Implications of Rice Biotechnology On Optimal Rice Crop Rotation In the Mississippi River Delta Region

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Introduction

Important factors affecting rice production in the Mississippi River Delta are weed and disease management decisions, especially to eliminate red rice and sheath blight, which are expensive to control without crop rotation. In an effort to address the red rice problem, several biotech rice varieties have been developed to resist wide spectrum herbicides. This new technology is expected to relax the constraint of switching in and out of rice to combat red rice and enable farmers to choose the most profitable cropping strategy.

Traditionally, rotation ensures a cost-effective method of pest control in eliminating red rice and sheath blight while taking advantage of the relationships between crops to increase yield and quality, and reduce yield variability. Soybeans preceding rice provides nitrogen in the soil, an input that enhances the output level of rice. When the red rice population exceeds a tolerable level, rotation out of rice becomes necessary to eliminate red rice problem. Hence, farmers experiencing a red rice problem are interested in biotech rice technology as a tool for decreasing the cost of pest management and improving farm productivity.

This paper evaluates the adoption of biotech rice and its effects on the current crop rotation in the rice-producing region of the Mississippi River Delta. The solution of the model provides the optimal rotation sequence that maximizes the farm returns. The next sections present the problem of red rice and sheath blight disease in rice production. Red rice and sheath blight are important parameters in the mathematical programming model used in this study.

The Red Rice Problem

All weeds combined were found to reduce rice yield by 34 percent in Texas, 12 percent in Missouri, and 17 percent in Arkansas, Louisiana, and Mississippi (Smith, 1988). Among all rice weeds, red rice (*O. sativa*) presents the most challenging problem to rice producers. Large areas in the southern U.S. are prone to red rice infestation. In a survey of distribution of weed species in Arkansas, Baldwin et al (1977) reported that 38 percent of the Arkansas rice acreage suffered from red rice infestation. Red rice was also found to be responsible of docking losses in 20 percent of the milled rice. Red rice could be present in 0.3 million acres of rice in Arkansas alone considering the state has averaged 1.5 million acres over the past ten years.

The identical growth requirements of red rice and commercial rice make it difficult to effectively suppress red rice in the rice crop. Red rice populations pertain to two strawhull or blackhull ecotypes. Both types produce fast maturing seeds, which after shattering germinate or stay dormant for several years. Red rice cannot be eliminated with conventional herbicides because of its close genetic relationship with domestic rice. Adequate red rice control is not possible without an integrated weed management program including selecting certified seeds, preplant incorporated application of molinate *(S-ethyl hexahydro-1H-azepine-1carbothiate)*, continuous or pinpoint flood water, and crop rotation (Noldin et al., 1998).

The density and composition of weed species in rice depend on rice cultivar, crop rotation, and weed control technology (Smith, 1988). For example, repeated tillage in dry-seeded rice reduced barnyard grass and sprangletop but enhanced infestations of blue-green algae, ducksalad, rice flatsedge, and red rice. Without adequate control, red rice competes for nutrients and light with commercial rice and damages crop production. In a 1982-83 study of red rice interference Diarra et al (1985) reported that red rice density is a limiting factor of rice yield, but the interaction effects vary with seeding rates. They planted 5 and 108 red rice plants in 100 plants per square meter of dry-seeded rice varieties (Lebonnet and Mars) and found that the red rice densities reduced the yield of cultivated rice by 21 and 80 percent, respectively.

Kwon et al. (1991) used Lemont and Newbonnet rice to study the interaction of red rice with rice yields in Arkansas. They established a rice yield function of a quadratic form starting at a threshold of two red rice plants per square meter and reaching a maximum yield loss at 40 red rice plants per square meter. Newbonnet, a taller variety than Lemont, was found to compete better with red rice. Moreover, the duration of interference decreased grain yield, meaning that early removal of red rice is important to rice growth.

Pantone and Baker (1991) investigated the damage of red rice competition using a reciprocal yield analysis of a commercial rice variety (Mars) between 1985 and 1989 (Rice Research Station of Crowley LA.). The reciprocal of the average plant yield was estimated as a function of red rice and Mars densities to determine the coefficients of inter-competition and predict yields at different red rice densities. At a fixed density of 100 rice plants per square meter, red rice densities of 4, 16, and 25 reduced grain yield by 20, 43, and 57 percent, respectively.

The Sheath Blight Problem

Sheath blight disease is another issue that is important to consider in our programming framework. Sheath blight is a widely established rice disease in the Southern United States, which affects 50 to 66 percent of rice fields in Arkansas and damages commercial rice (Cartwright and Lee). Yield losses due to sheath blight are estimated between 5 to 15 percent. The disease attacks the flag leaf before the grain fills, which interferes with formation of the grain. Rice grains mature earlier and become susceptible to breakage during milling.

The fungus *Rhizoctonia solani AG1-1A,* also called *Thanatephorus cucumeris* causes sheath blight. The fungus spreads when infected plant residue from a previous season comes into contact with a rice stem. Sheath blight can infect soybeans, grown in rotation with rice, but the fungus causes the most damage to rice. Factors that increase the risk of sheath blight include planting of the susceptible rice varieties, short rotations, high use of nitrogen fertilizer, and reduced tillage practices.

Control of sheath blight includes longer rotations and tillage to eliminate the sources of fungus, the selection of tolerant varieties, and a careful use of fungicides. In the fields where rotation practices of two years or more are used to help control red rice, sheath blight has been decreased in comparison to fields where rice is produced in shorter rotation. However, the capacity of the fungus to survive on residues makes its control difficult solely with rotation, especially under reduced tillage, which tends to leave more residues on the ground. Since the fungus survives better in infected debris, tillage and burning are found to be good method to prevent sheath blight. Other measures are the selection of appropriate seeding and nitrogen fertilizer application rates. Seeding rates of

15 to 20 plants per square foot is considered to provide the optimal stand thickness that reduces the risk of infection due to the proximity of adjacent plants.

The Herbicide-Resistant Biotech Rice Technology

Genetic engineering companies are currently developing rice varieties that are quality enhancing or herbicide tolerant. These varieties include Clearfield IMI (*Imidazolinone*) rice by American Cyanamid and Liberty Link rice by Aventis. Monsnato who was working on Roundup Ready rice has recently discontinued research to develop this variety.

Clearfield IMI is a mutated rice developed by radioactive bombardment of a conventional rice plant, a technology that has been used to achieve short stature rice varieties. IMI rice, while herbicide tolerant, is not strictly considered a biotech since this term is applied only to transgenic varieties. Liberty Link rice contains an inserted gene that triggers an enzyme which provides special traits for resisting nonselective herbicides. Clearfield IMI and Liberty Link are important from the perspective of the producer and the environment because they can reduce production costs, by reducing herbicide applications and increasing the quality premium in the price of rice received by producers.

Liberty Link rice was approved in 1999 and may become the first GMO rice on the seed market. Liberty Link rice was developed by the insertion of the bar gene encoding P*hosphinothricin acetyl transferase* (pat) derived from the bacterium *Streptomyces Hygroscopicus*, into Bengal rice, a popular medium grain variety. The pat gene was inserted into the rice tissue to eliminate glutamine synthetase, which causes a fatal accumulation of ammonia in normal plants. The tissues were used to regenerate a transgenic rice variety, which was evaluated in greenhouses and field trials for tolerance to herbicides. The new variety is resistant to glufosinate ammonium, a herbicide that controls several weeds including red rice. Resistance to a nonselective herbicide such as glufosinate ammonium is a desired characteristic in the southern regions where the technology makes it economically feasible to control red rice.

Weed-Crop Competition Models

Research has used the theory of plant density to predict the effect of weeds on commercial crops. The core of the crop-weed competition theory assumes that plant density and yields are inter-related and that plant productivity depends on the inter- and intra-specific competition.

A common technique for analyzing crop weed interactions is partial additive experimental design, in which the crop species is maintained constant and the weed density is left to vary (Radosevich, 1987; Rejmanek et al. 1989). Diarra et al. (1985) and Kwon et al. (1991) used a partial additive model by in their studies of red rice interference on cultivated rice. The substitutive experimental design and replacement series model compares the yields of two plant species at various densities while holding constant the total number of plants. This model provides information on the coefficients of competition between two plant species such as the agronomic equations developed by Pantone and Baker (1991) which are used in this research to describe the dynamics of rice yield relative to red rice densities.

Models of weed-crop interactions to predict crop productivity treat weed density as a yield-reducing factor. A second group of competition models emphasize the interrelations of weed population dynamics and crop yield loss. In these models weed populations follow a statistical distribution which evolves over time in relation to the number of weed plants, the size of the seed base, control measures, choice of crop, and density feedback (Groenendael, 1988).

Model and Data

The research utilizes a multi-year nonlinear mixed integer-programming model to maximize the aggregate farm gross margin. The model consists of choosing the crop rotation cycle that maximizes the farm gross margin subject to crop yields and crop rotation dynamics. Farmers are assumed to choose a crop rotation scheme among three possible crops to maximize the expected gross margin over a 10-year planning horizon.

The crop selection includes three decision variables, regular rice, biotech rice, and soybeans. Only one crop can be grown in any given year. A crop decision depends on the gross margin that is possible given the costs of production, red rice and sheath blight control, and the market prices. Red rice cannot be controlled in continuous regular rice production. Red rice can be controlled in soybeans and biotech rice with herbicide applications.

The density of red rice is assumed to be a function of the seed bank, crops in the preceding years, the current crop, and the weed control activity. The level of sheath blight depends on the preceding crop and the rate of fertilizer use. Sheath blight normally occurs with short rotation practices when intensive nitrogen applications are required to sustain rice yields.

Our model assumes that the producer seeks to maximize the present value of gross margins over a 10-year planning horizon. The objective function, expressed in gross margin per acre is V_t.

$$V_t = \text{Max} \sum_{t=0}^{t=9}(GM_{ct}+GM_{bt}+GM_{st})$$

$$V_t = \sum_{t=0}^{T=9}(P_{ct}-C_{ct})Y_{ct}\, X_{rt}+(P_{st}-C_{st})Y_s X_{st}\, (1-X_{rt})*X_{bt}+(P_{bt}-C_{bt})Y_{bt}*(1-X_{bt})$$

where $GM_{ct,}$ $GM_{st,}$ GM_{bt} are discounted gross margins of conventional rice, soybeans, and biotech rice, respectively, and $Y_{rt,}$ $Y_{ct,}Y_{bt,}$ are the yields for red rice, conventional rice, and biotech rice, respectively. The prices P_{ct}, $P_{bt\,,}$ P_{st} are commercial prices for conventional rice, biotech rice and soybeans and $X_{rt} = 1$ if regular rice is grown, 0 otherwise, $X_{rt} = 1$ if soybeans are grown, 0 otherwise, and $X_{bt} = 0$ if biotech rice is grown, 1 otherwise. The costs C_{ct}, C_{st}, and C_{bt} are the crop production costs less depreciation and taxes for conventional rice, soybeans, and biotech rice, respectively.

Red rice dynamics and its effects on cultivated rice yields are modeled after research on reciprocal yield analysis of red rice competition in cultivated rice (Pantone and Baker, 1991).

$Y_{rt} = [a_{ro} + a_{rrt}D_{rt} + a_{rct}D_{ct}]^{-1} *D_{rt}$

$Y_{ct} = [a_{co} + a_{cct}D_{ct} + a_{crt}D_{rt}]^{-1}*D_{ct}$

$Y_{bt} = [a_{bo} + a_{bbt}D_{bt} + a_{brt}D_{rt}]^{-1} *D_{bt}$

$D_{rt} = B_t\, [G_t(1-I_{jt})]$; where j = c, b or s.

$B_t = B_{t-1} + S_tY_{rt} + dorm_{t-1} + dorm_{t-2}$

Where D_{rt} is red rice density, B_t is red rice seed bank, D_{ct} and D_{bt} are densities of conventional and biotech rice and S_t is the red rice shatter rate. B_0 and D_{r0} are starting seed bank and red rice density, which are given. Competition coefficients among and between rice varieties are a_{rrt}, a_{cct}, a_{bbt}, a_{rct}, a_{crt}, $a_{brt,}$ and $a_{crt.}$ Red rice germination rate is G_t and I_{jt} represents the herbicide kill rate associated with crop j. The parameters $dorm_{t-1}$ and $dorm_{t-2}$ are the germination rates for red rice seeds that were dormant for one and two years, respectively.

The model determines the optimal crop rotation cycle given the management strategy to control red rice and allows flexibility in the choice of the rotation sequence given that crops in year t are dependent on crops chosen in previous years. Crop rotation dynamics are established in the following three equations. This ensures that only one crop is produced in a year, all crop sequences are allowed, and available land (one acre in the model) is allocated to the crop production.

$$\sum_{j=c,\, b,\, s} X_{ijt} = X_{jt-1}$$

where X_{ij} is a binary variable equal to 1 if crop i = conventional rice (c), biotech rice (b), or soybeans (s) follows crop j (j= rice, biotech, or soybeans).

$$\sum_{i=c,\, b,\, s} X_{ijt} = X_{it}$$

where X_{it} is a binary variable 1 to ensure that land allocated to crops is equal between years.

$\sum_{i=c,\, b,\, s} X_{it} = 1$ meaning that only one crop is produced in any given year.

In this model, a continuous sequence of rice production imposes a penalty on rice yields to account for increasing levels of sheath blight. Rice yields are assumed to decrease 2.5 percent per year under continuous rice practice with a maximum reduction of 5 percent.

The costs of production for soybeans and rice are from the University of Arkansas Cooperative Extension Service crop budgets for 2001. The market prices received by producers are from the USDA-National Agricultural Statistics Service. Crop production costs for conventional rice and soybeans are representative of a no-till, silt-loam farm in eastern Arkansas. Production costs for biotech rice are from a study on Economic Analysis of Adopting Liberty Link Rice (Annou et. al, 2000). Specific herbicide kill rates are obtained from research by agronomists at the State Rice Research Experiment station in Stuttgart (Arkansas). The data on the competition between rice and red rice comes from research by Pantone and Baker (1991).

Results

Solving the mathematical programming model provides the crop rotation schemes that maximize the farm gross margins without and with biotech rice technology. Gross margin is total revenue from rice and soybeans minus production costs. Production costs include variable and fixed costs but exclude depreciation and taxes. Production costs also include the technology fee assessed by the Biotech Company. In the base scenario technology fee is assumed to be $25 per acre.

Red rice density is determined by the red rice yield in the last season, the shatter rate, the germination rate in this season, and the kill rates of herbicides associated with the crop produced. The model assumes an initial red rice density of 1.5 plants per square meter with a kill rate of 0.75, 0.85, and 0.95 for conventional rice, biotech rice, and soybeans, respectively. A specified fraction of the emerging red rice seeds are killed with herbicide treatments and only a small proportion survives to maturity.

Without biotech rice technology, farmers choose only between conventional rice and soybeans. With an initial red rice density of 1.5 per square meter the model provides results that are consistent with the current crop rotation practices observed in the Mississippi Delta regions (Table 1, column 1). The results replicated the three-year rotation cycle of conventional rice-soybeans-soybeans with a total of four years of conventional rice and six years of soybeans. The 10-year present value of gross margins is $845 per acre. The major factor that restricts continuous rice production is red rice densities, which are reported in the Tables. Soybeans allow for greater reduction of red rice densities due to more effective herbicide treatments (higher kill rate).

With biotech rice, rotation practices change to include five years of biotech rice, one year of conventional rice, and only four years of soybeans. This indicates a reduction in soybeans by two years and an increase in total rice by two years. Biotech rice displaced conventional rice three years and soybeans two years. The discounted total gross margin is $966 per acre which is an increase of 14 percent over 10 years as compared to the base $845. Continuous rice is not optimal in this scenario because the kill rate of biotech rice still allows an increase in red rice densities but at a lower rate of increase than in conventional rice.

Two different scenarios are conducted with changes in the technology fee to test the sensitivity of biotech planting relative to the cost of the technology. The first scenario is a decrease in technology fee from $25 to $15 per acre. The change results in a rotation practice that is similar to the base scenario but with an earlier planting of consecutive years of biotech rice. The red rice density remains a major limiting factor of crop selection given the kill rate of biotech rice. Over the planning horizon an equal number of years are planted to biotech rice in the base scenario and in the low cost technology scenario. The low cost scenario increased total gross margin by $22 per acre, to $988 per acre.

The second scenario increased technology fee from $25 to $35 per acre. Under this scenario the higher cost of the technology reduced biotech rice planting to only four years over the planning horizon. Soybeans are substituted for biotech rice in the initial years of the planning horizon to reduce red rice to a level that allows alternating years of biotech and soybeans in the remaining years of the planning period. The higher cost reduces the profitability of biotech rice as compared to soybeans to control red rice. In this scenario the discounted total gross margin declined to $907 per acre, a decrease of 6 percent relative to the base scenario.

In Table 2, the sensitivity analysis changed the relative price of rice to soybeans to evaluate the change on the optimal rotation scheme. The base scenario includes a market price of rice of $6.50 per hundredweight and soybeans of $5.50 per bushel. It is assumed that biotech rice and commercial rice can be sold for the same price. The baseline is the same as the technology scenarios in Table 1 with a $25 per acre technology fee. Three price scenarios are conducted; the first scenario is a decrease in soybean price by 15 percent, to $4.675 per bushel. The second and third scenarios have an increase in price by 13 percent and 20 percent respectively.

Under the first scenario, decrease in price by 15 percent, the optimal rotation sequence changed to an earlier adoption of biotech rice, although the number of years planted to rice, biotech rice and soybeans did not change in the planning horizon. Soybeans are less profitable which results in a later adoption of soybeans and a decrease in gross margin by $138, from $966 to $828 per acre. Under second and third scenarios, soybeans became more profitable and displaced production of biotech rice by one year over the planning horizon as compared to the base. As the price of soybeans increases, the present value of revenue from soybeans increases which results in earlier production of soybeans in the planning period. Gross margin increased to $1,082 per acre and $1,184 per acre for the 13 and 20 percent increase in soybean prices, respectively.

The third sensitivity analysis (Table 3) is a change in the biotech herbicide kill rate from 85 percent in the base (column 1) to 90 percent and 95 percent. The herbicide kill rates for conventional rice and soybeans are 75 percent and 95 percent respectively. The higher kill rates increased the efficiency of controlling red rice density with biotech rice, which results in a shift toward continuous production of biotech rice in place of soybeans. Under the kill rate of 90 percent, planting of biotech rice increased 2 years, to 7 out of 10 years. The gross margin improved $126 per acre, from $966 to $1,092 per acre.

The 95 percent kill rate scenario also exhibited a similar increase in biotech rice plantings, biotech rice was substituted for soybeans in year 6 and conventional rice replaced biotech rice in the 10th year of the planning horizon. When red rice control using biotech rice is as effective as soybeans, the optimal crop rotation becomes continuous rice. Both conventional rice and soybeans are less likely to be selected because biotech rice becomes more profitable and red rice can still be controlled.

Often rice grown in continuous years results in the development of sheath blight. In the baseline sheath blight is imposed as a penalty on yield when rice is produced in consecutive years. A rate of 5 percent was included in the baseline as a penalty for continuous rice, which is a reduction in rice yield by 2.5 percent in the second year of rice production and increases to 5 percent by the third year of consecutive rice production. The maximum decrease in yield is set at 5 percent per year.

The last scenario (Table 3, last column) doubles the yield penalty for sheath blight to 5 percent in the second year of continuous rice with a maximum of 10 percent per year. The increased yield penalty reduced the profitability of continuous biotech rice production even though the kill rate of biotech herbicide is as efficient as soybeans.

Conclusion

This research has examined the crop rotation schemes, which maximizes farm returns in the Mississippi River Delta region with introduction of biotech rice. The results show greater flexibility in planting decisions for rice producers through alternative rotation schemes. The study showed increased returns to rice producers under optimal crop rotation sequences but these returns are dependent on the cost of biotech rice, relative price of rice and soybeans, and the effectiveness of red rice control. Sensitivity analysis indicates consideration of rice disease affects the choice of rotation schemes.

Results from this study benefit producers and the industry by providing information on the potential effects of the new biotech rice on crop rotation decisions and farm income. The results provide an indication of the incentives to adopt biotech rice. This type of research is important because producers are facing new technology with greater uncertainty as opposed to well-established farming practices.

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Table 1: Optimal Rice Rotation Without and With Biotech Rice Technology Under Alternative Technology Fees

	Current Rotation Practice Without Biotech Rice		Rotations With Introduction of Biotech Rice					
			Technology Fee = $15 per acre		Technology Fee = $25 per acre		Technology Fee = $35 per acre	
Year	Crops	Red Rice Density	Crops	Red Rice Density	Crops	Red Rice Density	Crops	Red Rice Density
0	Rice	1.474	Rice	1.474	Rice	1.474	Rice	1.474
1	Soybeans	0.731	Soybeans	0.731	Soybeans	0.731	Soybeans	0.731
2	Soybeans	0.471	**Biotech**	1.414	**Biotech**	1.414	Soybeans	0.471
3	**Rice**	1.815	Soybeans	0.808	Soybeans	0.808	**Biotech**	1.089
4	Soybeans	0.931	**Biotech**	1.562	**Biotech**	1.562	Soybeans	0.598
5	Soybeans	0.587	**Biotech**	2.630	Soybeans	0.877	**Biotech**	1.159
6	**Rice**	2.250	Soybeans	1.359	**Biotech**	1.700	Soybeans	0.659
7	Soybeans	1.143	**Biotech**	2.685	Soybeans	0.952	**Biotech**	1.282
8	Soybeans	0.717	Soybeans	1.474	**Biotech**	1.842	Soybeans	0.724
9	**Rice**	2.745	**Biotech**	2.818	**Biotech**	3.084	**Biotech**	1.408
	Rice = 4 years Soybeans = 6 years Gross Margin = $845 per acre		Rice = 1 year **Biotech = 5 years** Soybeans = 4 years Gross Margin = $ 988 per acre		Rice = 1 year **Biotech = 5 years** Soybeans = 4 years Gross Margin = $966 per acre		Rice = 1 year **Biotech = 4 years** Soybeans = 5 years Gross Margin = $907 per acre	

Table 2: Optimal Rice Rotation Under Alternative Relative Prices of Rice and Soybeans

Tech Fee = $25.0	Rotation Practice for Prices: Soybeans = $5.5 per bushel Rice = $6.50 per Cwt.		Sensitivity to Relative Prices of Rice to Soybeans					
			$4.675 per bushel of Soybeans		$ 6.314 per bushel of Soybeans		$6.875 per bushel of Soybeans	
Year	Crops	Red Rice Density	Crops	Red Rice Density	Crops	Red Rice Density	Crops	Red Rice Density
0	Rice	1.474	Rice	1.474	Rice	1.414	Rice	1.474
1	Soybeans	0.731	Soybeans	0.734	Soybeans	0.731	Soybeans	0.731
2	**Biotech**	1.414	**Biotech**	1.414	**Biotech**	1.414	Soybeans	0.471
3	Soybeans	0.808	**Biotech**	2.423	Soybeans	0.808	Soybeans	0.363
4	**Biotech**	1.562	Soybeans	1.256	**Biotech**	1.562	**Biotech**	0.755
5	Soybeans	0.877	**Biotech**	2.483	Soybeans	0.877	Soybeans	0.418
6	**Biotech**	1.700	Soybeans	1.370	Soybeans	0.567	**Biotech**	0.819
7	Soybeans	0.952	**Biotech**	2.623	**Biotech**	1.268	Soybeans	0.469
8	**Biotech**	1.842	Soybeans	1.440	Soybeans	0.696	**Biotech**	0.915
9	**Biotech**	3.084	**Biotech**	2.763	**Biotech**	1.348	**Biotech**	1.564
Results	Rice = 1 year **Biotech = 5 years** Soybeans = 4 years Gross Margin = $966 per acre		Rice = 1 year **Biotech = 5 years** Soybeans = 4 years Gross Margin = $828 per acre		Rice = 1 year **Biotech = 4 years** Soybeans = 5 years Gross Margin = $1082 per acre		Rice = 1 year **Biotech = 4 years** Soybeans = 5 years Gross Margin = $1184 per acre	

Table 3: Optimal Rice Rotation Under Alternative Kill Rates of Biotech Herbicides and Yield Penalty

Tech Fee = $25.0			Sensitivity to Biotech Herbicide Kill Rate and Yield Loss in Continuous Rice					
	Biotech Kill Rate = 85 Percent Yield Penalty = 5 percent		Kill Rate = 90 percent Yield Penalty = 5 percent		Kill Rate = 95 percent Yield Penalty = 5 percent		Kill Rate = 95 percent Yield Penalty = 10 percent	
Year	Crops	Red Rice Density	Crops	Red Rice Density	Crops	Red Rice Density	Crops	Red Rice Density
0	Rice	1.474	Rice	1.474	Rice	1.474	Rice	1.474
1	Soybeans	0.731	Soybeans	0.731	Soybeans	0.731	Soybeans	0.731
2	Soybeans	1.414	**Biotech**	0.943	**Biotech**	0.471	Biotech	0.471
3	**Biotech**	0.808	**Biotech**	1.176	**Biotech**	0.363	**Biotech**	0.363
4	Soybeans	1.562	Soybeans	0.667	**Biotech**	0.252	Soybeans	0.252
5	**Biotech**	0.877	**Biotech**	0.905	**Biotech**	0.175	**Biotech**	0.175
6	Soybeans	1.700	**Biotech**	1.098	**Biotech**	0.124	Soybeans	0.124
7	**Biotech**	0.952	**Biotech**	1.249	**Biotech**	0.088	**Biotech**	0.088
8	**Biotech**	1.842	**Biotech**	1.440	**Biotech**	0.062	**Biotech**	0.062
9	**Biotech**	3.084	**Biotech**	1.656	Rice	0.219	Rice	0.219
Results	Rice = 1 year **Biotech = 5 years** Soybeans = 4 years Gross Margin = $966 per acre		Rice = 1 year **Biotech = 7 years** Soybeans = 2 years Gross Margin = $1092 per acre		Rice = 2 years **Biotech = 7 years** Soybeans = 1 years Gross Margin = $1227 per acre		Rice = 2 years **Biotech = 5 years** Soybeans = 3 years Gross Margin = $1106 per acre	