# Foliar Fungicide Application in Northeast Texas: Yield Response and Profitability

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# Abstract

Fungal diseases are the number one reason for crops losses around the world and have a significant impact on yield and quality.  Previous studies suggest that up to 42% yield loss caused by fungal diseases can be prevented by applying foliar fungicides to winter wheat. Contemporaneous research on wheat cultivars and foliar fungicides is essential to find solutions to the instability of farm incomes from the various economic, environmental, and biological factors.  Local wheat production data on fungicide application, yield, and disease severity for four soft-red winter wheat cultivars (Magnolia, Terral LA 841, Pioneer 25R47, Coker 9553) for two years (2011 and 2012) and three locations in Northeast Texas (Royce City, Howe, and Leonard) was used to study the economics of one foliar fungicide (tebuconazole).  The fungicide was applied as a preventive measure, and the study found positive (two-year average) net returns. The profitability analysis indicated that 66% of the observations resulted in positive net returns from fungicide applications during the two years.  A sensitivity analysis showed that most of the cultivars considered have the potential to produce a yield gain that would break even the cost of fungicide application.

**Key words:**  winter wheat, foliar fungal diseases, fungicides, net returns, profitability

## Introduction

Many economic, environmental, and biological factors influence whether many U.S. farmers will have positive or negative net returns. Among the biological factors, 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. Up to 42% yield loss caused by fungal diseases can be prevented by applying foliar fungicides to winter wheat (Wegulo et. al, 2009). Fungal diseases have a significant economic impact on most crops' yield and quality, and for that reason, managing fungal diseases is an essential component of the production system.

Universities, farm associations, farm organizations, and many government agencies are constantly conducting research on wheat cultivars and foliar fungicides to find solutions to the instability of farm incomes. This study was conducted to earn a better understanding of the impact of foliar fungicides on wheat yields and net returns in Northeast Texas, and to assist wheat growers in Northeast Texas with economic tools that may allow them to assess the economic benefits from foliar fungicide applications. The objective is to evaluate yield and net return from using the foliar fungicide Tebuconazole in wheat production.

Wheat is the third largest crop planted in the U.S., behind corn and soybean. It generates about 198,000 jobs and accounts for $20.6 billion to the U.S. economy (Richardson, Outlaw and Raulston, 2006). In 2007, Texas ranked as the 4th largest wheat producing state with about 3.84 million acres in production (2007 Census of Agriculture, 2007, pp. 475-483). Wheat is the third most planted crop behind forages and cotton in Texas. In 2005, the wheat industry generated 11,273 jobs and contributed with $658.8 million to the Texas economy (Richardson, Outlaw and Raulston, 2006).

The U.S. is the world's largest wheat producing and exporting country. World wheat trade is expected to increase with the continuous population growth in Egypt, Algeria, Iraq, Brazil, Mexico, Indonesia, Nigeria, and other developing countries (USDA-ERS, 2012). Wheat is very likely to remain an important agricultural export for years to come.

According to Wegulo et al. (2012), the most prevailing foliar diseases in winter wheat in the Great Plains of the United States 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) are sometimes considered less common (Wegulo et al., 2012), and sometimes considered the most frequent in the wheat producing regions of the U.S. (Kolmer, 2007).

A fungicide is a specific type of pesticide which is used to control fungal diseases (McGrath, 2004). In the U.S., the foliar fungicides used in wheat are usually grouped in two categories: strobilurins and triazoles. Wegulo et al. (2012) explain that strobilurins are quinone outside inhibitors (QoI) that interfere with energy production in fungi (Vincelli, 2002). Strobilurins act as local systemics by inhibiting fungal spore germination and early infection, and are highly effective when applied preventively. The strobilurins have a single-site mode of action. Azoxystrobin, pyraclostrobin and trifloxystrobin are examples of strobilurin fungicides used in the U.S. Wegulo et al. (2012) explain that, triazoles, on the other hand, are characterized by having a five-membered ring of two carbon atoms and three nitrogen atoms. They are curative and move systemically through the plant xylem. Triazoles slow fungal growth through the inhibition of sterol biosynthesis (Horst, 1987, pp. 205-231). Sterols are essential building blocks of fungal cell membranes and are inhibited at a single site by triazoles. Triazoles are highly effective and reliable because of their curative activity against early fungal infections and their ability to redistribute in the crop (Hewitt, 1998). Metconazole, propiconazole, prothioconazole, and tebuconazole are examples of triazoles used in cereal crop production in the U.S.

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 seeds, bulbs, roots, soils, foliage, and plant trunks. They are also sprayed in the air in enclosed areas such as greenhouses and covered soil, and applied as a dip or spray to harvested products in the packinghouse (McGrath, 2004).

Fungicide prices influence the decision of spraying or not spraying. To be effective, most fungicides need to be applied before the disease occurs or at the appearance of the first symptoms. When the fungicide is applied before flag leaf emergences, it generally results in less disease control on the upper leaves during grain development and smaller yield benefits (De wolf et al., 2012). In general, fungicides primarily protect plants from getting infected and just few fungicides are effective in plants that have already been infected (McGrath, 2004). The benefits from fungicide applications in crop production are reflected in returns of up to three times the cost involved (McGrath, 2004). However, Hershman (2012) and McGrath (2004) explained that when the disease severity is low and there is minimal yield loss, applying a fungicide will not result in either a yield or an economic advantage. Consequently, at the appearance of the first symptoms, it is critical to assess the potential yield loss.

Various studies in the U.S have demonstrated yield increases in winter wheat from fungicide applications. Wegulo et al. (2009) showed that up to 42% yield loss was prevented by applying foliar fungicides to winter wheat. Chen (2012) explained that yield losses of up to 60% due to stripe rust have been documented in experimental fields. O'Brien (2007) showed that potential average wheat yield losses of 30 % are common in Kansas when leaf rust is not controlled at flowering. Wiik and Rosenqvist (2010) showed that the use of a fungicide in winter wheat in Southern Sweden was more profitable (net return of $27 per ha on average).

## Data

Wheat production data on fungicide treatment, location, yield, and disease severity for four soft-red winter wheat cultivars (Magnolia, Terral LA 841, Pioneer 25R47, Coker 9553) was obtained from the Texas A&M AgriLife Extension Representative in Commerce, TX.

Their field trials were conducted in 2011 and 2012 at three locations in Northeast Texas: a location in Royce City (32°58′27″N, 96°19′58″W), a location in Howe town (33°30′18″N, 96°36′51″W), and a location in Leonard city (33°22′59″N, 96°14′43″W). The corresponding elevations at each of these locations are 167 m, 256 m, and 219 m. 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 are typical soils characteristics where wheat is grown in Northeast Texas.

The fungicide treatments consisted of a tebuconazole application of 280 g/ha. The application was done when the plants were approximately at Feekes Growth stage 10. The plots were sprayed with a CO2 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. Table 1 summarizes the three locations where the trials were conducted, their soil types, the weather conditions, and the planting, spraying, and harvesting dates.

The most common months of fungal disease infection in Northeast Texas are February, March and April. According to the National Weather Service Forecast Office (2013), the average rainfall during those three months in Royse City, Howe, and Leonard were 86 millimeters, 89 millimeters, and 95 millimeters respectively. During the same three months, the corresponding minimum and maximum temperatures in Royse City, Howe, and Leonard were 8 $^{o}$C and 20 $^{o}$C, 7 $^{o}$C and 18 $^{o}$C, and 11 $^{o}$C and 16 $^{o}$C respectively.

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. Flag leaves on each plant were visually assessed for the presence of Septoria, barley yellow dwarf, leaf rust, and strip rust.

The harvest was done with a research Kincaid combine (Kincaid Manufacturing, Haven, Kansas). Grain yield in bushels per acre was recorded at the end of the experiment. 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.

Wheat prices per bushel were obtained Texas A&M AgriLife Extension-Extension Agricultural Economics (2011, 2012). The average wheat price regardless of variety and location over the two yeas analyzed was $0.25/kg. The tebuconazole cost ($12.36/ha) and its application cost ($4.94) were obtained from fungicide companies in Northeast Texas, and they did not change over the two years analyzed.

**Methods and Procedures**

Effects of tebuconazole applications on disease severity, net returns, and wheat yields response were evaluated by analyses of variance using the GLM procedure in SAS version 9.3. Several linear models were developed to test treatment interactions with location, cultivar, year and block. The general form of the linear model is

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

where $\mu$ is the overall yield mean from the treated group, $\alpha_i$ is the effect due to the $i^{th}$ treatment, $\beta_j$ represents the effect from the $j^{th}$ block, $\gamma_k$ is the effect from the $k^{th}$ cultivar, $\delta_l$ is the effect from the $l^{th}$ location, $\lambda_m$ is the effect from the $m^{th}$ year, $\alpha_{\gamma ik}$ represents the interaction effect of the $i^{th}$ level of treatment depending on the $k^{th}$ level of cultivar, and $\varepsilon_{ij}$ is the error term. The errors are assumed to be independently normally distributed with a zero mean and constant variance.

Tukey means separation tests at 5% significance levels were used to perform means comparisons between sprayed and non-sprayed treatments for yield gain and net returns from tebuconazole application, among cultivars, location, and years. Subsequently, the differences in yield between the sprayed and non-sprayed treatments were used to analyze wheat yield response and net returns from tebuconazole treatments. Finally, similar to Bestor (2011), Munkvold et al. (2001), De Bruin et al. (2010), and Esker and Conley (2012), a profitability analysis was conducted based on Bayesian inference.

Net returns ($/kg), $Rn = P * (Y_t - Y_c) - (C_f + C_a)$, were calculated using treatment means. Following Bestor (2011) and Munkvold et al. (2001), the probability of tebuconazole treatments resulting in a yield difference larger than the estimated yield difference needed to offset the cost of tebuconazole was calculated from the observed yield difference between the treated and untreated plots and their observed standard deviation which was calculated from a pooled variance. That is, the probability that net returns from a tebuconazole treatment will at least break even, $PT\,[Rn > (1+0)*(C_f + C_a)]$; be at least 25% greater than the investment on tebuconazole, $PT\,[Rn > (1+0.25)*(C_f + C_a)]$; and be at least 50% greater than the investment on tebuconazole $PT\,[Rn > (1+0.50)*(C_f + C_a)]$ are estimated as

$$(2)\qquad PT = 1 - Prob\ t\left[\frac{\beta_0 - (Y_f - Y_c)}{Sp^2(1/\mathrm{n}_\mathrm{t} + 1/\mathrm{n}_\mathrm{c})^{1/2}},\ df_e\right],$$

where $C_f$ is the fungicide cost ($/ha), $C_a$ is the cost of fungicide applications ($/ha); $\beta_0$ is the yield difference needed to offset the cost of tebuconazole application (kg/ha), $Y_f$ is the observed yield from tebuconazole treatment (kg/ha), $Y_c$ is the observed yield from the untreated plots (kg/ha), $S_p^2 = \frac{(n_t-1)S_1^2+(n_c-1)S_2^2}{(n_t-1)+(n_c-1)}$ is a pool variance (Box and Tiago, 1973), $S_1^2$ is the variance of the observed yield from the treated plot, $S_2^2$ is the variance of the observed yield from the untreated plot, $n_\mathrm{t}$ is the number of observations in the treated plot, and $n_\mathrm{c}$ is the number of observations in the control plot.

The yield difference needed to offset the cost of tebuconazole application is computed as

$$(3)\qquad \beta_0 = \frac{(1 + ER_n)\ (C_f + C_a)}{P},$$

where $P$ is the wheat price ($/kg); $C_f$ is the fungicide cost ($/ha); and $C_a$ is the cost of fungicide applications ($/ha); and $ER_n$ = 0, 0.25, or 0.50, when breaking even, achieving net returns 25% greater, or achieving net returns 50% greater than the investment in tebuconazole respectively.

Finally, a sensitivity analysis at various wheat prices and fungicide cost was used to evaluate net return and the yield response needed to break even from spraying tebuconazole. The sensitivity analysis assists wheat farmers in Northeast Texas with educated expectations about their net returns and yield gains needed to break even given wheat prices and fungicide costs. It provides insight in deciding whether to spray or not spray given the farmers' expectations about wheat prices and fungicide costs.

## Results and Discussion

Overall (treated + untreated) average yields (kg/ha) in 2011 and 2012 were found to be statistically different at the 5% significance level (Table 2). This statistical difference in yield may be attributed to the presence of a disease in the Howe location in 2011 as discussed below, but it could also be partially attributed to the 56.13% increase in precipitation from 2011 to 2012 and other differences in uncontrollable factors between 2011 and 2012 (Table 1). Although the difference in yield may not be attributed to the fungicide application, it is worth noting that fungicide application was found to have a statistical significant effect ($P<0.05$) on the overall yield (Table 3).

The fungal diseases Septoria, leaf rust, and stripe rust were not found in both the treated and untreated plots during the two years analyzed. However, barley yellow dwarf infected both the treated and untreated plots only at the Howe location in 2011. Table 4 reports the infection levels in both the treated and untreated plots at the Howe location while table 5 shows that Coker

9553 had the lowest infection level and the highest overall yield in the presence of barley yellow dwarf.

Table 6 shows that, in 2011, there was no significant difference on overall yield between the treated and untreated plots. Several studies have found statistical differences in yield between fungicide treated and untreated plots (Reid and Swart 2004; Wiik and Rosenqvist 2010). Our unexpected findings in 2011 may be attributed to the infection of barley yellow dwarf in the Howe location in 2011. Wiik and Rosenqvist (2010) explain that uncontrollable factors such as the emergence of new diseasses can affect yield gain.

Unlike 2011, in 2012, there was statistical difference on overall yield between the treated and untreated plots (Table 7). Our findings in 2012, although conservative, are consistent with previous studies. The difference in wheat yield in 2012 represented an 8.6% increase of the treated group over the untreated group. Reid and Swart (2004) reported yield increases of 34% to 41% of treated plots over untreated plots.

Several results, although expected, were also important to confirm. For example, similar to Orum, Pinnschmidt, and Jorgensen (2006), there were statistical differences in yields (Table 8) and net returns (Table 9) among locations during each year. Statistical differences in locations are usually attributed to agronomic practices such as crop rotation, soil quality, and disease severity (Orum, Pinnschmidt, and Jorgensen, 2006), but they may also be attributed to differences in fungicides used and temperature conditions (Tadesse, Ayalew, and Badebo, 2010). There were two different but similar soil types in study. Statistical differences among locations in this study may be attributed to small differences in soil types, amount of rainfall, and elevations over the sea level; and/or several other uncontrollable factors such as temperature and wind (Table 1).

There were also statistical differences in yield (Table 10) and net returns (Table 11) among cultivars during each year. Interestingly, Coker 9553 was not only statistically different from other cultivars each year; but unexpectedly, it also consistently resulted in the highest average yield each year. Although Coker 9553 provided the highest average yield in each of the two years (Table 10), it did not necessarily provide the highest average net return (Table 11). This means that high net yields do not necessarily mean high net returns from fungicide applications.

Net returns from investing in tebuconazole in 2011 were estimated at -3.53 $/ha (Table 12). This was expected since there was no statistical difference in yield between the treated and untreated plots. For the opposite reason, in 2012, net returns from investing in tebuconazole were $107.7/ha (Table 12). More importantly, our conservative 8.6% yield increase of the treated over the untreated plot results in a positive return from investing in tebuconazole. In fact, the positive net return in 2012 offset the relatively small negative net return in 2011, and it results in an overall positive net return.

Sensitivity analyses on net returns and yield were conducted to investigate the impact of various wheat prices and fungicide costs (fungicide + application costs) on net returns and break-even yield responses from tebuconazole. Table 13 reports the net return change ($/ha) from tebuconazole applications under various wheat prices and fungicide cost. Table 14 reports the yield gain (kg/ha) that is needed to break even at various wheat prices and fungicide cost.

## Conclusion

Wheat is the third largest crop planted in the U.S. with Texas being the fourth largest wheat producing state. For wheat to remain competitive locally, nationally, and internationally; wheat growers must obtain appropriate yields and net returns, and reduce its dependency on government programs.  A feasible solution to this challenge may simply be a crop loss reduction. 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).

Up to 42% yield loss caused by fungal diseases can be prevented by applying foliar fungicides to winter wheat (Wegulo et. al, 2009).  However, for foliar fungicides to be effective, they need to be applied before the disease occurs or at the appearance of the first symptoms (McGrath, 2004).  Wegulo et al. (2011) and Wiik and Rosenqvist (2010) suggested that net returns can be negative when disease severity rates are low and yet fungicides are applied.  This study found positive (two-year average) net returns when a foliar fungicide (tebuconazole) was applied as a preventive measure. During the first year (2011) the net return was estimated to be negative, -$3.53/ha, but wheat yield from the treated plots were not statistically different from the untreated plots at the 5% significant level.  The emergence of a disease in one of the locations after the fungicide was applied may have affected yield in 2011.  Unlike 2011, the net return from spraying tebuconzole in 2012 was estimated to be $107.70/ha, and wheat yield from the treated plots were statistically different from the untreated plots.

Several studies have found statistical differences in yield between fungicide treated and untreated plots (Reid and Swart 2004; Wiik and Rosenqvist 2010).  Our findings in 2012, although conservative (an 8.6% increase of the treated group over the untreated group), are consistent with previous studies.  Reid and Swart (2004) reported yield increases of 34% to 41% of treated plots over untreated plots.  Our conservative 8.6% yield gain resulted in a positive return from investing in tebuconazole.  In fact, the positive net return of $107.7/ha in 2012 offset the relatively small negative net return of -$3.53/ha in 2011, resulting in an overall positive net return.

Similar to Orum, Pinnschmidt, and Jorgensen (2006), there were statistical differences in yields and net returns among locations during each year. These differences may be attributed to small differences in soil types and their elevation above the sea level, and/or differences in several other uncontrollable factors such as rainfall, temperature, and wind. There were also statistical differences in yield and net returns among cultivars. Interestingly, Coker 9553 was statistically different from other cultivars and it also provided the highest average. However, it did not necessarily provide the highest average net return, which suggests that high net yields do not necessarily mean high probabilities of obtaining net returns from fungicide applications.

Our profitability analysis found that 66% of the observations resulted in positive net returns from fungicide applications during the two years of study. In addition, our sensitivity analysis of net returns and yield gains at various wheat prices and fungicide costs showed that most of the cultivars have the potential to produce a yield gain that at least breaks even the fungicide application decision.

Our study made several contributions to the current literature review on the economics of fungicide applications in wheat production. First, the study contributes with additional findings related to the economic effect of fungicide applications to prevent fungal diseases on wheat production. Second, the study illustrates the applicability of a Bayesian inference approach in evaluating net returns from fungicide applications. Finally, our study assists wheat farmers in Northeast Texas, who regularly use fungicides to control foliar fungal diseases, with economic tools to make educated decisions about their fungicide selection and expectations.

Our study is also an interdisciplinary (Agricultural Economics and Plant and Soil Science) and inter-institutional (a higher education institution and an extension service office). It is an example of how higher education and service institutions can join efforts to address the needs of Northeast Texas wheat growers of using economic tools to assess potential economic benefits from foliar fungicide applications. The study combines agronomical and economic procedures to provide insight and/or assist farmers in their decision making process.

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**Tables**

**Table 1.** Locations, Soil Types, Dates, and Weather

| | | Soil | | | | | Weather During Spray Date | | | Winter Season |
|---|---|---|---|---|---|---|---|---|---|---|
| Year | Location | Type | Elev. (m) | Date Planted | Date Sprayed | Date Harvested | Wind (km/h) | Temp ($^oC$) | Relative Humidity (%) | Rainfall (mm) |
| 2011 | Howe | Houston Black or Leson Clays | 256 | 10/29/10 | 4/1/11 | 06/07/11 | 6.4 | 18.3 | 61.6 | 361 |
| 2011 | Leonard | Houston Black or Leson Clays | 219 | 11/10/10 | 3/8/11 | 06/02/11 | 8.0 | 12.1 | 61.6 | 314 |
| 2011 | Royse City | Houston Black or Leson Clays | 167 | 11/19/10 | 3/27/11 | 05/31/11 | 6.4 | 18.3 | 61.6 | 369 |
| 2012 | Howe | Houston Black or Leson Clays | 256 | 11/02/11 | 3/29/12 | 05/22/12 | 4.8 | 27.5 | 51.8 | 537 |
| 2012 | Leonard | Houston Black or Leson Clays | 219 | 10/31/11 | 3/28/12 | 06/06/12 | 6.4 | 24.4 | 61.0 | 556 |
| 2012 | Royse City | Houston Black or Leson Clays | 167 | 11/01/11 | 3/28/12 | 05/17/12 | 8.0 | 20.0 | 87.0 | 537 |

*Source:* The wheat trials were conducted by Texas A&M AgriLife Extension Representative in Commerce, TX. The amount of rainfall during the winter season was obtained from the National Weather Service Forecast Office (2013).

**Table 2.** Yield Response (kg/ha) to Fungicide Applications per Year

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

* Means represent averages across three locations and four cultivars. Means with the same letter are not statistically different at α=0.05 significance level.

**Table 3.** ANOVA for Wheat Yield Response (kg/ha) to Fungicide Applications in 2011 and 2012

| Source | DF | F Value | Pr > F |
|---|---|---|---|
| Year | 1 | 601.25 | <0.0001 |
| Location | 2 | 111.08 | <0.0001 |
| Location*Year | 2 | 6.98 | 0.0011 |
| Treatment | 1 | 39.45 | <0.0001 |
| Treatment*Year | 1 | 25.48 | <0.0001 |
| Location*Treatment | 2 | 6.66 | 0.0015 |
| Location*Treatment*Year | 2 | 4.01 | 0.0195 |
| Cultivar | 3 | 35.71 | <0.0001 |
| Cultivar*Year | 3 | 14.13 | <0.0001 |
| Location*Cultivar | 6 | 10.13 | <0.0001 |
| Location*Cultivar*Year | 6 | 14.56 | <0.0001 |
| Treatment*Cultivar | 3 | 2.59 | 0.0535 |
| Treatment*Cultivar*Year | 3 | 1.77 | 0.1540 |
| Location*Treatment*Cultivar | 6 | 1.31 | 0.2515 |
| Location*Treatment*Cultivar*Year | 6 | 0.80 | 0.5706 |
| Rep(location) | 15 | 2.81 | 0.0005 |

**Table 4.** Levels of Barley Yellow Dwarf Infection (%) from the Non-Treated and the Treated Experiments with Tebuconazole at the Howe Location 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 |

* Means represent averages across four cultivars.

**Table 5.** 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 |

**Table 6.** ANOVA for the Wheat Yield Response (kg/ha) 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 7.** ANOVA for Yield Response (kg/ha) to Fungicide Applications in 2012

| Source | DF | F Value | Pr > F |
|---|---|---|---|
| Location | 2 | 40.76 | <0.0001 |
| Treatment | 1 | 80.59 | <0.0001 |
| Location*Treatment | 2 | 13.12 | <0.0001 |
| Cultivar | 3 | 35.62 | <0.0001 |
| Location*Cultivar | 6 | 27.00 | <0.0001 |
| Treatment*Cultivar | 3 | 5.08 | 0.0025 |
| Location*Treatment*Cultivar | 6 | 1.95 | 0.0802 |
| Rep(location) | 15 | 5.86 | <0.0001 |

**Table 8.** Yield Response (kg/ha) to Fungicide Applications per Location

| 2011 | | | 2012 | | |
|---|---|---|---|---|---|
| Location | N | Mean (kg/ha)* | Location | N | Mean (kg/ha)* |
| Howe | 48 | 5,200.63a | Howe | 48 | 6,113.62a |
| Royse City | 48 | 4,504.90b | Royse City | 48 | 5,616.40b |
| Leonard | 48 | 4,190.78c | Leonard | 48 | 5,521.06b |

* Means represent averages across four cultivars. Means with the same letter in a year are not statistically different at α=0.05 significance level.

**Table 9.** Net Return ($/ha) from Fungicide Applications per Location

| 2011 | | | 2012 | | |
|---|---|---|---|---|---|
| Location | N | Mean (kg/ha)* | Location | N | Mean (kg/ha)* |
| Howe | 24 | 11.77a | Howe | 24 | 204.46a |
| Leonard | 24 | -5.45a | Royse City | 24 | 73.25b |
| Royse City | 24 | -16.90a | Leonard | 24 | 45.39b |

* Means represent averages across four cultivars. Means with the same letter in a year are not statistically different at α=0.05 significance level.

**Table 10.** Yield Response (kg/ha) to Fungicide Applications per Cultivar

| 2011 | | | 2012 | | |
|---|---|---|---|---|---|
| Cultivar | N | Mean (kg/ha)* | Cultivar | N | Mean (kg/ha)* |
| Coker 9553 | 36 | 4,974.75a | Coker 9553 | 36 | 6,215.04a |
| Terral LA841 | 36 | 4,698.27b | Pioneer 25R47 | 36 | 5,763.93b |
| Magnolia | 36 | 4,604.81b | Magnolia | 36 | 5,619.46b |
| Pioneer 25R47 | 36 | 4,250.59c | Terral LA841 | 36 | 5,403.00c |

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

**Table 11.** Net Return ($/ha) from Fungicide Applications per Cultivar

| 2011 | | | 2012 | | |
|---|---|---|---|---|---|
| | N | Mean | Cultivar | N | Mean ($/ha)* |
| Cooker 9553 | 18 | 16.83a | Magnolia | 18 | 182.80a |
| Magnolia | 18 | -0.32a | Terral LA841 | 18 | 133.43ab |
| Terral LA841 | 18 | -1.55a | Coker 9553 | 18 | 73.92b |
| Pioneer 25R47 | 18 | -29.06a | Pioneer 25R47 | 18 | 40.66b |

* Means represent averaged across three locations. Means with the same letter in a year are not statistically different at α=0.05 significance level.

**Table 12.** Net Return ($/ha) from Fungicide Applications per Year

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

* Means represent averages across three locations and four cultivars. Means with the same letter are not statistically different at α=0.05 significance level.

**Table 13.** Net Returns Increase ($/ha) from Tebuconazole Applications at Various Wheat Prices and Fungicide Costs

| | | Tebuconazole Cost ($/ha)* | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|
| | | 24.21 | 22.48 | 20.75 | 19.02 | 17.29 | 15.56 | 13.83 | 12.10 | 10.37 |
| Wheat Price ($/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 |

* Tebuconazole cost includes fungicide cost plus application cost.

**Table 14.** Yield Increase (kg/ha) Needed to Break Even at Various Wheat Prices and Fungicide Costs

| | | Tebuconazole Cost ($/ha)* | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|
| | | 24.21 | 22.48 | 20.75 | 19.02 | 17.29 | 15.56 | 13.83 | 12.10 | 10.37 |
| Wheat Price ($/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 |

* Tebuconazole cost includes fungicide cost plus application cost.