied before the disease occurs or at the first appearance of symptoms. Additionally, McGrath (2004) pointed out that fungicides can only protect plants from getting infected and few fungicides are effective in plants that have already been infected.

According to Wegulo et al. (2009), U.S. studies have demonstrated yield increases in winter wheat due to fungicide applications. Most of these studies showed that up to 42% yield loss were prevented by spraying foliar fungicides in winter wheat. Hershman (2012) stated that fungicides are not used to get a “yield bump”. They actually protect yield potential that was already built into the crop from the management of controllable factors (fertilization, pest control, water irrigation, crop rotation) and uncontrollable factors (soil type, weather conditions). Some studies stated that when disease severity seems to reduce crop yields, then it is time to apply fungicides that may help protect the crop from potential losses. On the other hand, if disease severity is low such that no or nominal yield loss is possible, then applying a fungicide will not result in either a yield or economic advantage (Hershman, 2012).

Considering the importance of managing fungal diseases in wheat production, further research is needed to determine the economic benefits from foliar fungicide applications and their impact on net yields from Northeast Texas. For this reason, the Texas A&M AgriLife Extension Representative in Commerce, TX conducted a study to evaluate the response of four soft red winter wheat cultivars (Magnolia, Terral LA 841, Pioneer 25R47, and Coker 9553) with a tebuconazole application treatment vs. a non-application treatment (control). The experiments were conducted in Royse City, Howe, and Leonard during 2011 and 2012. The variables measured at the end of the study were grain yield in kg/ha and disease severity (%).

Consequently, this study used information on wheat fungicide trials available by the Texas A&M AgriLife Extension Representative in Commerce, TX. The main purpose was to address the impact of foliar fungicide applications on yields and net returns in wheat production in Northeast Texas. This study explained several economic tools that can be used to determine the impact of fungicide applications on wheat production. Important aspects such as the role of disease severity, wheat cultivar and weather conditions on fungicide efficacy to produce better yields are also discussed in this research.

The general objective of this study was to assist wheat growers in Northeast Texas with economic tools that allow them to assess the economic benefits from foliar fungicide applications in wheat production for Northeast. The specific objectives of the study were 1) to determine the effect of fungicide applications on the overall yield and net returns from wheat production 2) to determine the probability of obtaining profitable returns from tebuconazole applications and 3) to analyze net returns from fungicide spraying by using a sensitivity net return analysis.

Data on disease severity and wheat yield were analyzed using the PROC GLM in SAS, Statistical Software (SAS Institute, Cary, NC) version 9.3. Analysis of variance (ANOVA) models were developed to test treatment interactions with location, cultivar and year. Tukey's means separation test at 5% significance level was used to perform means comparisons between treatments.

Results from the disease severity analysis (Section 4.1) show that there was not fungal disease ratings recorded during the two years study. However, barley yellow dwarf which is a viral infection was detected at very low levels of infection at the Howe location in 2011. No other disease infection was observed at the other two locations (Royse City and Leonard). There were significant differences of barley yellow dwarf infection among cultivars (Table 4.2). The cultivar Cooer 9553 showed the lowest infection level and the highest overall yield (5646.26

kg/ha) in presence of barley yellow dwarf infection among the rest of cultivars that were evaluated (Table 4.4). Additionally, the highest infection level of barley yellow dwarf (1.79%) was found on Pioneer 25R47 (4633.61 kg/ha). Findings from this analysis suggest that in general, fungicides may affect wheat yields differently depending on the cultivar resistance to fungal disease, disease infection level and weather conditions.

The yield analysis (Section 4.2) from fungicide application was found to be statistically different ($P<0.05$) on the overall yield between years compared to the non-application treatment (Table 4.5). In 2011, there was not a significant effect of tebuconazole treatment on the overall yield response compared to the control. However, there were significant differences on yield response among cultivars and locations (Table 4.6). The cultivar Coker 9553 provided the highest mean yield with 4974.75 kg/ha while Pioneer 25R47 provided the lowest average yield with 4250.59 kg/ha, with the lowest average yield obtained that year. The highest yield was obtained from Howe with 5200.63 kg/ha, followed by Royse City and Leonard that produced 4504.9 kg/ha and 4190.78 kg/ha, respectively. From the significant interaction between locations and cultivars in 2011, the highest yield was obtained from the cultivar Coker 9553 located at Howe with 5646.26 kg/ha (Table 4.8).

Different from 2011, in 2012 significant effects of tebuconazole treatments on yield response were observed between the treated and the untreated plots (Table 4.11). These differences represent 8.6% of yield increase between the tebuconazole treatments over the control in 2012. Differences in grain yield across cultivar and location, as well as the interaction on these variables were observed (Table 4.12). The Howe location displayed statistical significant differences from the other two locations in this study and had the highest average yield response with 6113.62 kg/ha (Table 4.13). The highest mean yields were obtained from the cultivar Coker 9553 (6215.04 kg/ha), followed by Pioneer 25R47 (5763.93 kg/ha), Magnolia (5619.46 kg/ha) and Terral LA 841 (5403.00 kg/ha). Pioneer 25R47 and Magnolia displayed statistical significant differences from each other (Table 4.14). In both years (2011 and 2012) the highest yields were obtained from the same cultivar and location. Findings from this study showed that the effect of fungicide applications on final wheat yield greatly depends on the cultivar potential to produce yields.

Results from the net returns analysis (Section 4.3) showed a significant difference between years ($P<0.05$), locations ($P<0.05$) and a significant interaction between them ($P<0.05$) (Table 4.16). In 2011, the mean net returns were -3.53 $/ha. This net return is lower than net returns from 2012, which were $107.7/ha (Table 4.17). Net returns of $108/ha were obtained at Howe during the two years of study and demonstrated to be greater and significantly different from Royse City that produced $28.18/ha and Leonard with $19.97/ha. In 2012, differences in both, cultivar and locations were found (Table 4.18). Net returns from the cultivar Magnolia ($182.8/ha) was similar to Terral LA841 ($133.43/ha) and had the highest net yields compared to the other cultivars (Table 4.20). In 2012, net returns demonstrated significant differences between locations in which means were significantly different and higher at Howe ($204.46/ha) than the rest of the locations (Table 4.21).

Briefly, this analysis showed that net returns from fungicide applications vary by location and cultivar used in wheat production. Consequently, the effect of agronomic characteristics such as soil type, fertilization, weather conditions and cultivar resistant on wheat yields should be considered when analyzing net returns from tebuconazole applications. Such agronomic characteristics were not considered in this present study, however they are recommended to be taken into account in future experimental trials.

The profitability analysis conducted in this study was based on a Bayesian inference method. This method is very common and has been previously employed by De Bruin et al. (2010), and Esker and Conley (2012), Bestor et al. (2011), and Munkvold et al. (2001) to determine the probability of achieving net returns from fungicide applications. The Bayesian method allows growers to determine the probability of breaking even under different wheat prices and fungicide costs scenarios. In this study, the probability of breaking even, and getting net returns of 25% and 50% on the tebuconazole investments were evaluated under two different scenarios of wheat prices ($0.25/ha and $0.30/ha) and a single tebuconazole treatment price ($17.29/ha).

The profitability analysis found that during the two years of study, 66% of the observations resulted in positive net returns from fungicide applications (Table 4.23). The 73% of the observations from Howe resulted in positive net returns to the grower and was the greatest proportion along the other locations. Coker 9553 resulted in 35 out of 48 observations with positive net returns (72%) across the two years of study.

The probability of making net returns from a single fungicide application ranged from 0.03 to 1.00 at a wheat price of $0.25/kg and from 0.034 to 1 at $0.30/kg (Table 4.26). This study found that the probability of making 25% net return from fungicide investment was also evaluated and ranged from 0.024 to 1 at a grain price of $0.25/kg and probabilities from 0.29 to 1.00 at a wheat price of at $0.30/kg. The lowest probability occurred when the probability of obtaining 50% net returns on investments was calculated and increased when the wheat price changed from $25/kg to $30/kg.

On average, the lowest probability of achieving positive net returns from a single fungicide treatment was observed from the cultivar Pioneer 25R47 and it increased as wheat price changed from $25/kg to $0.3/kg. Coker 9553 obtained the highest yield response from the yield analysis; however, the results from the probability analysis did not indicate that Coker 9553 had the highest probability of obtaining net returns (Table 4.28).

One of the more significant findings from the profitability analysis is that the probability of obtaining net returns from fungicide application is more susceptible to changes in wheat price than fungicide cost. Certainly, data in Chapter 3 shows that there is more variability in wheat prices than fungicide cost during the development of this study. For the farmers, this means that the probability of obtaining net returns will vary mostly because of changes in wheat prices than changes in fungicide cost.

Other major findings was that high net yields do not necessarily mean high probabilities of obtaining net returns from fungicide applications. This is because the probability of breaking even from fungicide usage in wheat is linked to the yield magnitude. The yield magnitude corresponds to the cultivar potential to produce yield. This scenario occurred when the highest yields were not obtained from the same cultivars where the highest net returns were observed in this study.

Sensitivity analyses in net returns and yield increases were also performed in this study (Section 4.5). These analyses considered an optimistic and a pessimistic scenario. The optimistic scenario considered increases in wheat prices vs. decreasing fungicides cost. The pessimistic scenario considered decreases in wheat prices vs. increases in fungicide costs. Along with the net return analysis, an analysis of the proportion (%) of treatments that resulted in positive net returns from fungicide application was performed.

Most of the cultivars that were evaluated in this study demonstrated to have the potential to produce a yield increase that would break even the cost of fungicide applications even in the pessimistic scenario. However, the average yield increase from Pioneer 25R47 (99.80 kg/ha) during the two years of study were found to be the more susceptible to get the lowest net returns when having constant changes in wheat price and fungicide cost (Table 4.31). Different from Pioneer 25R47, the cultivar Magnolia produced the highest mean yield increase during this study and therefore is expected to get the highest returns.

Results from the sensitivity analysis showed that net returns from fungicide applications will not always be obtained from the cultivars with the highest net yields. Additionally, high net incomes can be obtained from the cultivars with the highest net yields but it does not necessarily mean that the net returns are from tebuconazole applications. It is most likely attributed to the cultivar's high potential to produce yield. This conclusion seems to be supported by the fact that positive net returns are still observed scenarios of high fungicide cost and low wheat prices. In this study, such scenarios were observed in untreated fungicide observations that resulted in positive net returns.

5.1 Significance of the Findings

This study made several contributions to the current literature review on the economics from fungicide applications in wheat. First, the study provides additional findings with respect to the influence of disease infection on the response of wheat yields from fungicide applications. Findings also enhance our understanding of the relevance of cultivar resistance to fungal diseases and cultivars yield potential effect on the final yield response from fungicide applications. Additionally, the current findings indicate that further research needs to be done incorporating weather climate and agronomic managements on the final effects of foliar fungicides on net returns.

The method used to evaluate the probability of obtaining positive net returns from fungicides may be applied to other studies elsewhere in the world. In addition, the study suggests that the main effect of foliar fungicides on yield response is not reflected on cultivars with the highest net yield but that it is reflected on cultivars with high yield increases that resulted from fungicide applications. In summary, this study suggest that the impact of fungicide applications in promoting profitable benefits in wheat production depends on fungal disease severity, cultivar yield potential, weather conditions, agronomic management practices and finally but not less important on the fungicide efficacy to control fungal diseases.

5.2 Limitations

There were several challenges with the two-year experiment conducted by the Texas A&M AgriLife Extension Representative in Commerce, Texas. First, the data only considered cultivars that were partially resistant to leaf rust and stem rust. Since leaf rust and stripe rust are the most common diseases in wheat production in Northeast Texas, no fungal diseases were recorded, except for barley yellow dwarf which is a viral disease that was observed in one year and at one single location. Therefore, infection rates from fungal diseases were not observed on the cultivars that were evaluated.

Secondly, the study did not evaluate the use of different fungicides at different rates of application. This limited the study to an analysis of tebuconazole treatments at 280.2 g/ha at every single location each year. This specific fungicide and application rate was used based on the assumption that tebuconazole gives better results to wheat farmers in controlling fungal diseases compared to other fungicides.

This current research was unable to evaluate the effect of precipitation on the performance of fungicide applications in wheat production. Data was collected from the nearest weather station that records the same weather report for the three locations on evaluation. Therefore, the amount of precipitation on each city was reported to be same, except for those locations in which wheat was planted at different days and therefore had different precipitation during those days. Since most of the wheat cultivars were planted during the same days, the effect of precipitation in this study was limited to a yearly comparison according to the nearest weather station reports.

The current study has only examined the economic impact of fungal diseases in wheat production. There are many other factors that affect the wheat industry such as government regulations and foregoing competitors. Furthermore, since the data was collected from a subsample of Northeast Texas counties, it should be emphasized that the data is not likely to be representative of the entire state of Texas. Finally, there could be errors unknown to the researcher from using data from a secondary source. For example, these errors may include errors in measurement of the variables, and/or errors from effect of unintentionally uncontrolled variables in the experiment.

5.3 Recommendations for Further Research

Several questions have emerged during the development of this study. More information on precipitation (mm) would help this research to establish a greater degree of accuracy when making conclusions about the effect of fungicide on wheat production. Therefore, further work needs to be done to determine whether there is a statistical effect of weather on disease severity from fungal infections, net yields and fungicide applications.

I would also recommend adding more counties from the state of Texas to determine the effect of fungicides across the entire state of Texas. Similarly, the effect of other agronomic variables such fertilization, soil type, crop rotation and herbicide application on wheat yields can further be explored. According to previous experiments done by the Texas A&M AgriLife Extension Representative located in Commerce, Texas (Texas A&M AgriLife Extension Service, 2012), better results in yield from fungicide applications were found when using a single tebuconazole application to control fungal diseases in wheat. For this reason, it is important for the Texas A&M AgriLife Extension Representative in Commerce, Texas to evaluate the economic effect of just one single fungicide on partially resistant cultivars. However, it would be more interesting to assess the effects of different fungicide at different rates on more cultivars. For this reason, it is recommended that future trials should be done to assess the interaction of different levels of those variables on the economic effects from fungicide applications.

A multiple regression analysis could be estimated to evaluate the effect of fungicides in wheat production. This analysis could include the effect of other independent variables such as fertilization, rainfall, herbicides, fungicide type, number of applications and fungicide application timing on wheat yield. A multiple regression analysis was not considered in this study because many of these variables were not provided.

5.4 Implications

The findings from this study have brought up some important considerations when evaluating the effect of fungicides in wheat. An implication from these findings is that disease severity should be taken into account when analyzing effect of foliar fungicides in controlling fungal diseases in wheat.

Another important implication is that the probability of obtaining net returns from fungicide applications greatly depends on the magnitude of the yield difference between the treated and non-treated experiment. Therefore, a need for knowledge on cultivar potential to produce yield should be considered when evaluating the effect of fungicides on yield increase and net returns on wheat.

5.5 Main Conclusions

From the findings of this study, we can make the following conclusions: better yields can be obtained by planting cultivars with partial resistance to fungal diseases and by planting cultivars with high yield potential. Cultivars with partial resistance to common fungal diseases in wheat production help to reduce the risk of disease infection. Choosing cultivars with high yield potential will reduce the likeliness of obtaining negative returns. Cultivars with high yield potential will increase yield per acre and increase income from wheat production. As explained before, applying fungicides when there are not fungal disease symptoms do not produce profits, unless the cultivar used is highly susceptible to that specific fungal disease. For this reason, it is important to choose cultivars that are partially resistant to the most common diseases that could affect wheat production.

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APPENDICES

APPENDIX A

ADDITIONAL SAS OUTPUT

ADDITIONAL SAS OPUTPUT

Table A.1. ANOVA Source of Variation and Coefficient Variation Results for Barley Yellow Dwarf Disease Severity (%) at Howe in 2011

Source of Variation					
Source	DF	Sum of Squares	Mean Square	F Value	Pr > F
Model	7	5.41	0.77	5.67	0.0001
Error	40	5.46	0.14		
Corrected Total	47	10.87			

Coefficient Variation			
R-Square	Coefficient Variation	Root MSE	Barley Yellow Dwarf Severity Mean
0.50	27.07	0.37	1.36

Table A.2. ANOVA Source of Variation and Coefficient Variation Results for the Wheat Yield (kg/ha) Response to Fungicide Applications among all Locations and Cultivars in 2011 and 2012

Source of Variation					
Model	62	193,050,960.80	3,113,725.20	20.79	<0.0001
Error	225	33,692,768.00	149,745.60		
Corrected Total	287	226,743,728.80			
Model	62	193,050,960.80	3,113,725.20	20.79	<0.0001

Coefficient Variation			
R-Square	Coefficient Variation	Root MSE	Yield Mean
0.85	7.45	386.97	5,191.23

Table A.3. ANOVA Source of Variation and Coefficient Variation Results for the Wheat Yield (kg/ha) Response to Fungicide Applications among all Locations and Cultivars in 2011

Source of Variation					
Source	DF	Sum of Squares	Mean Square	F Value	Pr > F
Model	38	41,658,581.40	1,096,278.46	8.03	<0.0001
Error	105	14,329,883.30	136,475.08		
Corrected Total	143	55,988,464.70			

Coefficient Variation			
R-Square	Coefficient Variation	Root MSE	Yield Mean
0.74	7.98	369.43	4632.11

Table A.4. ANOVA Source of Variation and Coefficient Variation Results for Wheat Yield (kg/ha) Response to Fungicide Applications among all Locations and Cultivars in 2012

Source of Variation					
Source	DF	Sum of Squares	Mean Square	F Value	Pr > F
Model	38	68,200,581.46	1,794,752	15.05	<0.0001
Error	105	12,519,520.63	119,234		
Corrected Total	143	80,720,102.10			

Coefficient Variation			
R-Square	Coefficient Variation	Root MSE	Yield Mean
0.84	6.00	345.30	5,750.36

Table A.5. ANOVA Source of Variation and Coefficient Variation Results for the Wheat Net Return ($/kg) Response to Fungicide Applications among all Locations and Cultivars in 2011 and 2012

Source of Variation					
Source	DF	Sum of Squares	Mean Square	F Value	Pr > F
Model	23	1,265,201	55,008.70	2.70	0.0002
Error	120	2,443,170	20,359.70		
Corrected Total	143	3,708,371			

Coefficient Variation			
R-Square	Coefficient Variation	Root MSE	Net Return Mean
0.3411	273.93	142.68	52.08

Table A.6. ANOVA Source of Variation and Coefficient of Variation Results for the Wheat Net Return ($/kg) Response to Fungicide Applications among all Locations and Cultivars in 2011

Source of Variation					
Source	DF	Sum of Squares	Mean Square	F Value	Pr > F
Model	11	100633	9148.49	0.36	0.9672
Error	60	1534429	25573.80		
Corrected Total	71	1635063			

Coefficient Variation			
R-Square	Coefficient Variation	Root MSE	Net Return Mean
0.06	-4536.00	159.92	-3.53

Table A.7. ANOVA Source of Variation and Coefficient Variation Results for the Wheat Net Return ($/kg) Response to Fungicide Applications among all Locations and Cultivars in 2012

Source of Variation					
Source	DF	Sum of Squares	Mean Square	F Value	Pr > F
Model	11	719,184	65380.40	4.32	<0.0001
Error	60	908,740	15145.70		
Corrected Total	71	1,627,924			

Coefficient Variation			
R-Square	Coefficient Variation	Root MSE	Net Return Mean
0.44178	114.26	123.06	107.70

Table A.8. ANOVA Results for the Wheat Net Return ($/kg) Response to Fungicide Applications among all Locations and Cultivars in 2011

Source	DF	Type III SS	Mean Square	F Value	Pr > F
Location	2	9990.53	4995.26	0.20	0.8200
Cultivar	3	19446.10	6482.04	0.25	0.8600
Cultivar*Location	6	71196.70	11866.10	0.46	0.8300

VITA

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