Economic Impacts of Plant Biotechnology in the Northern Plains Region of Texas

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ABSTRACT

The impacts of expected advances in crop biotechnology in the Northern Plains Region of Texas are estimated by optimizing the risk/return trade-off for representative farms. Historical yield distributions are used to derive baseline optimal solutions for the representative farms. Expected advances in crop biotechnology are incorporated into the representative farm models using yield distributions from a panel of biological experts. The results indicate that such advances could significantly increase producers' revenues and generally decrease the associated risks.

KEYWORDS: biotechnology, risk premium

Biotechnology, in its most general form, encompasses a wide range of techniques that use biological knowledge to modify living organisms. These techniques range from simple and well documented to complex and state-of-the-art. The more sophisticated techniques identified with genetic engineering have become a novelty of interest to the American public. Media reports routinely use the word *biotechnology* in reference to genetic engineering, so modern use of the term in the United States is generally associated with the newer technologies closely related to genetic engineering and recombinant DNA. As a result, the current interest in the possible impacts of biotechnology on production agriculture results from the discovery of new ways to manipulate and transfer genes from one organism to another. Modification of the genetic scheme of plants has been the focus of a long and growing list of crop production research strategies. Biotechnological approaches can lead to transgenic plants that can optimize the exploitation of specific environments.

As world economies and international trade become increasingly market-driven, the question of *'Which biotechnologies should be developed with limited resources?'* becomes increasingly determined by market forces. Based upon market needs, genetically modified products are developed and used by producers. Because of development costs, new products are not likely to be brought to the market before the status of consumer and producer acceptance has been, at least, partially established. Consumer acceptance hinges on perceived social and economic costs and benefits to society. Producer support of new technologies generally depends on consumer acceptance and the economic feasibility of production (Caswell, Fuglie, and Klotz, 1994).

The flexibility of genetic approaches permits researchers to address many problems in agricultural crop production. Biotechnology can directly affect producers by influencing

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yields, quality characteristics, or production costs. Each of these effects can be influenced by either changing their expected levels or by reducing the uncertainty associated with realizing the expected level. A firm engaged in agricultural production is governed by general economic principles common to all types of firms and industries. Because the definition of profit is the difference between revenue and costs, maximization of profit entails the joint optimization of revenue and costs. Producers must simultaneously decide the optimal level of revenue to maximize profit while minimizing the associated costs required to generate that level of revenue. Given that uncertainty cannot be eliminated from the producer's decisions, the objective of the producer becomes maximization of the *expected* level of profit. Such an objective is achieved through optimization of the expected level of yields that optimizes the expected level of revenue. Because of the simultaneous decisions on revenue and costs required to attain maximum profit, uncertainty about the revenue received for the crop affects the expected level of profit through uncertainty of revenues and costs. Thus, the producer's objective becomes the maximization of expected utility of profit through optimization of expected yields and revenue, given the uncertainly associated with production of the crop.

Costs of crop production are jointly determined with expected revenue. As a result, the producer wishing to achieve the maximum profit minimizes costs of production with respect to the expected level of revenue. Therefore, a producer has control of three factors to bring profit closer to its maximum: increase the expected level of yields, reduce the risk involved, or lower production costs. Because the objective is obtaining maximum utility of profit, a producer is faced with the problem of always striving to improve at least one of these three factors.

The Northern Plains Region of Texas (NPRT) is an important area for crop production in the United States. Much of the NPRT, the segment in which most regional crop production takes place, lies in a zone classified as semiarid. To assess the feasibility of continued research on plant stress reduction through genetic engineering in the NPRT, a need exists to evaluate the economic impacts of genetically engineered crop varieties on the profitability of agricultural operations in the region. The objective of this study is to estimate and analyze the impacts on farm profitability and enterprise selection of expected biotechnological advances in crops grown in the NPRT.

LITERATURE REVIEW

Limited research exists on the potential physical impacts of genetically engineered plants. However, literature addressing such ideas is becoming increasingly available. The lack of research into the physical impacts of biotechnology probably results from the modest number of innovations sufficiently developed to support quantitative impact studies. Genetically engineered variations, such as Bt cotton and greenbug tolerant wheat could increase agricultural productivity. Some biotechnologies have been developed and are in current use, either commercially or in wide scale testing. Rummel et al. (1994) evaluated genetically engineered cotton plants coded with the Bt gene for resistance to bollworms in the Texas Southern High Plains, an area included in the NPRT. Plants with the Bt gene sustained less bollworm injury to squares and green bolls than two highly adapted commercial cultivars. The economic feasibility of such Bt technology in cotton grown on the Texas Southern High Plains will determine the degree of adoption by producers. Some knowledge of the economic impacts to the area is necessary to help to determine whether to allocate a sizeable investment to further development of the technology.

Tauer and Love (1989) measured the potential economic impact of using herbicide-resistant corn varieties in the United States. The study examined the impacts on production, acreages, costs, prices, and producer and consumer surplus. Overall, they found that the expected yield increases would be small and likely to lead to small changes in regional acreages and income. The results of this study suggest that the gains from herbicide resistance in corn will probably result from technologies that are cost reducing rather than yield enhancing. This conclusion emphasizes the distinction between the two types of technologies. Because the immediate impacts expected in corn from herbicide tolerance are significant, the short to medium term aggregate impacts of biotechnology in corn could be expected to be mostly cost reducing instead of yield enhancing. Therefore, an estimation of the impacts of short to medium term yield enhancing biotechnologies in corn, such as those in this study, could be considered as a minor part of the total impact.

Halbrendt and Blase (1989) used a multi-equation model to estimate the impact of biological nitrogen fixation technology on U.S. nitrogen fertilizer demand and planted corn acreage. They considered three levels of reduced fertilizer application due to biological nitrogen fixation technology. They concluded that a decrease in nitrogen fertilizer demand and a reduction in corn acreage planted would be the result of lower production costs. Like the work of Tauer and Love (1989), this study suggests that gains from biotechnology in corn will take the form of cost-reducing technologies and not yield-enhancing technologies. Biological nitrogen fixation in corn is concluded to lower levels of nitrogen fertilizer application, thereby lowering production costs. Combining the near-term expectations for biological nitrogen fixation in corn with herbicide tolerance, short-term expectations for biotechnology in corn could lean even further toward cost reducing technologies.

Tauer (1989) estimated the economic impact of future biological nitrogen fixation technologies using AGSIM, an econometric simulation model of United States agriculture. He modeled five scenarios that represented five possible states after biotechnological innovation. He concluded that biological nitrogen fixation technologies could have a high value to society. Tauer estimated the benefits that might be attributed to biological nitrogen fixation technology if nitrogen fertilizer application were eliminated on the major crops in the United States to be almost $4.5 billion. Tauer indicated that crop plant biotechnology is likely to have substantial economic impacts to producers and to the larger society.

Chiou, Chen, and Capps (1993) developed a structural qualitative choice model to estimate the impact of genetic improvements in cotton fiber quality resulting from inserting Bt-toxin genes into cotton plants. They developed two simulation scenarios using projections of staple length and strength improvements to estimate potential economic gains. They found that enhancements in fiber characteristics could change cotton prices. Thus, these improvements could affect the profitability of cotton production. Price changes resulting from quality improvements would have an effect on the revenue received by cotton producers.

Significant influences in agricultural production decisions are: (1) the level of risk inherent in the enterprise, and (2) the attitude of the decision maker toward the inherent risks. The risk attitudes, or risk preference, of a decision maker are difficult to quantify. Protracted debate continues about the appropriate technique for quantifying individual risk preferences. Smith and Mandac (1995) focused on the use of fertilizer in rice production to find whether empirical objective distributions can be taken as reasonable approximations of farmers' risk perceptions. They concluded that properly estimated objective distributions could be used to approximate upper limits of the effects of producer risk aversion on farmers' allocative decisions.

The issue of technology adoption, if, when, and why a firm decides to exploit a new technology, involves the analysis and evaluation of factors affecting the decision to adopt a new technology such as the usefulness and cost of the innovation and the risk associated with the innovation. Szmedra, Wetzstein, and McClendon (1990) developed a dynamic theoretical framework to estimate the degree of technology adoption, full or partial. They found that varying adoption rates among producers may be explained by differing levels of existing technology and the producer's level of risk preference.

Anderson and Hazell (1994) confirm that the empirical evidence on the importance of risk in adoption decisions is not conclusive. They point to studies by Roumasset (1976) and Walker (1981) to refute risk's role in technology adoption decisions. Likewise, they refer to Moscardi and de Janvry (1977), O'Mara (1983), Gerhart (1975), Anderson and Hamal (1983), Binswanger et al. (1982), and Krause et al. (1990) to support the role of risk in technology adoption. They conclude that the contrasting results may be due to the sophistication of the relationship between crop yield risks and the variability of farm income.

METHODS, PROCEDURES, AND MODEL FORMULATION

Upland cotton, grain sorghum, winter wheat, and corn are the primary field crops produced in the NPRT, a 55-county area in Northwest Texas. Most of the production of these four crops in Texas takes place in the NPRT. Cotton production for 1996 in the NPRT was 3.3 million bales, making up 18% of total national cotton production. Regional production of grain sorghum was 52 million bushels, representing 11% of grain sorghum production in the United States. Of the 1.5 billion bushels of all wheat produced in the nation, the NPRT produced 41 million bushels. NPRT production of corn in 1996 was 156 million bushels, representing approximately 2% of corn production in the United States (USDA, various).

Representative farms were used to evaluate the effects of yield-altering biotechnologies on profitability and enterprise selection of farm entities. These farms were used to determine optimal levels of production and net returns for whole farms composed of risky crop enterprises before and after expected biotechnological shifts in the crop production functions. The NPRT was disaggregated into four subregions. The subregions are the Northern High Plains, the Transition, the Southern High Plains, and the Northern Low Plains subregions. Four representative farms, one for each subregion, were developed (Figure 1).

Two sets of quadratic programming models were developed for each representative farm. The two sets of models differ in two ways. First, the models in one set contained constraints on the number of acres planted to each crop enterprise. These acreage constraints were designed to emulate the effects of federal agricultural programs that govern crop plantings. No such constraints were included in the models of the alternate set. This dissimilarity allowed analysis of the impacts of historical commodity price supports versus the current trend toward elimination of agricultural subsidies. Second, the models in one set used historical crop yields for analysis of profitability and enterprise selection. Expected crop yields, due to biotechnological advances, were used in the alternate set of models. A detailed discussion of the two sets of models follows.

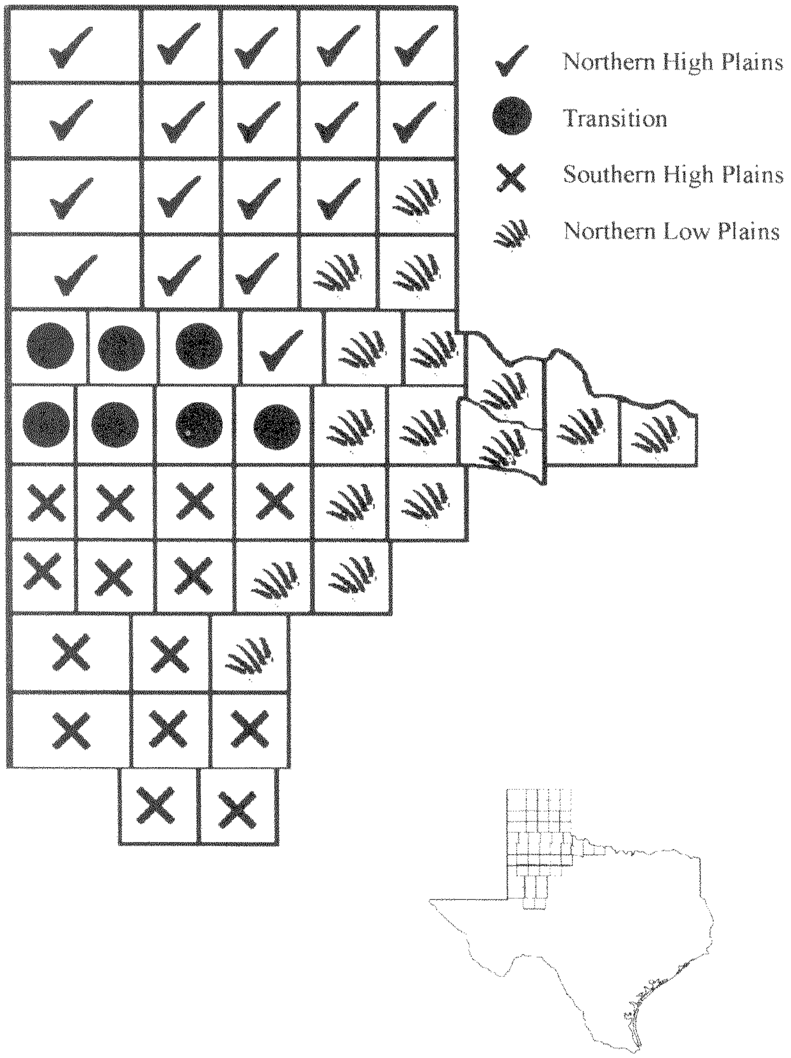

Figure 1. Subregions of the Northern Plains Region of Texas.

One set of models, called the baseline set (BASELINE), was developed to simulate current typical crop production decisions of producers in the representative subregion. Crop enterprise acreages were held constant and historical crop yields were used in the BASELINE set. A second set of models, the biotechnology set (BIOTECH), was developed to account for the expected changes in crop yields brought about by biotechnology. Assumed in the BIOTECH set is that crop enterprise acreages are not fixed, but producers are allowed to select enterprise acreages, and the expected crop yields and the variation from expected crop yields are altered because of biotechnological advances.

Asymmetric quadratic programming was used to allow for stochasticity of net revenues, resulting from crop yield and output price variability, to be maximized subject to production constraints. Parameters, applicable to the representative farms before the introduction of biotechnology-enhanced crops, were used in the BASELINE set. The BASELINE set was designed to model the current regulatory and production conditions facing producers. Parameters applicable to the representative farms after the introduction of biotechnology-enhanced crops were used in the BIOTECH set. New expected crop yield distributions resulting from biotechnological advances were used in the BIOTECH set. Clearly, the selection of the crop yield distributions for each set is important. The crop yield distributions used in the BASELINE set represent actual crop yield series, while the expected crop yield distributions used in the BIOTECH set were elicited from an expert panel. Because of the stochasticity of the crop yields and therefore crop net returns, in both representative farm model sets, a measure estimating the level of producer risk aversion was necessary.

The information required to develop the representative farm models consisted of farm size, available crop enterprises, federal farm program details, crop yield statistics, cattle grazing fees, costs of production, and producer risk preferences. Sizes in acres and available crop enterprises of representative farms were determined using data from the 1992 Census of Agriculture

Federal farm program provisions were integrated into the representative farm models to capture the effects of farm subsidies. The models included federal price supports as they existed up through the 1995 crop season. Federal program payments are incorporated into the representative models by increasing or having no effect on total revenue, depending upon whether the target price is above the national market price. The models allow for program payments to accrue to representative producers when the market price of a commodity falls below the mandated target price. The target prices used for cotton, sorghum, wheat, and corn were $0.73/lb., $2.61/bu., $4.00/bu., and $2.75/bu., respectively. The national market price for each commodity used in the representative models was the five-year arithmetic mean of the actual national market price for the 1989-1993 period. The program yields maintained on each representative farm were determined by soliciting a subjective judgement of the county average from Farm Service Administration employees in a sampling of the counties in each subregion.

As born out in the Federal Agricultural Improvement and Reform Act (FAIR) of 1996, however, the contemporary political climate is amenable to reducing agricultural subsidies. Because of the structure of declining program payments called for in the FAIR Act, the uncertainty regarding the federal agricultural program after the cessation of the FAIR Act in 2002, and the effect of the FAIR Act on commodity prices, the 1990 program provisions were judged sufficiently appropriate for the representative models. Therefore, a simplified rendering of the structure of farm price supports from the Food, Agriculture, Conservation, and Trade Act of 1990 was used in the representative farm models.

Wheat production in each of the representative subregions is generally a multiproduct enterprise generating grain and cattle grazing. Therefore, revenue from cattle grazing is included in the representative farm models. Wheat was assumed to be grazed for 4.5 months by cattle initially weighing 450 pounds at a fee of $3.50/cwt/month. Stocking rates were assumed to be one acre of wheat pasture per calf for irrigated wheat and 3.5 acres of wheat pasture per calf for dryland wheat. Gross revenue from grazing totaled $60.75/acre for irrigated wheat and $17.36/acre for dryland wheat. The calculation for wheat grazing revenue is typical of such contractual arrangements in the region.

Production costs were subtracted from gross revenues to derive crop net returns per acre for the representative farms. Production costs, variable and fixed costs, were taken from Texas Crop Enterprise Budgets (Texas Agricultural Extension Service, 1995). Budget entries from the Panhandle, the South Plains, and the Rolling Plains districts were combined to match as closely as possible the production costs of the representative subregions.

Because of the focus of this study being the application of biotechnology as output enhancing, the crop yield distributions exemplified in the models are the fundamental elements that drive the analysis. Because the study emphasizes the analysis of *future* impacts from crop plant biotechnology, the crop yield distributions used in the BIOTECH set take the designation of *expected* crop yield distributions.

The modeling of the representative farms was designed to analyze enterprise selection on the representative farms given the two combinations of regulatory and production conditions described in the two model sets. That is, part of the modeling solution should provide optimal crop enterprise acreages for each crop enterprise available to a representative farm. Therefore, solution of the models requires information on expected crop yields, expected variation from expected levels of crop yields, and expected relationships between yields of each crop.

Determination of the crop yield distributions of the Baseline set for each representative subregion was made by considering the historical crop yield series of each county in a representative subregion. A geographically weighted average in which the average across counties gave equal weight to each county in the representative subregion, was selected. The advantage of this method is that the average crop yields for all the crops in the model apply to each county in the representative subregion.

The crop yield distributions used in the BASELINE set are founded upon an historical period of twenty-two growing seasons from 1972 through 1993. The historical crop yield series were taken from USDA Crop County Statistics. The crop yield levels used in the BASELINE set were the continuations of the crop yield trends present in the historical data. The trends in the historical crop yield data were found using ordinary least squares regression. Two regression functional forms were investigated for each crop in each representative subregion. The crop yield series were examined for confirmation of a linear trend and a quadratic trend. The regression equation providing the best fitting trend for each crop yield series was selected and used to form an expected crop yield level.

The variations from expected levels of crop yields and relationships between yields of each crop were needed for the BASELINE set. Calculation of such variations and relationships within and among crop yield series required that technological trends be removed from the crop yield series. A method for detrending each crop yield series was used and is later discussed in detail. For each crop yield series, the variation from the expected level was calculated as the expected variance of the detrended crop yield series. Likewise, for each crop yield series, the relationship between the yields of each crop were calculated as the expected covariance of the detrended crop yield series with each of the other detrended crop yield series present on the representative farm. The variance and covariance of the crop yield series were descriptive of the detrended crop yield series because the accuracy of such descriptive statistics taken on the actual crop yield series would suffer from the technological trends in the series.

The detrended crop yield series were calculated in a two-step approach. First, the regression deviations were calculated for each crop yield series as the difference between the actual crop yield observation and the regression or predicted crop yield observation. Second, the deviations were added to the expected crop yield levels to generate detrended crop yield series with an expected value equal to the expected crop yield level. The variance and covariances were then taken from the detrended crop yield series.

The BIOTECH set used crop yield distributions altered to reveal the impacts of output enhancing biotechnology. Solution of the models of the BIOTECH set required information on expected crop yields, expected variation from expected levels of crop yields, and expected relationships between yields of each crop, similar to the BASELINE set. However, the expected crop yields and expected variation were elicited from an expert panel. Once obtained, the expected crop yield levels and the variance of crop yield levels were incorporated into the models of the BIOTECH set. The covariances between crop yields of crops in the representative subregion are assumed to remain unchanged from the BASELINE set.

As mentioned above, the expected crop yields and expected variation were elicited from an expert panel. The expert panel was made up of 13 scientists from biological and agricultural fields who are directly involved in some aspect of crop plant biotechnology research. The purpose of the panel within the context of the broader research project was discussed with each panel member. Through these discussions, a time horizon of 20 years was established for the BIOTECH modeling sets. That is, the expectations obtained from the panel members are for a twenty-year horizon. The panel interview was conducted in 1996, therefore, based upon the twenty-year time horizon, expectations produced from the panel are for the year 2016.

Overall, panel members were not comfortable separating the crop yield impacts directly resulting from biotechnology from the total crop yield impacts expected to take place within the twenty year horizon. Therefore, panel members were asked to return their expectations about total crop yields. Most of the difference between current crop yields and future crop yields was agreed by panel members to result from biotechnology

The Triangular Distribution Procedure (Young, 1983) was used to subjectively elicit expectations of crop yield distributions. Each panel member was asked to specify the *most likely*, *maximum*, and *minimum* expected crop yields for each crop in each representative subregion. Once the three estimates were obtained, mean crop yields and the variance of crop yields for each panel member were calculated. Once elicited and transformed into expected crop yields and variances, the individual expectations of the panel members were aggregated to provide a single expectation of crop yields and variance of crop yields for each crop in each representative subregion (Middleton, 1996). The mean and standard deviation of current and future expected crop yields are found in Table 1.

Because of the stochasticity of the crop yields in the representative farm models, a measure estimating the level of producer risk aversion was necessary in the modeling. The modeling technique used a standardized risk measurement to introduce producer risk preferences into the models. The risk aversion coefficient, denoted by λ or RAC, is equal to the Arrow-Pratt absolute risk aversion coefficient divided by two. The RAC is used in the modeling to express producer risk preferences. A wide array of risk aversion levels was tested for each representative farm to establish a range in which the RAC of subregional crop producers would be expected to lie. The bounds of the range of coefficients were determined by an iterative process of refining the bounds and running the BASELINE model set until the appropriate bounds were identified.

The set of production constraints and opportunities faced by producers in each subregion can be broadly defined and, hence, differ among subregions. Therefore, because producers' attitudes have adapted to the local conditions that help determine the profitability of available enterprises, the bounds on the range of producer risk aversion are different for each representative subregion. The range of producer risk aversion was equally divided to produce nine risk aversion coefficients (RAC), the set of which remains unchanged for each representative subregion. For each subregional model set, nine models were developed, varying only the level of risk aversion. Therefore, for the representative farm

Table 1. Current expected crop yields compared with future (twenty-year) expected crop yields elicited from expert panel.

Northern High Plains		Northern High Plains		Transition		Southern High Plains		Northern Low Plains	
		Current	Future	Current	Future	Current	Future	Current	Future
		expected yield in units per acre							
Irrigated Cotton	MEAN	—	—	593.77	662.36	694.36	742.35	558.95	633.40
(lb/ac)	STD	—	—	108.81	71.59	81.17	74.40	93.44	66.98
Dryland Cotton	MEAN	—	—	342.29	371.89	330.18	365.33	343.71	376.24
(lb/ac)	STD	—	—	85.44	46.75	88.95	44.11	69.66	38.49
Irrigated Sorghum	MEAN	101.65	109.76	94.76	104.77	69.82	77.69	—	—
(bu/ac)	STD	7.00	12.47	7.67	11.20	7.61	7.18	— N—	
Dryland Sorghum	MEAN	49.83	54.53	49.31	54.55	36.02	42.41	40.41	46.28
(bu/ac)	STD	7.07	6.56	9.43	7.12	7.40	5.81	4.68	5.67
Irrigated Wheat	MEAN	48.66	54.98	49.35	55.96	—	—	—	—
(bu/ac)	STD	9.79	7.41	10.29	7.66	—	—	—	—
Dryland Wheat	MEAN	23.77	27.16	22.84	26.42	20.72	23.51	23.59	25.72
(bu/ac)	STD	6.05	4.38	5.71	4.26	4.88	3.52	5.09	3.58
Corn	MEAN	164.50	177.96	160.72	176.56	—	—	—	—
(bu/ac)	STD	13.76	15.30	10.54	14.78	—	—	—	—

in each subregion, two sets of models (BASELINE and BIOTECH), both consisting of nine models with differing RACs, were solved

The asymmetric quadratic programming models were of the general form:

$$\text{(1)} \qquad Max\ Z = C'X - \lambda X'\Sigma X$$

$$\text{(2)} \qquad subject\ to\text{:}\ AX \leq b,$$

$$\text{(3)} \qquad X \geq 0.$$

Where Z represents expected net returns discounted for the producer's risk premium, C is the vector of net return coefficients, λ is the risk aversion coefficient, Σ is the variance-covariance matrix of net returns associated with the various enterprises, X is the vector of enterprises, A is the matrix of technical coefficients of the constraints, and b is the vector of constraint values. The first term on the right-hand side of the objective function, C′X, represents the product of the vector of net return coefficients and the vector of decision variables (i.e., levels of enterprise acreages). This product is the expected net return for the representative farm. The second term on the right-hand side of the objective function, λX′ΣX, is equal to the risk premium. The risk premium can be separated into the risk aversion coefficient, λ, and the variance of net returns, X′ΣX. To simplify the discussion of the model solutions, Z is defined as the expected net returns discounted for the producer's risk preference (ENRD), C′X is referred to as the expected net return (ENR), X′ΣX is defined as the variance of net returns (VNR), λ is referred to as the risk aversion coefficient (RAC), and λX′ΣX is the risk premium (RP).

RESULTS

The representative farm models were formulated to maximize total ENRD from crop production given production constraints on available irrigation water, labor, land and capital investment, financial parameters, economic relationships, and institutional regulations. The decision variables were the acreages of cropland allocated to production of each crop enterprise. For each of the four representative subregions (Northern High Plains, Transition, Southern High Plains, and Northern Low Plains), two set of models (BASELINE and BIOTECH) were estimated. The results are presented in Tables 2 to 5.

As expected in all of the BASELINE sets, because the crop enterprise acreages are fixed on the representative farm, the producer's level of risk aversion makes no difference in the enterprise selection. Therefore, within a model set for each of the nine models having different RACs, the ENR is identical. However, the ENRDs and the risk premiums vary according to the level of risk aversion

For each subregion, the BASELINE set is designed to mimic current producer decisions and is based on current crop yield distributions, federal price subsidies, and acreage regulations. The BIOTECH set is designed to mimic future producer decisions based on the expected crop yield distributions and the expected regulatory atmosphere of no agricultural producer subsidies or acreage regulations. Therefore, a comparison of the results from the two sets of models provides insight into the impacts of biotechnology on producer decisions and net returns (Tables 2 to 5). A detailed discussion of the results for each subregion is available from the authors, therefore in the interest of brevity only a discussion of the overall results is presented here

Changes in enterprise selection on the representative farms from the BASELINE set to the BIOTECH set provide an idea of possible acreage shifts into and out of each

Table 2. Optimal solutions and associated enterprise levels for the Northern High Plains subregion representative models.

	RAC								
	0.00e+00	1.38e−05	2.75e−05	4.13e−05	5.50e−05	6.88e−05	8.25e−05	9.63e−05	1.10e−04
ENR					dollars				
BASELINE	24,277	24,277	24,277	24,277	24,277	24,277	24,277	24,277	24,277
BIOTECH	60,367	60,367	60,367	55,039	51,891	50,003	48,744	47,844	47,140
RP									
BASELINE	0	1,817	3,634	5,451	7,268	9,084	10,901	12,718	14,317
BIOTECH	0	5,062	10,123	8,729	7,976	7,834	8,016	8,377	8,851
Total Cropland					acres				
BASELINE	739	739	739	739	739	739	739	739	739
BIOTECH	739	739	739	739	739	739	739	739	739
Irrigated Sorghum									
BASELINE	103	103	103	103	103	103	103	103	103
BIOTECH	0	0	0	0	0	0	0	0	0
Dryland Sorghum									
BASELINE	101	101	101	101	101	101	101	101	101
BIOTECH	239	239	239	373	453	500	532	555	572
Irrigated Wheat									
BASELINE	171	171	171	171	171	171	171	171	171
BIOTECH	0	0	0	0	0	0	0	0	0
Dryland Wheat									
BASELINE	244	244	244	244	244	244	244	244	244
BIOTECH	0	0	0	0	0	0	0	0	0
Corn									
BASELINE	120	120	120	120	120	120	120	120	120
BIOTECH	500	500	500	366	286	239	207	184	167

RAC = Risk Aversion Coefficient; ENR = Expected Net Return; RP = Risk Premium

Table 3. Optimal solutions and associated enterprise levels for the Transition subregion representative models.

	RAC								
	0.00e+00	1.00e−05	2.00e−05	3.00e−05	4.00e−05	5.00e−05	6.00e−05	7.00e−05	8.00e−05
ENR	dollars								
BASELINE	37,636	37,636	37,636	37,636	37,636	37,636	37,636	37,636	37,636
BIOTECH	80,666	80,457	80,453	80,452	78,912	73,510	69,909	67,336	65,407
RP									
BASELINE	0	4,676	9,352	14,028	18,704	23,380	28,056	32,732	37,408
BIOTECH	0	4,805	9,604	14,404	17,621	15,949	15,178	14,920	14,985
Total Cropland	acres								
BASELINE	858	858	858	858	858	858	858	858	858
BIOTECH	858	858	858	858	858	858	858	858	858
Irrigated Cotton									
BASELINE	264	264	264	264	264	264	264	264	264
BIOTECH	0	251	256	257	249	218	198	183	172
Dryland Cotton									
BASELINE	60	60	60	60	60	60	60	60	60
BIOTECH	0	0	0	0	0	0	0	0	0
Irrigated Sorghum									
BASELINE	91	91	91	91	91	91	91	91	91
BIOTECH	0	0	0	0	0	0	0	0	0
Dryland Sorghum									
BASELINE	65	65	65	65	65	65	65	65	65
BIOTECH	158	158	158	158	191	308	385	441	482
Irrigated Wheat									
BASELINE	77	77	77	77	77	77	77	77	77
BIOTECH	0	0	0	0	0	0	0	0	0

Table 3. *(Continued)*

Dryland Wheat									
BASELINE	91	91	91	91	91	91	91	91	91
BIOTECH	0	0	0	0	0	0	0	0	0
Corn									
BASELINE	210	210	210	210	210	210	210	210	210
BIOTECH	700	449	444	443	418	332	275	234	204

RAC = Risk Aversion Coefficient; ENR = Expected Net Return; RP = Risk Premium

Table 4. Optimal solutions and associated enterprise levels for the Southern High Plains subregion representative models.

	RAC								
	0.00e + 00	1.88e − 06	3.75e − 06	5.63e − 06	7.50e − 06	9.38e − 06	1.13e − 05	1.31e − 05	1.50e − 05
ENR					dollars				
BASELINE	40,831	40,831	40,831	40,831	40,831	40,831	40,831	40,831	40,831
BIOTECH	79,972	79,972	79,972	79,972	79,972	79,972	79,972	79,972	79,972
RP									
BASELINE	0	2,217	4,433	6,650	8,867	11,084	13,300	15,517	17,734
BIOTECH	0	1,952	3,904	5,857	7,809	9,761	11,713	13,665	15,618
Total Cropland					acres				
BASELINE	921	921	921	921	921	921	921	921	921
BIOTECH	921	921	921	921	921	921	921	921	921
Irrigated Cotton									
BASELINE	318	318	318	318	318	318	318	318	318
BIOTECH	400	400	400	400	400	400	400	400	400
Dryland Cotton									
BASELINE	419	419	419	419	419	419	419	419	419
BIOTECH	521	521	521	521	521	521	521	521	521
Irrigated Sorghum									
BASELINE	50	50	50	50	50	50	50	50	50
BIOTECH	0	0	0	0	0	0	0	0	0
Dryland Sorghum									
BASELINE	112	112	112	112	112	112	112	112	112
BIOTECH	0	0	0	0	0	0	0	0	0
Dryland Wheat									
BASELINE	22	22	22	22	22	22	22	22	22
BIOTECH	0	0	0	0	0	0	0	0	0

RAC = Risk Aversion Coefficient; ENR = Expected Net Return; RP = Risk Premium

Table 5. Optimal solutions and associated enterprise levels for the Northern Low Plains subregion representative models.

	RAC								
	0.00e+00	1.63e−05	3.25e−05	4.88e−05	6.50e−05	8.13e−05	9.75e−05	1.14e−05	1.30e−05
					dollars				
ENR									
BASELINE	26,906	26,906	26,906	26,906	26,906	26,906	26,906	26,906	26,906
BIOTECH	65,094	65,094	65,094	65,094	65,094	65,094	65,094	65,094	65,094
RP									
BASELINE	0	3,211	6,422	9,633	12,844	16,055	19,266	22,477	25,688
BIOTECH	0	3,507	7,013	10,520	14,026	17,533	21,039	24,546	28,052
					acres				
Total Cropland									
BASELINE	566	566	566	566	566	566	566	566	566
BIOTECH	566	566	566	566	566	566	566	566	566
Irrigated Cotton									
BASELINE	22	22	22	22	22	22	22	22	22
BIOTECH	0	0	0	0	0	0	0	0	0
Dryland Cotton									
BASELINE	258	258	258	258	258	258	258	258	258
BIOTECH	566	566	566	566	566	566	566	566	566
Dryland Sorghum									
BASELINE	20	20	20	20	20	20	20	20	20
BIOTECH	0	0	0	0	0	0	0	0	0
Dryland Wheat									
BASELINE	266	266	266	266	266	266	266	266	266
BIOTECH	0	0	0	0	0	0	0	0	0

RAC = Risk Aversion Coefficient; ENR = Expected Net Return; RP = Risk Premium

subregion because of biotechnology developments. Acres of irrigated cotton continue around 250 acres in the Transition farm, decrease from 22 acres to zero acres in the Northern Low Plains farm, but increase about 25% in the Southern High Plains farm from around 320 acres to 400 acres. Irrigated cotton acreage would continue higher on the Southern High Plains farm if it were not constrained by irrigation water availability. Acres of dryland cotton fall from 60 acres to zero acres in the Transition farm, however, acreage increases about 100 acres and 300 acres in the Southern High Plains and Northern Low Plains farms, respectively.

Irrigated sorghum production goes to zero on all farms, removing irrigated sorghum from production in the entire NPRT. However, dryland sorghum acreage increases about 350 acres in the Northern High Plains farm and 135 acres in the Transition farm. Decreases of about 110 acres in the Southern High Plains farm and about 20 acres in the Northern Low Plains farm result in an aggregate increase of about 120 percent or 355 acres of dryland sorghum in the NPRT. Irrigated wheat production in the Northern High Plains and Transition farms goes from 171 acres and 77 acres, respectively, to zero. Likewise, dryland wheat production declines to zero on all four farms in the NPRT. On the Northern High Plains, the Transition, the Southern High Plains, and the Northern Low Plains farms, 244 acres, 91 acres, 22 acres, and 266 acres, respectively, are lost in dryland wheat production. Corn acreage increases on the Northern High Plains farm from 120 acres to 300 acres and on the Transition farm from 210 acres to 400 acres. In both cases, the less risk averse producer increases corn acreage up to the point of constraining irrigation water.

CONCLUSIONS

This study attempts to bring together both theoretical and empirical methods of economic analysis to address the crop productivity impacts of plant stress and biotechnology, as they affect the decision-making behavior of economic agents. The empirical models developed here are for four representative farms in four distinct representative areas of the NPRT. Changes in the specification of the characteristics of the representative farms would be expected to cause changes with respect to the optimal solutions. However, the models developed here are flexible enough to accommodate additional characteristics and/or constraints that may be found in other regions where biotechnology would be expected to have significant impacts on agricultural production. Also, the models constructed here represent a general depiction of the farming conditions in each subregion of the NPRT, and thus, the results should remain robust across different farms in each particular subregion.

The results show that marked increases in producers' expected net returns and in the expected levels of payoff that account for producers' risk preferences are anticipated to accompany advances in crop biotechnology. Likewise, for the higher levels of risk aversion, developments in crop biotechnology are expected to reduce producers' risk premiums for each subregion except the Northern Low Plains subregion, where risk premiums increase slightly. At lower levels of risk aversion, risk premiums are expected to, at worst, also increase slightly. Therefore, biotechnological advances can be expected to reduce the proportion of expected net returns represented by the risk premiums for each subregion. These results have consequential and timely implications.

Producers, historically relying on federal farm programs for some protection against uncertainty, may face the reduction or elimination of farm program payments. The current political climate surrounding the federal farm support program calls for decreased program payments to producers. Total withdrawal of agricultural subsidization by the federal government may become a reality early in the twenty-first century. Under such conditions, many farmers will be forced to seek alternative risk management strategies. Expected biotechnological progress such as was examined in this study could allow farmers to realize added benefits from risk management. Depending upon the time frame of actual elimination of farm subsidies and the urgency to find a risk management tool to replace the subsidies, realization of such benefits could speed the rate of adoption of biotechnologically enhanced crops.

It is likely that expected net returns will increase because of biotechnology. The increases estimated in this study provide some idea of the expected benefits that can be anticipated. Such an estimate allows the calculation of the maximum *rent* that farmers would be willing to pay for such technology. An estimation of the *rent* could aid companies and institutions in developing investment analyses and so, budgeting of research funding for biotech products.

Based on the results of the representative farm models, expected biotechnology developments will entice producers in the region to change their enterprise selections. Such changes in enterprise selection will precipitate shifts in the typical quantities of crops grown between subregions and even into and out of the region. Keep in mind that these shifts are expected to take place gradually over an extended period of time and therefore, might not be impeded by the rigidities of a shorter time period.

Overall, biotechnology will encourage increased production of dryland sorghum and cotton at the expense of wheat and irrigated sorghum acreages. The representative models typically indicate that acres of irrigated crops will tend to decrease as advances in crop biotechnology are adopted, especially for producers at higher levels of risk aversion. Such a decrease in irrigated acreage may coincide with increased demand for water for uses other than agriculture. As a result of the increased non-agricultural demand, the cost of irrigation water could increase and further decrease its use in the crop production systems. The difference in the relative changes in irrigated versus dryland crop acreages expresses an awareness that dryland crop yields stand to benefit most from biotechnology.

The flexibility of the representative models developed here could be altered to discern the impacts of biotech innovations that differ from those expected by the expert panel members. The impacts of specific shorter-term biotech products could be incorporated into the models to determine the effect on crop production in the region. Or, the consequences of shifting funding priority from research in one crop to another could also be analyzed. Likewise, the flexibility of the models allows not only for analysis of yield changing technologies, but also, for relatively simple introduction of cost changing biotechnologies.

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