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## **The Economic Impact of Rice Blast Alleviation in the Mid-South of the United States**

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## Abstract

The rice blast fungus, *Magnaporthe oryzae*, causes extensive damage to rice production globally, which often results in costly fungicide applications and yield losses. These inefficiencies harm farmers via increased costs in production and subsequently drive up food prices for consumers, which can, in turn, give rise to food insecurity in low-income countries. Moreover, there are blast-resistant rice varieties commercially available in the United States; however, breeding for resistance remains problematic because the fungus continuously evolves. In 2013, scientists at Kansas State University identified a blast-resistant gene in a wild rice variety that could be cisgenically transferred into currently cultivated, high-yielding varieties. Due to regulatory protocols on Genetically Modified Organisms in other countries, this technology is not been commercially available to producers. Consequently, the environmental and financial costs of fungicide applications and subsequent yield losses from the rice blast disease, remain high in the United States and other countries. Correspondingly, the aim of this study is to estimate the increased costs for three different rice blast scenarios in the Mid-South of the United States between 2002 and 2014. In the first scenario, we quantified the costs of two preventive fungicide applications to all hectares sown to blast-susceptible varieties; in the second, we quantified the costs of two mitigating fungicide applications on one blast outbreak area that was simulated based on historical outbreaks; and in the third, we quantified the costs of two mitigating fungicide applications on a simulated outbreak with additional yield loss caused by the fungus. The total financial costs of the rice blast disease for all years in each of the three scenarios were \$265,691,269, \$117,507,463, and \$775,071,706 respectively. Overall, these findings necessitate: (1) more research on cisgenic breeding for blast resistance, (2) more robust policy negotiations, and (3) wide-spread adoption by farmers.

## Introduction

Rice is a crucial food staple for more than half of the world; accordingly, its supply must increase twofold by 2050 to keep up with the demand from population growth. The rice blast fungus has a critical influence on rice yields and production costs (Skamnioti and Gurr, 2009). From 2002 to 2014, rice producers in Arkansas, Mississippi and Louisiana planted over eight million hectares of rice to varieties that were susceptible to the rice blast fungus. Rice blast is caused by the *Magnaporthe oryzae* fungus and is one of the most frequent and costly rice diseases in the Mid-South and temperate rice-growing regions (Wang and Valent, 2009). The fungus survives on infected rice straw and seed between cropping seasons. During production, brown blast lesions typically form as oval-shaped spots on rice leaves, and when climatic conditions are favorable, these lesions then produce spores that are asexually transported to other plants, where they continue the infection process throughout the growing season.

The yield losses associated with these blast outbreaks have at times reached 50% or more (Khush and Jena, 2009). The cost of mitigating these blast infections via fungicide can reach over \$49 per hectare and even then, the fungus can cause yield loss depending on varietal susceptibility and the degree of infection at the time of the fungicide application. In the early 2000s, rice producers focused on increasing overall yields and total revenue, but paid little attention to blast, presumably because of its prevailing effect on the cost of production rather than yield. However, in more recent years, we find a slight upward trend in producers' selection of cultivars with blast resistance (See Figure 1). Although there are blast-resistant cultivars available for production, most are hybrid lines released by RiceTec, and in 2016, were associated with a seed premium of approximately \$237.12 per hectare (UACES, 2016).

Overall, the most tangible outcome of a breeding program of any type is increased yield. "Maintenance breeding" generally results in pathogen resistance for a crop specimen. Economists and policy makers tend to undervalue the productivity losses that can be evaded by informative agricultural research. Accordingly, the substantial economic benefit that accrues from avoided yield losses through resistance to those pathogens is often forgotten in the cost-benefit analysis of such breeding programs.

Previous studies (Marasas et al. 2003) on breeding programs have estimated that the economic impact of a research program's breeding efforts for pathogen resistance (maintenance breeding) can be as great, if not greater than the impact of increased yields. Peng et al. (2010) analyzed and emphasized the importance of maintenance breeding for rice in South Asia, where they claim a lack of genetic gain is causing a slower rate of yield increase. Their study provides strong reasoning for continuous maintenance breeding to preserve rice yield potential through improved resistance to rapidly evolving biotic stresses such as diseases and insects. Peng et al. (2010) reinforce the idea that if maintenance breeding programs are discontinued or diminished, it will be difficult for global rice production to keep up with the increasing demand for rice.

Since the beginning of the 21<sup>st</sup> century, scientists have established blast resistance in high-yielding rice varieties using cisgenics, a form of genetic modification (GM; Qu et al., 2006). Hypothetically, blast resistance could be established in all susceptible cultivars with these new breeding techniques, but this has not yet become a reality due to regulations. In the context of this study, cisgenic breeding would be used as a type of maintenance breeding technique to simultaneously “maintain” high yields and breed for pathogen resistance. Nonetheless, no GM rice is currently commercially available for production worldwide, even though other traditional row crops such as soybeans, cotton, and corn have GM varieties in the United States. Consequently, embedded disease packages for rice cultivars are not as robust as their GM crop counterparts, and disease is a major obstacle for rice breeders globally. A recent 2013 USDA/NIFA project at Kansas State University has begun researching cisgenic breeding as a potential method to combat rice blast disease. Both cisgenesis and transgenesis are plant breeding techniques that can be used to introduce new genes into plant genomes. However, transgenesis uses genetic material from a non-plant organism, or from a donor plant that is sexually incompatible with the recipient plant, while cisgenesis involves the introduction of genetic material from a crossable, sexually compatible plant (Schouten et al., 2006).

In this case, cisgenic rice would be produced via the insertion of a rice blast-resistant gene (*Pi9*) from a low-yielding wild rice variety (*Oryza minuta*) into a high-yielding and widely cultivated variety (Qu et al., 2006). Other cisgenic crops are produced with the same transformation technologies (Agrobacterium-mediated transformation or biolistic transformation) used in producing transgenic plants; however, with cisgenic rice, the entire inserted gene (including promoter, coding sequence, intron and terminator sequences) is naturally found in rice, or other sexually compatible plants. Any selection marker gene used in the transformation process is removed so that no foreign DNA sequences remain in the cisgenic plant. While this technology has proved successful in experimental settings (Qu et al., 2006), it has not been made commercially available due to regulatory protocols. While traditional breeding can transfer blast-resistant genes like the *Pi-ta*, which was isolated in the rice variety Katy, a variety may take up to 10 years from its initial cross to its commercial release (Nalley et al., 2011). During this 10-year lag, the blast virus can mutate and overcome the resistant gene. This was found in the case of the *Pi-ta* gene, isolated in 1989 and bred into multiple varieties only to be overcome by a new race of blast, *IE-1k*, which was first found in 1994 and has since caused field damage to some cultivars that were once considered blast resistant (UACES, 2015).

The European Union imports approximately 1.5 million metric tonnes of rice each year, most of which comes from the United States (FAS, 2015). Furthermore, the European Food Safety Agency has created strict policies prohibiting the importation of GM foods (EFSA, 2013); thus, producers in the United States have little incentive to advocate for the release of GM rice cultivars such as cisgenically produced, blast-resistant rice, that have been proven successful in experiments. For this reason, the cost of rice production to U.S. farmers has been inflated, the supply of global rice has diminished, and the use of fungicides for the control of blast disease is still prevalent. Given the fact that cisgenic breeding can greatly reduce the time from initial crossing to release, resistance genes could be delivered to producers quickly for a more comprehensive disease package. While this will not slow or mitigate the mutation of the blast fungus, it allows for a faster dissemination of technology to combat it.

In this study, we estimated the increased costs (fungicide and its application) and decreased the revenue (yield loss) associated with sowing blast susceptible varieties in rice production between 2002 and 2014 in Arkansas, Mississippi and Louisiana. Currently, the literature is devoid of estimations of per hectare costs and revenue effects for blast infections, even though the rice blast fungus is responsible for approximately 30% of losses in global rice production—the equivalent of feeding 60 million people; therefore, the rice blast fungus is a key concern in combating food insecurity (Peter, 2013). Ultimately, rice producers and consumers, who experience high prices due to low supply, assume the costs of the absence of blast resistance in the high-yielding cultivars throughout the Mid-South of the U.S. Thus, the costs associated with blast can be estimated based on (1) the area planted to blast-susceptible rice varieties, (2) historical rice yield data, (3) blast infection rates, (4) subsequent yield losses, and (5) fungicide applications, in order to estimate the economic value of blast resistance via cisgenic breeding for producers and consumers.

Additionally, crop productivity enhancement is measured in terms of increased yield gains, while productivity maintenance is measured in terms of the yield losses that would have occurred in the absence of research investment. With this in mind, our study examines the counterfactual case of blast resistance, wherein the economic (increased yield and decreased price) and environmental benefits were estimated as if all rice in Arkansas, Louisiana and Mississippi had been sown to blast-resistant varieties from 2002-2014. Moreover, it is important to present scientific, political and consumer groups with an estimation of the economic benefit of blast alleviation via cisgenics, as one of the potential assets of adopting genetically modified (GM) rice, both domestically and globally. While blast resistance will not be the sole determining factor for the adoption of GM rice, it provides an additional economic and environmental incentive for producers, consumers and policy-makers to pay attention to in their decisions about GM rice.

## **Materials and Methods**

In this study, the cost of blast was estimated for Arkansas, Mississippi and Louisiana using three production scenarios for the period of 2002 to 2014. First, the annual varietal area planted for each rice-growing county in Arkansas, Louisiana and Mississippi was collected from 2002 to 2014 (Proceedings of the Rice Technical Working Group, various years). Additionally, the annual varietal yield ( $\text{Mg ha}^{-1}$ ) data by state were also collected (ARPT, 2015; LSU Ag Center, 2015b; and MAFES, 2015b). These yield data were collected from university-run experiment stations and can be viewed as “yield potential”. Although a gap between experimental and actual producer yields exists, Brennan (1984) concluded that the most reliable sources of relative yields are cultivar trials outside of actual farm observations. While yields are often greater from experimental test plots than from producers’ fields, the relative yield difference between varieties are comparable. Finally, this study consisted of 59 rice varieties, 33 rice-growing counties in Arkansas, 35 parishes in Louisiana, and 28 counties in Mississippi for a total of 6,744 observations (see Table A1 in the Appendix).

### *Blast Ratings*

Blast susceptibility rankings were collected from historical plantings at Mississippi State University (MAFES, 2014), University of Arkansas (UACES, 2015), and Louisiana State University (LSU Ag Center, 2015) for each variety. All three universities use a Likert scale of blast susceptibility; Resistant (R), Moderately Resistant (MR), Moderately Susceptible (MS), Susceptible (S) and Very Susceptible (VS). A list of these rankings by variety can be found in Table A1. These rankings are derived from historical and recent observations of test plots and in grower fields across each state. In Arkansas (ARPT, 2015), the rankings were based on conditions that favor severe blast proliferation, including: excessive nitrogen rates, or low flood depth. Correspondingly, in instances where a variety becomes less resistant to blast (the pathogen constantly evolves to break down resistance), the updated rating is used. In terms of this study, the decisive factor is whether a variety is or is not blast resistant. If a variety is blast resistant, it is assumed to have neither mitigation costs, nor yield loss.



### *Yield Loss by Blast Ratings*

It is uncommon practice for university extension services to record blast outbreaks, or yield losses with associated blast outbreaks, with the exception of anomalies, like in 2012. Extensive, systematic field-level yield and quality loss estimates due to rice blast have not been developed in the U.S. Instead, current estimates are recorded corresponding loss to total crop loss, depending on the inoculum density, pathogen aggressiveness, environmental conditions, cultivar susceptibility, and interaction with other cultural parameters (Groth et al., 2013). Similarly, field-level estimates of blast loss have also been difficult to estimate because of lack of data on the numerous and often simultaneous diseases affecting rice, as well as the underground damage associated with root diseases, and the lack of qualitative information on distribution and severity in commercial fields.

Additionally, the literature is scarce regarding replicated trials that document yield loss associated with blast on commonly cultivated rice varieties in the U.S. To illustrate, there are several studies (Bastiaans, 1993; Naik et al., 2012; Ziegler et al., 1994) that analyze only one variety in the field, and several more (Koutroubas et al., 2008 & 2009; Groth et al., 2014; Bonman et al., 1991) that analyze multiple causes of varying resistance in replicated field trials. In such studies, yield losses range from 6% (Groth et al., 2014) on a moderately resistant variety (Caffey) in Louisiana, to 50.2% (Bonman et al., 1991) on a susceptible variety (Daechang) in Korea. Groth et al. (various years) is the only source of multi-year, multi-variety yield loss data from blast inoculations. Given the lack of locational and varietal-specific rates of yield response to blast, the estimates put forth by Groth et al. (various years) were used in our study to estimate yield losses caused by blast susceptibility ratings. Furthermore, because yield loss caused by blast is determined by the severity and timing of the infection, a static percentage yield loss would not be appropriate in this study; as such, a simulated range of yield loss was developed based on susceptibility rankings and empirical losses, as reported by Groth et al. (various years).

### *Cost of Blast Mitigation*

The two most commonly used fungicides for rice blast are Quilt Xcel™ (active ingredients: 13.5% Azoxystrobin and 11.7% Propiconazole) and Quadris™ (active ingredient: 22.9% Azoxystrobin); they are both produced by Syngenta. Their prices vary greatly by retailer and are affected by rebates, etc. In 2015, the average cost for Quilt Xcel to the grower was approximately \$46.23 liter<sup>-1</sup> (Driggs, 2015). Comparatively, the average cost for Quadris is approximately \$72.65 liter<sup>-1</sup>. The commonly applied rate for Quilt Xcel in the Mid-South, U.S. is 1.28 liters/ha, and for Quadris, it is 0.73 liters/ha. Thus, the estimated cost of Quadris is \$53.08 ha<sup>-1</sup>, and for Quilt Xcel, it is \$59.11 ha<sup>-1</sup>. Four crop dusting services in the Delta of Arkansas and Mississippi were contacted in August, 2015, and an average application rate of aerial fungicide was recorded at \$19.77 ha<sup>-1</sup>. Additionally, data is not available for the percentage of hectares which were treated with Quadris or Quilt Xcel; as such, the average price of both fungicides, \$56.10 ha<sup>-1</sup>, were taken and then added to the cost of aerial application for a total cost of \$75.87 ha<sup>-1</sup>. Finally, because both the historical cost of aerial application and fungicide costs were prohibitive to obtain, they were assumed as constant across time, although adjusted for inflation.

#### *Blast Outbreak Scenario One*

In the first scenario, all hectares of rice ( $A$ ) produced in year  $t$  in county  $l$  that were sown to non-resistant variety  $i$  were assumed to be treated with one application of fungicide. Scenario one was modeled as follows:

$$TC_t^1 = C_h \sum_l A_{ilt} \quad (1)$$

Where the annual, total economic cost of blast for scenario one ( $TC_t^1$ ) is the summation of all actual historic hectares of susceptible rice varieties sown in each rice-producing county in a given year, multiplied by the cost of fungicide application per hectare ( $C_h$ ). The probability of a blast outbreak on 100% of the susceptible acres is negligible, but many producers apply a preventative fungicide application regardless of the presence of blast. Also, one application of fungicide (Quadris) was built into the 2015 extension budgets of Arkansas, Louisiana and Mississippi (Flanders and Watkins, 2015; Salassi

et al., 2015; Falconer et al., 2015). It was assumed that once the fungicide is applied, there is no associated yield loss from blast, and the fungus does not need to be sprayed again.

### *Blast Outbreak Scenario Two*

In the second scenario, the model simulates the area of susceptible varieties that are infected with blast based off of empirical trials (Norman and Moldenhauer, 2015). Outbreak acreage and percentages are scarce in the literature for Mid-South rice production, but Norman and Moldenhauer (2015 and various years) provide estimates of the yearly percentage of Arkansas rice acreage that required a fungicide application. Studies for Louisiana and Mississippi did not exist at the time of the study and as such, it was assumed that there were proportional fungicide applications in all three states. Ideally, state-specific distributions would be preferred as Louisiana typically has a higher incidence of blast than Arkansas and Mississippi, given its climatic differences—mainly its lower probability of a hard overwinter freeze to kill the fungus. Accordingly, based off of historical Arkansas data, a triangular distribution with a minimum of 0%, a mean of 22.11% and a maximum of 61.95% infected area was used. It is important to note that infection does not imply yield loss, only that the plant has been infected.

With this in mind, scenario two simulates a percentage of infected varieties and then applies two applications of fungicide to help mitigate this outbreak with no associated yield loss. Subsequently, two applications are recommended: one at the late booting stage and one seven days after the 90% panicle emergence of the main tiller when blast is spotted in a field (UACES, 2015). Thus, scenario two was modeled as follows:

$$TC_t^2 = 2C_h\lambda \sum_l A_{ilt} \quad (2)$$

Where the annual total economic cost of blast for scenario two ( $TC_t^2$ ) is the summation of the simulated, all actual historic hectares of susceptible rice varieties sown in each rice-producing county in a given year, multiplied by the simulated, infested percentage—infection rates ( $\lambda$ )—of blast, and the cost of fungicide application per hectare ( $C_h$ ) is doubled. Equation 2 is a function of time, given that the county

level varietal distribution and the area sown to susceptible varieties changes yearly. In this scenario, varietal blast ratings do not affect the probability of infection; all varieties that are non-resistant have equal probabilities of infection. Finally, the associated varietal blast ratings will be used in scenario three, which accounts for yield loss.

### *Blast Outbreak Scenario Three*

In the third scenario, the model simulates the area of susceptible varieties that are infected with blast, and simulates a corresponding yield loss associated with the infection, based on empirical field trials. Moreover, outbreaks and their associated yield losses were modeled using the same probability distribution for infection rates in scenario two and the empirical yield loss studies compiled by Groth et al. (2014). In this scenario, as in scenario two, the infected areas are assumed to be associated with two applications of fungicide, but unlike in scenario two, there will now be a yield loss associated with the infection. While a percentage yield loss is simulated for each susceptible variety, it is recognized that each variety has a different blast susceptibility rating and a different yield potential. As such, Each variety's average yield is denoted by county, as reported by each state's extension service (ARPT, 2015; LSU Ag Center, 2015b; MAFES, 2015b).

For certain years, there were no test plot yield observations for particular varieties in specific counties/parishes that were reported as sown to a specific percentage of that county/parish. That is, not every county/parish had a test plot that tested every variety sown in that county/parish. As such, all observations of unreported variety specific yields within that state in that year were averaged, and that average yield was assigned to that county for that variety for that year. Average yields by variety are reported in Table A1. Scenario three was modeled as follows:

$$TC_t^3 = TC_t^2 + \sum_l \gamma_l P_{tl} Y_{il} \quad (3)$$

Where the annual, total economic cost of blast for scenario three ( $TC_t^3$ ) is the summation of the annual, total economic cost calculated for scenario two ( $TC_t^2$ ), and the product of the simulated yield loss due to

blast ( $\gamma_i Y_{il}$ ), associated with variety  $l$ , and the annual rice price ( $P_t$ ), relevant to county  $i$ . The price ( $P_t$ ), is measured in \$/kg and aggregated at the state level, and  $\gamma_i$  is the simulated percentage of the specific blast rating yield loss. The mean percentage yield loss for the various blast susceptibility ratings are: 0.00%, 9.97%, 12.35%, 15.89%, and 16.65%, respectively, for resistant, moderately resistant, moderately susceptible, susceptible, and very susceptible. Note that a triangular distribution  $\gamma_i$  is used based on its respective mean, standard deviation, minimum, and maximum presented in Table 1, as similar to the simulated infection rate ( $\lambda$ ).

## Results

The total (aggregated annual) economic cost results of scenarios one, two, and three are presented in Tables 2, 3 and 4, respectively, and the results for the aggregate quantity of applied fungicide is presented in Table 5. For state level results, see Tables A2, A3, and A4 in the Appendix. All monetary values are included in this paper and on the aforementioned tables in 2014 terms. First, the results from scenario one show that, on average, 20.44 million dollars is spent annually in Arkansas, Louisiana and Mississippi on blast prevention (one aerial application of fungicide at a cost of \$75.87 ha<sup>-1</sup>). The largest cost of blast prevention is for Arkansas, the largest rice growing state, estimated at an average of 13.20 million dollars annually. Louisiana is estimated to spend 4.98 million dollars annually and Mississippi is estimated to spend 2.26 million. Furthermore, the area planted to blast-susceptible rice varieties in Arkansas is 2.61 and 6.23 times larger than that of Louisiana and Mississippi, respectively. On an annual basis, Table 2 indicates that the potential annual loss to blast prevention in the Mid-South, U.S. is declining at an average of 7.51% annually. This decline is partly due to the adoption - estimated at 5.71% annually - of new hybrid varieties of rice that are resistant to blast.

Second, the results from scenario two indicate that, on average, producers spend 9.04 million dollars on blast mitigation, given an assumed average infestation rate of 22.11%, and that two aerial applications of fungicide are applied at a cost of \$151.74 ha<sup>-1</sup>. The mean of scenario two (9.04 million) is lower than the estimate in scenario one (20.44 million) due to the fact in scenario two, we simulate an

outbreak, which is a percentage of total susceptible hectares; whereas in scenario one, we apply one fungicide application to all susceptible hectares. If the maximum assumed infestation rate of 58.50% is applied to the susceptible hectares, then the potential economic loss reaches 25.31 million dollars annually. Moreover, the highest annual average cost of blast mitigation after an infection rate of 22.11% is calculated for Arkansas at \$5.84 Million. Arkansas is followed by Louisiana at \$2.20 Million and then Mississippi at \$1.00 Million. In addition to the area planted to blast-resistant conventional varieties, the potential economic loss is also increased by the simulated infestation rate. Thus, areas that are prone to blast outbreaks, e.g., Louisiana with its hot and humid conditions, are likely to be associated with higher losses. However, due to the lack of data on county-specific blast outbreaks, we are not able to verify this observation. The highest and lowest total, annual economic cost of blast mitigation after an infection rate of 22.11% in the Mid-South, U.S. for scenario two is calculated in 2005 and 2012, respectively. Overall, the total economic cost for the study period (2002-2014) is estimated to be \$117.51 million dollars.

Third, the results from scenario three show that an average of 50.58 million dollars is lost due to yield loss, in addition to the 9.04 million dollars lost to blast mitigation after an average infestation rate of 22.11% is applied to all susceptible hectares. Thus, on average, a total of 59.62 million dollars is lost annually due to blast after an average infestation rate of 22.11% is applied to all susceptible hectares. If the maximum infestation rate of 58.50% is applied to the susceptible hectares, then the potential economic loss—mitigation (25.31 million) plus yield loss (209.77 million)—is estimated to be 233.87 million annually. The highest annual average cost of blast mitigation after an infection rate of 22.11% is calculated for Arkansas at 39.47 million. Arkansas is followed by Louisiana at 12.94 million and then Mississippi at 7.22 million. The calculated potential economic loss as a share of the total value of rice production in each state for the period 2012-2014 is estimated at 2.39%, 2.28%, and 1.85%, respectively,

for Mississippi, Louisiana, and Arkansas<sup>1</sup>. Overall, the potential economic loss is estimated at 2.30% for scenario three as a share of the total value of rice production in the Mid-South, U.S.

Finally, the potential economic loss is also increased by the proportion of rice planted to varieties that are relatively less resistant (moderately susceptible, susceptible, or very susceptible) to blast, area planted to conventional varieties that are resistant to blast as well as the simulated infestation rate. For the our time frame (2002-2014), the proportion of rice planted to varieties that are susceptible to blast are estimated at 89.25%, 80.48%, and 77.70%, respectively, in Louisiana, Mississippi, and Arkansas.

## **Conclusions**

The results from this study reveal the substantiality of the economic cost to rice producers of blast susceptible varieties sown in the Mid-South, U.S. Blast resistance is a trait many producers have undervalued due to the fact that blast can be mitigated with a fungicide application. Under these conditions, many producers will opt for a higher-yielding variety that is blast susceptible, over a lower-yielding variety that is blast resistant. With the advent of hybrid rice and the disease packages associated with them, all of which are currently blast resistant, producers now have the option for higher yields and blast resistance, though they come with higher seed costs.

One of the most important findings of this study is potential economic savings that can be realized if blast resistance is bred into all cultivated varieties. With this in mind, cisgenic rice breeding could be used as a type of maintenance breeding technique to simultaneously “maintain” high yields and breed for pathogen resistance to diseases like blast. Given that cisgenic breeding falls under the GMO umbrella, there are no commercially bred, cisgenic rice lines available. That being said, cisgenic rice, at the very least, should be considered as a potential option to combating blast and other biotic and abiotic stresses. To emphasize, the technology is available to eliminate a fungus that by our estimates cause

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<sup>1</sup> The total value of rice production in each State are calculated as the product of total production and the price of rice in 2014 terms received by farmers retrieved from Rice Yearbook 2015.

anywhere from 9.04-59.62 million dollars in damage annually in just three southern states and also diminishes the global food supply. While cisgenics is not a permanent solution for blast resistance (the pathogen will eventually evolve and a new resistance gene will have to be found), it can speed up the dissemination of a resistance gene. Accordingly, this study illuminates some of the potential benefits of cisgenic rice adoption, in light of the complexity of global GMO acceptance. While blast alleviation alone will not be the catalyst for GMO adoption, it is one piece of the puzzle in helping policy makers and consumers to make better informed decisions.

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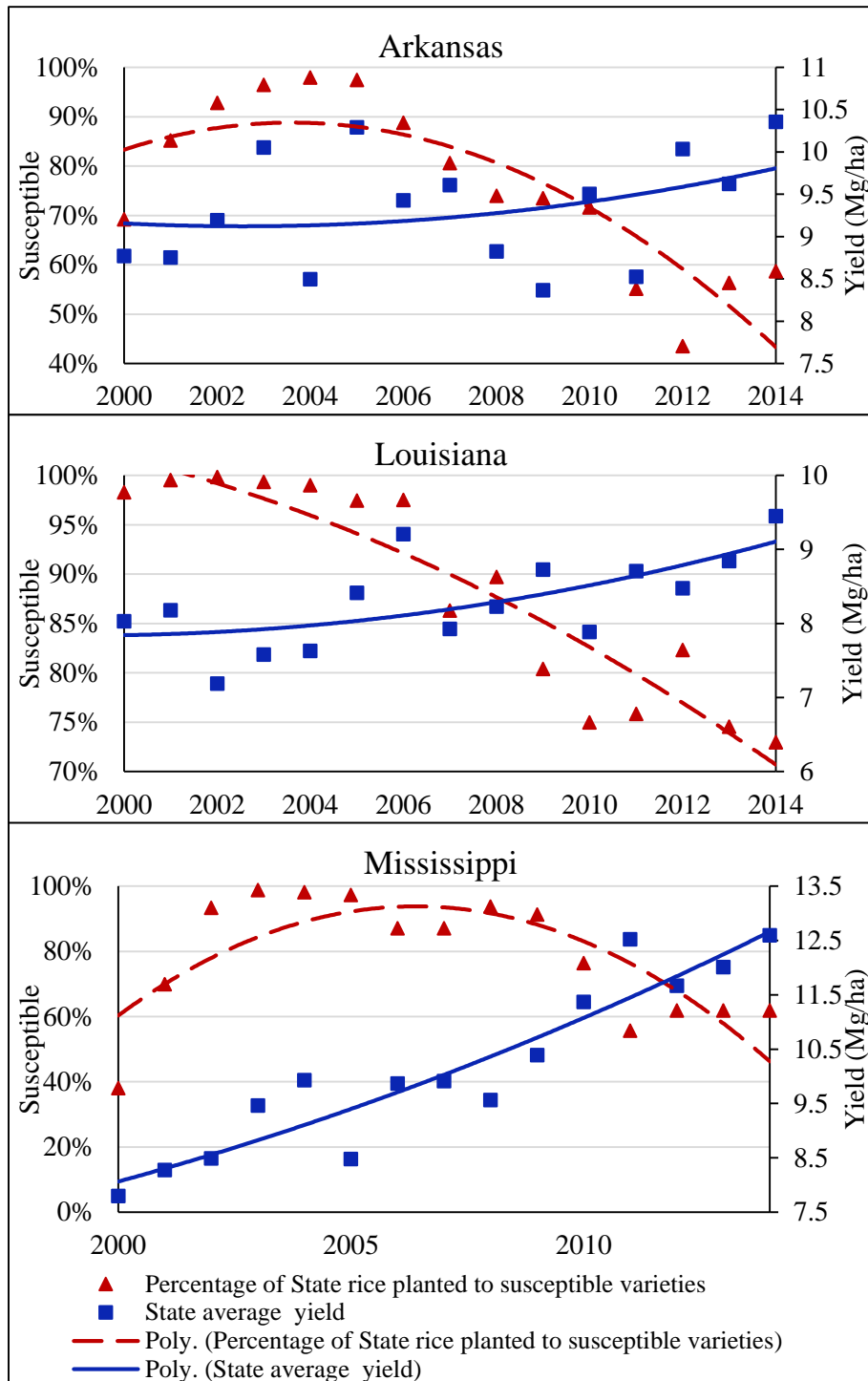


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## Tables and Figures

Figure 1: Plot of percentage of annual area planted to blast susceptible rice and average annual rice yield



*Table 1: Simulated infestation rate and yield loss rate by susceptibility rating (%)*

	Mean	Stdv	Max	Min
Infestation rate	22.11	14.49	58.50	0.10
<u>Blast yield loss rate by susceptibility rating</u>				
Resistant	0.00	0.00	0.00	0.00
Moderately resistant	9.79	5.59	21.41	0.00
Moderately susceptible	12.35	5.76	22.97	0.00
Susceptible	15.89	5.35	24.53	0.00
Very susceptible	16.65	8.52	34.48	0.00

*Table 2: Scenario one aggregate results*

Year	Area Susceptible (ha)	Prevention cost (US\$)
2002	846,422	27,441,008
2003	801,126	25,972,496
2004	882,344	28,605,598
2005	915,936	29,694,643
2006	660,924	21,427,152
2007	583,861	18,928,778
2008	618,541	20,053,103
2009	612,129	19,845,231
2010	712,545	23,100,703
2011	375,679	12,179,497
2012	344,778	11,177,714
2013	359,614	11,658,694
2014	481,390	15,606,653
Mean	630,407	20,437,790
Total	8,195,289	265,691,269
Scenario one: All susceptible area are sprayed once with Quilt Xcel fungicide to prevent an outbreak of blast		
See Table A2 for state specific results		

Table 3: Scenario two aggregate results

Year	Area Susceptible (ha)	Area Infested (ha)		Mitigation cost (US\$)	
		Mean	Max	Mean	Max
2002	846,422	187,174	524,092	12,136,354	33,982,115
2003	801,126	177,157	496,045	11,486,874	32,163,554
2004	882,344	195,117	546,334	12,651,418	35,424,308
2005	915,936	202,546	567,134	13,133,071	36,772,949
2006	660,924	146,154	409,234	9,476,601	26,534,737
2007	583,861	129,112	361,518	8,371,644	23,440,827
2008	618,541	136,781	382,991	8,868,900	24,833,156
2009	612,129	135,363	379,021	8,776,964	24,575,734
2010	712,545	157,569	441,197	10,216,764	28,607,212
2011	375,679	83,076	232,614	5,386,635	15,082,721
2012	344,778	76,243	213,482	4,943,575	13,842,143
2013	359,614	79,523	222,668	5,156,299	14,437,775
2014	481,390	106,452	298,069	6,902,365	19,326,808
Mean	630,407	139,405	390,338	9,039,036	25,309,541
Total	8,195,289	1,812,268	5,074,399	117,507,463	329,024,039

Scenario two: All susceptible hectares are infested with a simulated blast rate as shown on Table 1. The simulated infested hectares are then sprayed twice with Quilt Xcel fungicide to prevent a yield loss.

See Table A3 for state specific results

Table 4: Scenario three aggregate results

Year	Area Susceptible (ha)	Area Infested (ha)		Mitigation cost (US\$)		Average Total Yield Loss (US\$)		Average Total Loss (US\$)	
		Mean	Max	Mean	Max	Mean	Max	Mean	Max
2002	846,422	187,174	524,053	12,136,354	33,979,616	31,973,388	131,209,980	44,109,741	163,624,390
2003	801,126	177,157	496,008	11,486,874	32,161,188	57,362,707	232,189,721	68,849,581	262,869,465
2004	882,344	195,117	546,294	12,651,418	35,421,702	51,160,318	205,639,289	63,811,736	239,429,358
2005	915,936	202,546	567,092	13,133,071	36,770,244	60,714,581	241,220,779	73,847,651	276,297,272
2006	660,924	146,154	409,204	9,476,601	26,532,786	52,583,661	213,764,977	62,060,262	237,471,092
2007	583,861	129,112	361,491	8,371,644	23,439,102	57,585,719	230,070,941	65,957,363	252,430,366
2008	618,541	136,781	382,963	8,868,900	24,831,330	66,289,134	263,441,364	75,158,033	287,128,885
2009	612,129	135,363	378,993	8,776,964	24,573,926	62,086,561	266,364,021	70,863,525	290,135,086
2010	712,545	157,569	441,165	10,216,764	28,605,108	60,875,250	281,862,545	71,092,014	309,533,088
2011	375,679	83,076	232,597	5,386,635	15,081,612	35,541,682	155,476,780	40,928,317	170,065,657
2012	344,778	76,243	213,466	4,943,575	13,841,124	36,427,921	155,698,392	41,371,496	169,087,309
2013	359,614	79,523	222,651	5,156,299	14,436,713	37,780,794	155,951,166	42,937,093	169,722,879
2014	481,390	106,452	298,047	6,902,365	19,325,386	47,182,527	194,134,852	54,084,893	212,570,051
Mean	630,407	139,405	390,310	9,039,036	25,307,680	50,581,865	209,771,139	59,620,900	233,874,223
Total	8,195,289	1,812,268	5,074,026	117,507,463	328,999,837	657,564,242	2,727,024,807	775,071,706	3,040,364,899

Scenario three: All susceptible hectares are infested with a simulated blast rate as shown on Table 1.

The simulated infested hectares are then sprayed twice with Quilt Xcel fungicide; however because of untimely application spraying, the infested hectares experience a simulated yield loss depending on the blast resistance rate presented on Table 1.

See Table A4 for state specific results

Table5 : Aggregate toxicity from spraying Quilt Xcel

Year	Scenario one	Scenario two		Scenario three	
		Mean	Max	Mean	Max
2002	1,082,454	239,369	670,239	239,369	670,190
2003	1,024,527	226,559	634,371	226,559	634,325
2004	1,128,394	249,528	698,684	249,528	698,633
2005	1,171,353	259,027	725,284	259,027	725,231
2006	845,228	186,910	523,353	186,910	523,314
2007	746,676	165,116	462,330	165,116	462,296
2008	791,027	174,924	489,792	174,924	489,756
2009	782,827	173,111	484,715	173,111	484,679
2010	911,244	201,508	564,229	201,508	564,187
2011	480,440	106,242	297,481	106,242	297,459
2012	440,923	97,504	273,013	97,504	272,993
2013	459,896	101,699	284,761	101,699	284,740
2014	615,629	136,137	381,188	136,137	381,160
Mean	806,201	178,280	499,188	178,280	499,151
Total	10,480,617	2,317,635	6,489,440	2,317,635	6,488,963

Scenario one: All susceptible area are sprayed once with Quilt Xcel fungicide to prevent an outbreak of blast

Scenario two: All susceptible hectares are infested with a simulated blast rate as shown on Table 1. The simulated infested hectares are then sprayed twice with Quilt Xcel fungicide to prevent a yield loss.

Scenario three: All susceptible hectares are infested with a simulated blast rate as shown on Table 1. The simulated infested hectares are then sprayed twice with Quilt Xcel fungicide; however because of untimely application spraying, the infested hectares experience a simulated yield loss depending on the blast resistance rate presented on Table 1.

See Table A2 to A4 for state specific results



## Appendix

Table A1: Summary statistics of varieties used

Variety	Number of observation	Blast Susceptibility	Highest State % of rice hectares			Yield (Mg.ha-1)		
			AR	LA	MS	AR	LA	MS
Ahrent	46	R	2.55	-	-	8.70	-	-
Banks	23	MS	3.23	-	-	10.58	-	-
Bengal	310	S	21.65	4.05	-	8.85	7.91	-
Bowman	7	S	-	-	2.41	-	-	10.00
CL111	245	MS	6.66	33.04	12.36	8.77	8.61	11.78
CL121	47	S	1.39	2.23	-	8.18	6.48	-
CL131	145	MS	14.17	23.22	19.80	8.65	7.77	9.02
CL141	5	VS	-	0.14	-	-	6.31	-
CL142	30	S	8.53	0.14	-	7.40	9.10	-
CL151	348	VS	24.57	33.11	26.77	9.01	9.14	11.89
CL152	130	S	8.63	3.83	14.84	8.47	8.38	11.51
CL161	373	S	20.18	30.23	18.35	8.78	7.73	8.28
CL171	86	S	14.87	10.94	19.31	7.53	7.60	8.67
CL261	58	VS	6.52	3.59	-	8.43	8.02	-
CL271	4	MR	-	0.15	-	-	9.21	-
CLXL4534	50	R	-	-	8.02	-	-	14.71
CLXL6	5	R	-	-	0.42	-	-	8.38
CLXL710	7	R	-	0.15	-	-	10.25	-
CLXL712	1	R	-	0.07	-	-	9.86	-
CLXL723	198	R	11.15	2.63	7.21	10.50	11.13	11.87
CLXL729	378	R	17.19	8.77	14.42	10.16	10.78	12.13
CLXL730	131	R	10.14	5.06	1.47	10.34	10.46	10.25
CLXL745	359	R	33.41	15.72	22.67	9.12	10.85	13.01
CLXL746	16	R	-	1.33	-	-	8.11	-
CLXL753	111	R	12.84	5.70	3.91	12.19	10.85	14.28
CLXL754	3	R	-	2.18	-	-	11.43	-
CLXL756	50	R	-	-	1.00	-	-	11.74
CLXL8	161	R	5.97	2.39	2.93	10.39	9.24	9.51
CLXLblend	8	R	-	0.55	-	-	7.63	-
Caffey	8	MR	-	0.98	-	-	9.19	-
Catahoula	55	R	-	4.93	-	-	7.90	-
Cheniere	385	VS	11.54	24.31	17.98	8.92	7.95	10.71
Cocodrie	780	S	30.89	57.94	77.24	8.88	7.92	10.12
Cypress	290	MS	15.33	54.31	4.93	7.68	7.37	7.45
Dixiebelle	16	MR	-	-	0.67	-	-	8.43
Drew	86	R	28.39	0.23	0.15	9.32	9.32	9.34
Earl	13	MS	0.09	0.16	-	8.29	7.80	-
Francis	217	VS	12.94	0.90	2.00	9.69	7.20	10.11
Jackson	11	S	-	0.58	0.32	-	8.09	8.14
Jazzman2	15	MS	-	8.92	-	-	6.41	-
Jefferson	57	MS	-	1.62	1.92	-	7.15	7.22
Jupiter	291	S	15.25	13.88	-	9.91	8.75	-
Kaybonnet	42	R	2.39	0.23	0.69	8.31	8.31	8.31
LaGrue	76	S	11.04	-	0.22	9.93	-	9.70
Lemont	52	MR	-	1.21	60.59	-	6.55	6.83
Maybelle	30	S	-	2.00	-	-	6.18	-
Medark	18	S	1.22	-	-	9.81	-	-
Mermentau	44	MS	5.30	4.29	-	9.39	8.77	-
Neptune	26	MS	-	1.59	-	-	7.73	-
Pirogrot	13	MR	-	0.28	-	-	6.82	-
Priscilla	71	S	-	0.51	27.05	-	9.06	9.25
Rex	50	S	-	-	14.94	-	-	11.62
Rico	5	S	-	0.12	-	-	8.09	-
Roy J	75	S	15.47	-	-	10.75	-	-
Saber	6	R	-	0.45	0.10	-	6.70	8.02
Sabine	64	S	-	-	2.81	-	-	10.20
Saturn	7	MR	-	0.15	-	-	7.77	-
Trenasse	43	S	-	10.15	-	-	8.18	-
Wells	563	S	47.51	7.75	6.02	9.47	8.32	9.63

\*Locations in AR ; Arkansas, Ashley, Chicot, Clay, Conway, Craighead, Crittenden, Cross, Desha, Drew, Faulkner, Greene, Independence, Jackson, Jefferson, Lafayette, Lawrence, Lee, Lincoln, Lonoke, Miller, Mississippi, Monroe, Perry, Phillips, Poinsett, Pope, Prairie, Pulaski, Randolph, St. Francis, White, and Woodruff

\*\*Locations in LA; Acadia, Allen, Avoyelles, Beauregard, Bossier, Caddo, Calcasieu, Caldwell, Cameron, Catahoula, Concordia, East Carroll, Evangeline, Franklin, Grant, Iberia, Iberville, Jefferson Davis, La Salle, Lafayette Madison Morehouse Natchitoches, Ouachita, Point Coupee, Rapides, Red River, Richland, St Mary, St. Landry, St. Martin, Tensas, Vermilion, West Baton Rouge, and West Carroll.

\*\*Locations in MS; Adams, Bolivar, Coahoma, Desoto, Grenada, Holmes, Humphreys, Issaquena, Leflore, Panola, Quitman, Sharkey, Sunflower, Tallahatchie, Tate, Tunica, Washington, and Yazoo

Table A2: Scenario one results

Year	Area Susceptible (ha)	Prevention cost (US\$)	Quilt Xcel usage (liters)
Arkansas			
2002	534,600	17,331,716	683,677
2003	538,948	17,472,703	689,239
2004	571,365	18,523,648	730,695
2005	607,800	19,704,860	777,290
2006	462,128	14,982,201	590,997
2007	397,223	12,877,963	507,992
2008	384,862	12,477,241	492,185
2009	378,148	12,259,568	483,598
2010	465,384	15,087,738	595,160
2011	222,027	7,198,113	283,941
2012	191,309	6,202,239	244,657
2013	217,369	7,047,107	277,984
2014	322,470	10,454,485	412,394
Louisiana			
2002	214,359	6,949,530	274,135
2003	178,739	5,794,728	228,582
2004	211,873	6,868,908	270,955
2005	204,169	6,619,144	261,103
2006	135,293	4,386,212	173,021
2007	123,136	3,992,077	157,474
2008	149,545	4,848,243	191,247
2009	143,060	4,638,010	182,954
2010	154,043	4,994,058	196,999
2011	119,524	3,874,982	152,855
2012	121,875	3,951,195	155,861
2013	111,691	3,621,019	142,837
2014	128,365	4,161,599	164,161
Mississippi			
2002	97,463	3,159,762	124,642
2003	83,438	2,705,065	106,706
2004	99,107	3,213,042	126,744
2005	103,968	3,370,639	132,960
2006	63,502	2,058,739	81,210
2007	63,502	2,058,739	81,210
2008	84,134	2,727,618	107,595
2009	90,921	2,947,652	116,275
2010	93,119	3,018,907	119,086
2011	34,127	1,106,403	43,644
2012	31,594	1,024,279	40,404
2013	30,554	990,569	39,075
2014	30,554	990,569	39,075
Scenario one: All susceptible area are sprayed once with Quilt Xcel fungicide to prevent an outbreak of blast			

Table A3: Scenario two results

Year	Area Susceptible (ha)	Area Infested (ha)			Mitigation cost (US\$)			Quilt Xcel usage (liters)		
		Min	Mean	Max	Min	Mean	Max	Min	Mean	Max
Arkansas										
2002	534,600	10	118,219	331,016	676	7,665,310	21,463,074	13	151,185	423,323
2003	538,948	11	119,181	333,709	682	7,727,665	21,637,667	13	152,415	426,766
2004	571,365	11	126,349	353,780	723	8,192,467	22,939,126	14	161,582	452,435
2005	607,800	12	134,406	376,340	769	8,714,882	24,401,904	15	171,886	481,286
2006	462,128	9	102,193	286,143	584	6,626,188	18,553,505	12	130,690	365,936
2007	397,223	8	87,840	245,954	502	5,695,546	15,947,680	10	112,335	314,541
2008	384,862	8	85,107	238,301	487	5,518,318	15,451,438	10	108,839	304,753
2009	378,148	7	83,622	234,144	478	5,422,048	15,181,879	9	106,941	299,437
2010	465,384	9	102,913	288,159	589	6,672,864	18,684,198	12	131,611	368,514
2011	222,027	4	49,098	137,476	281	3,183,514	8,913,926	6	62,789	175,812
2012	191,309	4	42,305	118,456	242	2,743,069	7,680,666	5	54,102	151,488
2013	217,369	4	48,068	134,592	275	3,116,729	8,726,924	5	61,472	172,124
2014	322,470	6	71,310	199,669	408	4,623,713	12,946,519	8	91,195	255,348
Louisiana										
2002	214,359	4	47,402	132,728	271	3,073,573	8,606,088	5	60,621	169,740
2003	178,739	3	39,526	110,673	226	2,562,838	7,176,016	4	50,548	141,535
2004	211,873	4	46,853	131,188	268	3,037,917	8,506,248	5	59,918	167,771
2005	204,169	4	45,149	126,418	258	2,927,453	8,196,948	5	57,739	161,671
2006	135,293	3	29,918	83,772	171	1,939,893	5,431,753	3	38,261	107,132
2007	123,136	2	27,230	76,244	156	1,765,579	4,943,667	3	34,823	97,505
2008	149,545	3	33,070	92,596	189	2,144,236	6,003,918	4	42,291	118,417
2009	143,060	3	31,636	88,581	181	2,051,256	5,743,571	4	40,458	113,282
2010	154,043	3	34,064	95,381	195	2,208,726	6,184,491	4	43,563	121,979
2011	119,524	2	26,431	74,008	151	1,713,791	4,798,660	3	33,802	94,645
2012	121,875	2	26,951	75,463	154	1,747,498	4,893,041	3	34,466	96,507
2013	111,691	2	24,699	69,157	141	1,601,471	4,484,161	3	31,586	88,442
2014	128,365	3	28,386	79,482	162	1,840,553	5,153,599	3	36,302	101,646
Mississippi										
2002	97,463	2	21,553	60,348	123	1,397,470	3,912,954	2	27,563	77,176
2003	83,438	2	18,451	51,664	106	1,196,371	3,349,871	2	23,596	66,071
2004	99,107	2	21,916	61,365	125	1,421,034	3,978,934	2	28,027	78,478
2005	103,968	2	22,991	64,375	131	1,490,735	4,174,097	3	29,402	82,327
2006	63,502	1	14,043	39,320	80	910,520	2,549,480	2	17,958	50,284
2007	63,502	1	14,043	39,320	80	910,520	2,549,480	2	17,958	50,284
2008	84,134	2	18,605	52,094	106	1,206,346	3,377,800	2	23,793	66,621
2009	90,921	2	20,106	56,297	115	1,303,660	3,650,284	2	25,712	71,996
2010	93,119	2	20,592	57,658	118	1,335,174	3,738,523	2	26,334	73,736
2011	34,127	1	7,547	21,131	43	489,330	1,370,136	1	9,651	27,024
2012	31,594	1	6,987	19,563	40	453,009	1,268,436	1	8,935	25,018
2013	30,554	1	6,757	18,919	39	438,099	1,226,690	1	8,641	24,194
2014	30,554	1	6,757	18,919	39	438,099	1,226,690	1	8,641	24,194

Scenario two: All susceptible hectares are infested with a simulated blast rate as shown on Table ##. The simulated infested hectares are then sprayed twice with Quilt Xcel fungicide to prevent a yield loss.

Table A4: Scenario three results

Year	Area Susceptible (ha)	Area Infested (ha)			Mitigation cost (US\$)			Average Total Yield Loss (US\$)			Average Total Loss (US\$)			Quilt Xcel usage (liters)		
		Min	Mean	Max	Min	Mean	Max	Min	Mean	Max	Min	Mean	Max	Min	Mean	Max
Arkansas																
2002	534,600	5	118,219	330,992	342	7,665,310	21,461,495	1,034	21,496,471	87,530,861	1,377	29,161,781	108,003,773	7	151,185	423,292
2003	538,948	5	119,181	333,684	345	7,727,665	21,636,076	1,967	42,007,193	168,440,397	2,312	49,734,857	189,871,583	7	152,415	426,735
2004	571,365	6	126,349	353,754	366	8,192,467	22,937,438	1,539	33,071,487	131,861,309	1,905	41,263,954	153,742,178	7	161,582	452,402
2005	607,800	6	134,406	376,313	389	8,714,882	24,400,109	2,020	43,441,481	172,743,331	2,409	52,156,363	196,019,495	8	171,886	481,251
2006	462,128	5	102,193	286,122	296	6,626,188	18,552,140	1,782	37,335,978	152,478,856	2,078	43,962,166	169,054,544	6	130,690	365,909
2007	397,223	4	87,840	245,936	254	5,695,546	15,946,507	1,866	40,450,539	160,428,284	2,120	46,146,085	175,792,787	5	112,335	314,518
2008	384,862	4	85,107	238,283	246	5,518,318	15,450,302	1,901	41,427,806	163,795,686	2,147	46,946,124	178,430,721	5	108,839	304,731
2009	378,148	4	83,622	234,126	242	5,422,048	15,180,762	1,693	38,336,756	162,495,766	1,935	43,758,803	177,180,553	5	106,941	299,415
2010	465,384	5	102,913	288,137	298	6,672,864	18,682,824	1,771	40,790,045	190,225,222	2,069	47,462,909	208,297,654	6	131,611	368,487
2011	222,027	2	49,098	137,466	142	3,183,514	8,913,270	930	20,345,619	83,915,384	1,073	23,529,133	92,537,446	3	62,789	175,799
2012	191,309	2	42,305	118,447	122	2,743,069	7,680,101	1,027	22,230,929	93,020,780	1,150	24,973,998	100,449,962	2	54,102	151,477
2013	217,369	2	48,068	134,582	139	3,116,729	8,726,282	1,143	23,853,267	96,138,377	1,282	26,969,996	104,462,699	3	61,472	172,111
2014	322,470	3	71,310	199,654	206	4,623,713	12,945,567	1,568	32,361,975	131,310,545	1,774	36,985,688	143,156,929	4	91,195	255,329
Louisiana																
2002	214,359	2	47,402	132,718	137	3,073,573	8,605,455	319	6,030,709	25,680,635	456	9,104,283	33,889,696	3	60,621	169,728
2003	178,739	2	39,526	110,665	114	2,562,838	7,175,488	506	9,763,590	41,165,859	621	12,326,428	48,010,822	2	50,548	141,524
2004	211,873	2	46,853	131,179	136	3,037,917	8,505,622	549	11,130,207	45,635,451	685	14,168,124	53,749,278	3	59,918	167,759
2005	204,169	2	45,149	126,409	131	2,927,453	8,196,345	531	11,423,412	45,805,490	662	14,350,865	53,130,848	3	57,739	161,659
2006	135,293	1	29,918	83,765	87	1,939,893	5,431,353	512	10,158,853	41,862,894	599	12,098,746	46,979,347	2	38,261	107,124
2007	123,136	1	27,230	76,238	79	1,765,579	4,943,304	479	9,869,561	40,335,443	558	11,635,140	45,051,043	2	34,823	97,498
2008	149,545	1	33,070	92,589	96	2,144,236	6,003,477	693	14,791,210	59,071,994	789	16,935,446	64,798,931	2	42,291	118,408
2009	143,060	1	31,636	88,574	92	2,051,256	5,743,149	619	13,375,760	59,754,173	711	15,427,016	65,309,685	2	40,458	113,274
2010	154,043	2	34,064	95,374	99	2,208,726	6,184,036	504	10,962,664	52,005,813	603	13,171,390	57,987,809	2	43,563	121,970
2011	119,524	1	26,431	74,002	76	1,713,791	4,798,307	509	11,016,809	53,077,981	585	12,730,600	57,719,521	2	33,802	94,638
2012	121,875	1	26,951	75,458	78	1,747,498	4,892,681	496	10,126,978	47,047,051	574	11,874,476	51,779,882	2	34,466	96,500
2013	111,691	1	24,699	69,152	71	1,601,471	4,483,831	565	9,858,193	43,224,870	636	11,459,663	47,502,162	1	31,586	88,436
2014	128,365	1	28,386	79,476	82	1,840,553	5,153,220	622	11,095,837	48,152,816	704	12,936,391	53,068,662	2	36,302	101,639
Mississippi																
2002	97,463	1	21,553	60,343	62	1,397,470	3,912,666	211	4,446,207	17,998,485	274	5,843,678	21,869,018	1	27,563	77,171
2003	83,438	1	18,451	51,660	53	1,196,371	3,349,625	266	5,591,924	22,621,231	319	6,788,295	25,819,234	1	23,596	66,066
2004	99,107	1	21,916	61,361	63	1,421,034	3,978,642	331	6,958,624	28,142,529	394	8,379,658	31,937,902	1	28,027	78,472
2005	103,968	1	22,991	64,371	67	1,490,735	4,173,790	270	5,849,688	23,299,256	337	7,340,423	27,146,928	1	29,402	82,321
2006	63,502	1	14,043	39,317	41	910,520	2,549,292	240	5,088,830	20,549,486	281	5,999,350	23,074,637	1	17,958	50,280
2007	63,502	1	14,043	39,317	41	910,520	2,549,292	343	7,265,619	29,362,286	384	8,176,138	31,887,437	1	17,958	50,280
2008	84,134	1	18,605	52,091	54	1,206,346	3,377,552	477	10,070,117	40,769,112	531	11,276,463	44,114,678	1	23,793	66,616
2009	90,921	1	20,106	56,293	58	1,303,660	3,650,015	499	10,374,045	44,114,083	557	11,677,705	47,644,847	1	25,712	71,990
2010	93,119	1	20,592	57,653	60	1,335,174	3,738,248	428	9,122,541	39,631,511	488	10,457,715	43,247,625	1	26,334	73,731
2011	34,127	0	7,547	21,129	22	489,330	1,370,035	201	4,179,254	18,483,416	223	4,668,583	19,808,690	0	9,651	27,022
2012	31,594	0	6,987	19,561	20	453,009	1,268,343	200	4,070,014	16,615,787	221	4,523,023	17,825,707	0	8,935	25,016
2013	30,554	0	6,757	18,917	20	438,099	1,226,600	200	4,069,334	16,587,920	219	4,507,433	17,758,018	0	8,641	24,193
2014	30,554	0	6,757	18,917	20	438,099	1,226,600	183	3,724,715	15,174,361	202	4,162,814	16,344,460	0	8,641	24,193

Scenario three: All susceptible hectares are infested with a simulated blast rate as shown on Table ##. The simulated infested hectares are then sprayed twice with Quilt Xcel fungicide; however because of untimely application spraying, the infested hectares experience a simulated yield loss depending on the blast resistance rate presented on Table ##.

Table A5: Verities associated with the highest annual county total loss

Year	Variety	Total Loss (US\$)		
		Avg	Max	Min
Arkansas				
2002	Wells	470,178	1,292,745	15,063
2003	Wells	845,186	2,214,055	39,311
2004	Wells	619,428	1,737,301	17,946
2005	Wells	786,675	2,180,519	19,260
2006	Wells	555,549	1,991,546	8,378
2007	Wells	741,420	2,436,660	31,295
2008	Francis	413,338	1,752,278	8,810
2009	Jupiter	376,069	1,933,422	8,545
2010	CL151	649,992	2,238,647	19,411
2011	Jupiter	278,050	1,451,336	6,849
2012	CL151	361,135	1,335,632	26,181
2013	Jupiter	242,822	1,602,294	8,550
2014	Jupiter	377,788	2,317,571	6,505
Louisiana				
2002	Cocodrie	470,178	1,292,745	15,063
2003	Cocodrie	845,186	2,214,055	39,311
2004	Cocodrie	619,428	1,737,301	17,946
2005	CL161	786,675	2,180,519	19,260
2006	Cheniere	555,549	1,991,546	8,378
2007	Cocodrie	741,420	2,436,660	31,295
2008	CL161	413,338	1,752,278	8,810
2009	CL151	376,069	1,933,422	8,545
2010	CL151	649,992	2,238,647	19,411
2011	CL151	278,050	1,451,336	6,849
2012	CL151	361,135	1,335,632	26,181
2013	CL111	242,822	1,602,294	8,550
2014	CL111	377,788	2,317,571	6,505
Mississippi				
2002	Cocodrie	470,178	1,292,745	15,063
2003	Cocodrie	845,186	2,214,055	39,311
2004	Cocodrie	619,428	1,737,301	17,946
2005	Cocodrie	786,675	2,180,519	19,260
2006	Cocodrie	555,549	1,991,546	8,378
2007	Cocodrie	741,420	2,436,660	31,295
2008	Cocodrie	413,338	1,752,278	8,810
2009	CL151	376,069	1,933,422	8,545
2010	CL151	649,992	2,238,647	19,411
2011	CL151	278,050	1,451,336	6,849
2012	Rex	361,135	1,335,632	26,181
2013	CL152	242,822	1,602,294	8,550
2014	Rex	377,788	2,317,571	6,505