BIOPHYSICAL SIMULATION IN SUPPORT OF CROP PRODUCTION DECISIONS: A CASE STUDY IN THE BLACKLANDS REGION OF TEXAS

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Abstract

Economic feasibility of Texas Blacklands corn production in relation to sorghum, wheat, and cotton is studied. Biophysical simulation generated yield data are integrated with an economic decision model using quadratic programming. Given the various scenarios analyzed, corn is economically feasible for the Blacklands. A crop mix of half corn and half cotton production is selected under risk neutrality with wheat entering if risk aversion is present. Corn and grain sorghum production are highly substitutable. Profit effects attributed to changing corn planting dates are more pronounced than profit changes resulting from altering corn population or maturity class.

Key words: biophysical simulation, production management, risk, quadratic programming.

Farmers often seek new opportunities for income enhancement. These opportunities can involve new production practices, alternative production enterprises, and/or improved technologies. However, when evaluating such opportunities, farmers are often unable to obtain reliable data on which to base their decisions. During the last few years, scientists have developed biophysical crop-growth simulation models to provide such data. Musser and Tew cite three problem areas for which these biophysical simulation models are particularly suited for agricultural production analyses: 1) organization of input-output data, 2) examination of risk, and 3) dynamic decision making.

Increasing attention has been given to biophysical simulation in applied research. It appears that this attention will only increase. Previous researchers have addressed the use of biophysical models in research settings, concluding that these models provide a valuable source of production data (Musser and Tew; Boggess; Baier). Most of the previous studies relying on biophysical simulation have involved a single crop-growth simulation model (e.g., Mjelde et al.; Ahmed et al.; Boggess et al.; Harris and Mapp; Reichelderfer and Bender), although some have incorporated multiple crops (e.g., Bernardo et al.; Boggess and Amerling). In this study, a whole farm level analysis is done using data generated from four individual crop-growth simulation models.

One opportunity for farmers in the Blacklands prairie of Texas involves the production of corn. In recent years, hybrids have been developed which are well suited for this region. Consequently, planted corn acreage has been expanding (Parker et al.). Corn production is a possible substitute for production of the three major crops grown in the region: grain sorghum, winter wheat, and cotton. One issue regarding corn relates to its role in the farm crop mix. In addition, corn can be grown under many different production practices. Choice among production practices constitutes a second issue. The economic analysis of corn production is, however, complicated by the lack of available production data for this area. Biophysical simulation serves as a method of alleviating the limited production data problem.

The objectives of this study are to: 1) provide economic analyses of the corn production enterprise to assist Blacklands farm managers in decision making and 2) perform an integrated biophysical/economic analysis. In terms of the corn production objective, four issues

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are examined: 1) proportion of acreage devoted to corn production, 2) role of corn under alternative risk attitudes, 3) analysis of corn prices, and 4) analysis of corn production practices. More detailed explanation of the study can be found in Dillon or Dillon et al.

ANALYTICAL METHODS

The study involves the use of four biophysical simulators to generate data and an expected value-variance resource allocation quadratic programming model to perform the economic analyses. The economic production decision model provides the structure into which the biophysical models are integrated; it is therefore discussed first.

Production Decision Model

The production decision model is formulated and structured as a quadratic program designed to create a production management decision plan. The plan represents a utility maximizing plan formed in accordance with the decision maker's attitude toward risk. Production decisions involve allocating scarce resources in a risky weather environment within an equilibrium framework.

An overall schematic of the quadratic programming model is given in Figure 1. This figure is a simplification in that multiple activities and constraints are represented by single columns and rows, while matrices of coefficients are simply represented by their sign. Corn production activities, for instance, include 72 total production activities differing by planting date, plant population, and maturity class. Similarly, the modeled tractor time constraints are disaggregated on a weekly basis.

The activities of the production decision model may be categorized into seven types:

1. Production activities—The decision to engage in a production enterprise is embodied in these activities. Production practices distinguish alternative crops, planting dates, plant populations, and maturity classes. The production activi-

	Production Activities								Preplanting Operation				Planting Operation				Harvesting Operation							
	CORN	SORGHUM	WHEAT	COTTON	PRODUCT SALES	INPUT PURCHASES	PROFIT BY YEAR	MEAN PROFIT	CORN	SORGHUM	WHEAT	COTTON	CORN	SORGHUM	WHEAT	COTTON	CORN	SORGHUM	WHEAT	COTTON	TRACTOR SUBSTIT	PROFIT VARIANCE		RIGHT HAND SIDE
Objective Function								1														–		Max
Land Balance	1	1	1	1																			<=	+
Land Sequencing									1	1	1	1					−1	−1	−1	−1			<=	0
Large Tractor Time									+	+	+	+	+	+	+	+					1		<=	+
Small Tractor Time									+	+	+	+	+	+	+	+					−1		<=	+
Operation Sequencing																								
Preplant To Plant : Corn									−1				1										<=	0
: Sorghum										−1				1									<=	0
: Wheat											−1				1								<=	0
: Cotton												−1				1							<=	0
Plant To Harvest : Corn													−1				1						<=	0
: Sorghum														−1				1					<=	0
: Wheat															−1				1				<=	0
: Cotton																−1				1			<=	0
Harvest To Production : Corn	1																−1						<=	0
: Sorghum		1																−1					<=	0
: Wheat			1																−1				<=	0
: Cotton				1																−1			<=	0
Product Balance	–	–	–	–	+																		<=	0
Input Purchasing						–			+	+	+	+	+	+	+	+	+	+	+	+			<=	0
Profit Balance					+	–	−1																=	0
Mean Profit							+	−1															=	0

Figure 1. Schematic Tableau Depiction of the Blacklands Crop Production Management Model.

ties which utilize acreage require harvesting and other operations to be sequenced.

2. Product sales—The product sales allow gross revenue to be accrued. Activities are identified by product type and state of nature since yields differ by state of nature influencing product sales.
3. Input purchases—The purchase of inputs for production is depicted in these activities allowing variable costs to be incurred for the usage of inputs.
4. Profits by year—Profits attributed to a given state of nature are calculated in the model as gross revenue less variable costs under profit balance constraints, and the results are given in these variables.
5. Mean profits—Profits are averaged across states of nature to calculate expected profits under the assumption of equally likely states of nature. This variable represents the resulting expected profit.
6. Machinery operation activities—The performance of the required farming operations is represented in these activities. Machinery operations are classified by operation, tractor size required, crop, time period, preceding crop, and crop planting date and maturity class. Production operations require either small (100 HP) or large tractor (150 HP) time in the time period they are done. These operations also require the purchase of inputs and are subject to the crop rotation requirements.
7. Tractor substitution—Representation of the number of hours of large tractor time substituted for the small tractor per time period is embodied in these activities. The large tractor may be substituted for small tractor through the tractor substitution activities, but the converse is not allowed.

The constraints of the production decision model fall into eight types:

1. Land balance—This constraint ensures that the total land under production does not exceed the total amount available.
2. Land sequencing—Proper crop rotation patterns are modeled through land sequencing constraints. A complete discussion of the method employed may be found in El-Nazer and McCarl.
3. Tractor time availability—The performance of machinery operations is limited by the availability of the appropriate (large or small) tractor in the particular time period. Tractor substitution (large for small) possibilities are reflected in these constraints as well as tractor time requirements of machinery operations. Available tractor time estimation procedures are discussed below.
4. Operation sequencing—The proper sequencing of machinery operations is explicitly modeled in these constraints which ensures that the preceding operation is completed prior to performing the next operation. These rows are identified by crop, planting date (which influences time of operation as explained below), time period, and operation. Upon harvest, the production activity is complete.
5. Product balance—These constraints limit product sales to the amount produced. Biophysical simulation model yields from different production management practices are entered here under production activities to be sold at the commodity price under the product sales activities. Because yields depend on state of nature, these constraints are indexed by product and state of nature.
6. Input purchasing—These constraints require that a sufficient amount of each variable input has been purchased in order to perform machinery operations. Input requirements are entered under machinery operation activities and are purchased under input purchases at the appropriate input price.
7. Profit balance—These accounting rows calculate profits for each state of nature by subtracting input purchases from product sales.
8. Mean profit balance—Expected profits are calculated in this accounting row by averaging profits.

The objective function maximizes expected profit less the Pratt risk aversion coefficient times the variance of profit. Mathematical details of the model are found in the appendix. For a more detailed description of the economic model, see Dillon.

Machinery operation activities for corn and grain sorghum consist of crop residue removal, disking, chiseling, fertilizing, field cultivation, plant/apply fertilizer/apply insecticide/apply herbicide, row cultivation, and custom harvest. Wheat requires crop residue removal, fertilization, field cultivation, plant/apply fertilizer, custom herbicide application, custom insecticide application, and custom harvest. Cotton requires crop residue removal, disking, chiseling, fertilizing, field cultivation, plant/apply fertilizer/apply insecticide/apply herbicide, row cultivation, custom insecticide application, custom desiccant application, and custom harvest. These reflect the chisel-type, flat planting conventional system described by Morrison et al.

The timing of machinery operations is influenced by the planting date. In the model, each nonplanting operation is constrained to occur within an operation-specific time window relative to planting. All noncustom operations are subject to available tractor time. Thus, while row cultivation of corn is assumed to occur three or four weeks after planting, there must be suitable working conditions and tractor time available. Furthermore, continuous cotton is not allowed for agronomic reasons. Therefore, the planting of cotton must follow either corn, grain sorghum, or wheat. Continuous cotton is agronomically undesirable in terms of adverse effects regarding soil nutrient levels and pest populations.

The Pratt risk aversion coefficient is calculated using the method described in McCarl and Bessler. Briefly, a decision maker is assumed to maximize the lower limit from a confidence interval from a normal distribution of income. The risk aversion parameter is calculated by equating the marginal value of income under an E-V (Mean Variance) formulation with the marginal value of income when maximizing the mean minus a normal Z value times the standard error (i.e., maximizing the lower confidence interval limit). This involves dividing twice the Z value from the normal table corresponding to the confidence interval probability by an estimate of the standard deviation of income. The probability levels are varied from 50 percent risk neutrality (Z=0) to 90 percent (Z=1.645).

Data Specification for the Production Decision Model

Data required to specify the production decision model are: 1) available land, 2) available tractor time, 3) machinery working rates, 4) input requirements, 5) input prices, 6) crop yields, and 7) crop prices. The hypothetical farm is assumed to be a commercial operation and has adequate acreage for farming as a full-time occupation. The assigned land area available for production is 1,500 acres.

Available tractor time is calculated by multiplying the average number of workable field days per week by 10 working hours per day. The weekly number of days the tractor could work is calculated using a field days criteria function. The criteria used to identify a nonworking day are: 1) if it rained three consecutive days, the third day along with the following day is not considered a field day, 2) if the soil moisture of the top 11.8 inches (30 cm) is 70 percent or greater of water storage capacity on a given day, then that day is not considered a field day, and 3) if it rained 0.15 inches (0.38 cm) or more on a given day, then that day is not considered a field day.[1] The soil moisture portion of the biophysical corn model (which is common to all four models) is used to derive soil moisture. It is further assumed that labor is only performed on the farm six days out of the week. Therefore, the field days are adjusted by multiplying by 6/7.[2] Machinery working rates are those used in Morrison et al.

The production input (fuel, lubrication, repairs, maintenance, labor, fertilizer, nitrogen, herbicide, insecticide, seed, and operating capital) requirements for each crop are presented in Dillon. Input prices are representative of 1986 prices for the Blacklands area as given in Morrison et al. Farm program base acreage limitations are ignored, but 1986 government program loan levels and deficiency payments were used in determining product prices. The base product prices are assumed at $3.16 per bushel for corn, $4.35 per hundredweight for grain sorghum, $4.31 per bushel for wheat, $0.7233 per pound of cotton lint, and $69.00 per ton of cottonseed.

Biophysical Simulation Models

The biophysical simulation models are utilized to generate yields under the different crop production practices and weather patterns. Corn yields are simulated using the CORNF model by Stapper and Arkin; grain sorghum using the SORGF model by Maas and Arkin, 1978; winter wheat using the TAMW model by Maas and Arkin, 1980b; and cotton using the COTTAM model by Jackson et al. These biophysical simulation models require input data in five categories: 1) weather conditions, 2) soil characteristics, 3) geographical latitude, 4) phenological attributes, and

[1]These rules are modifications of criteria from several studies (Acharya et al.; Whitson et al.; Elliott et al.; Babeir et al.).

[2]The field time data assumptions were tested to see if they were critical to the results and were found not to be critical (Dillon).

5) production practices. Weather data include daily maximum temperature, minimum temperature, and rainfall. Data for these items were used which cover the 38-year period from 1949 to 1986. This led to generation of 37 different yield outcomes because of the overlap of two calendar years for the winter wheat growing season. The models perform daily calculations on soil water balance, evaporation, transpiration, vegetative growth, and photosynthetic processes to estimate final crop yield.

The production practices simulated include planting date and plant population for all four crops along with maturity class for corn and grain sorghum. These production practices were identified with the help of the Texas Agricultural Extension Service crop specialists and Texas Agricultural Experiment Station agronomists (Cothren; Coffman; T. Miller; F. Miller; Metzer; Rosenthal). Planting dates range from early to late season plantings for each crop. Weekly planting dates ranged from February 14 to April 4 for corn, February 28 to April 25 for grain sorghum, March 28 to May 23 for cotton, and October 3 to November 28 for winter wheat. Low, medium, and high plant populations are modeled. Plant populations in plants per acre are 15,000, 19,000, and 26,000 for corn; 50,000, 57,500, and 70,000 for grain sorghum; and 20,000, 42,000, and 80,000 for cotton. The wheat populations modeled are 15, 30, and 45 plants per square foot. These ranges include the majority of the Blackland producers. Average days to physiological maturity for the three corn maturity classes are 121 days for short season, 126 days for medium season, and 129 days for full season. Average days to physiological maturity for the three grain sorghum maturity classes are 105 days for short season, 111 days for medium season, and 115 days for full season.

Extensive validation of the yield responses to varying management practices was not possible because of insufficient data, which is the reason the biophysical simulation models are used. Indirect validation results may be found in the agronomic literature (Maas and Arkin, 1978, 1980a, 1980b; Stapper and Arkin; Larsen; Vanderlip and Arkin; Arkin et al.).

BIOPHYSICAL SIMULATION MODEL RESULTS

A total of 207 different simulated yields were generated under the alternative production practices for the four crops for each of the 37 years. There were 72 production alternatives simulated for corn (based on all combinations of eight planting dates, three maturity classes, and three plant populations), 81 for grain sorghum (based on nine planting dates, three maturity classes, and three plant populations), 27 for winter wheat (based on nine planting dates and three plant populations), and 27 for cotton (based on nine planting dates and three plant populations). This leads to 7,659 yield observations, and presentation of the simulation results for each crop would be extensive. Therefore, only a general overview of the corn results is presented (see Dillon for a more extensive discussion).

Corn yield across all production practices and years ranges from two to 182 bu/ac (bushels per acre) with an average of 54 and a standard deviation of 34 bu/ac (Table 1). Earlier planting dates exhibit consistently higher yields as do higher populations and earlier maturing varieties. Later planting dates exhibit increased yield variability as do higher plant populations and later maturing varieties. Discussion with agronomists and farm management experts indicated that the simulated yields were generally representative of actual yields received by commercial farmers in the Blacklands, although some concerns were raised about the corn maturity simulation results.

ECONOMIC RESULTS AND ANALYSIS

The economic analysis focuses on production management practices and associated profits. Results for two base conditions, risk neutrality and low risk aversion, are presented first. This discussion is followed by analysis on risk attitudes, corn prices, and corn production practices.

Base Conditions

Two different risk attitude assumptions are examined for base conditions. These base conditions include a risk neutral (50 percent certainty of achieving profits of at least the objective function value) and a low risk averse attitude (70 percent certainty of achieving profits at least equaling the objective function value).

The risk neutral profit maximizing solution exhibits expected profits of $170,103 with standard deviation of $102,900. Profits range between $13,120 and $482,453. The risk averse base scenario has much lower expected profits

TABLE 1. STATISTICAL CHARACTERISTICS OF BIOPHYSICAL SIMULATION CORN YIELD RESULTS (BUSHELS/ACRE)

Class	Level	Mean	Standard Deviation	Minimum Value	Maximum Value	Coefficient of Variation
All[a]		54.42	34.04	1.92	182.26	62.54
Planting[b] Date	2/14	63.52	31.85	6.93	165.89	50.14
	2/21	61.46	31.87	6.55	163.32	51.85
	2/28	59.24	32.37	6.50	171.87	54.64
	3/ 7	56.63	32.19	7.07	168.60	56.84
	3/14	53.17	33.14	4.10	182.26	62.31
	3/21	50.83	35.15	3.59	179.60	69.15
	3/28	47.47	35.44	2.39	182.12	74.66
	4/ 4	43.06	35.14	1.92	180.65	81.61
Plant[c] Population	15000	51.00	30.27	1.92	149.67	59.35
	19000	54.07	33.59	1.95	167.80	62.12
	26000	58.19	37.51	2.23	182.26	64.46
Maturity[d] Class	Short	59.82	26.38	8.70	138.03	44.10
	Medium	54.48	33.81	4.23	162.20	62.06
	Full	48.97	39.75	1.92	182.26	81.16

[a]All observations are used. Yields across all planting dates, plant populations, maturity classes, and years are included.

[b]Planting dates are in month/day. Yield observations for all years (1950–1986) under all remaining management practices (plant population and maturity class) are included.

[c]Plant populations are in plants/acre. Yield observations for all years (1950–1986) under all remaining management practices (planting date and maturity class) are included.

[d]Maturity classes are categorized by length of time to maturity. Yield observations for all years (1950–1986) under all remaining management practices (planting date and plant population) are included.

($109,742), a tighter range ($31,697 to $256,503), and a smaller standard deviation ($44,244). As expected, lower variation in profits is obtained at a sacrifice of expected profits. Note that the expected profits reflect the mean profit of the distribution associated with the resulting production decisions (and not the profit level achieved or exceeded 70 percent of the time in the case of risk aversion).

Different production management practices are employed in the risk neutral and risk averse base cases. The optimal crop mix for risk neutrality is 750 acres of corn and 750 acres of cotton.[3] For corn production, the decision model selects the two earliest corn planting dates (with 437 acres of corn planted in the week of 2/12–2/18 and 313 acres of corn planted in the week 2/19–2/25), the highest population, and the earliest maturity class. This mirrors the biophysical simulation results in that the management practices which produce the highest yields are selected. The model elects to produce cotton under the earliest two planting dates (planting 387 acres of cotton in the week of 3/26–4/1 and 363 acres in the week of 4/2–4/8) using the highest plant population. Again, the management practices which produce the highest average yields are selected. A 6-percent decrease in expected profits results from elimination of the corn production enterprise in the risk neutral model. Under this restriction, grain sorghum enters at 750 acres with cotton remaining at 750 acres.

Under the risk averse model, the crop mix is 258 acres of corn, 785 acres of wheat, and 457 acres of cotton. The less profitable but relatively more stable yielding (less variable relative to cotton and corn) early planted winter wheat crop is selected (762 acres planted in the week of 10/1–10/7 and 23 acres planted in the week of 10/8–10/14), with a mix between the low (692 acres) and the medium (93 acres) plant populations. These results are seemingly contrary in that lower populations of wheat not only possess lower mean yields than higher populations of wheat, but they also actually

[3]The rotational constraint prohibiting continuous cotton limits the solution to 750 acres of cotton.

TABLE 2. EXPECTED PROFITS, STANDARD DEVIATION OF PROFITS, AND PLANTED ACREAGE ASSOCIATED WITH DIFFERENT RISK AVERSION LEVELS

Risk Level[a]	Objective Function Value	Expected Profit	Standard Deviation of Profit	Planted Acreage				Total Land Used
				Corn	Grain Sorghum	Wheat	Cotton	
	Dollars			Acres				
50	170103	170103	102899	750	0	0	750	1500
55	130116	163986	89062	750	0	0	750	1500
60	102152	142800	68669	400	0	350	750	1500
65	85284	120655	51942	303	0	645	552	1500
70	74819	109742	44244	258	0	785	457	1500
75	65539	102652	40231	265	0	845	389	1500
80	57614	91951	34631	211	0	958	331	1500
85	50622	84203	30860	181	0	1040	279	1500
90	43567	74697	26720	159	0	976	229	1364

[a]These numbers stand for the income confidence interval level that goes into setting the risk aversion parameter. Namely, the risk aversion parameter is set so that the marginal contribution to income in the EV model is the same as that in a mean minus standard error model with a risk aversion which equals the normal Z value which yields the specified confidence interval. McCarl and Bessler provide details.

have higher coefficients of variation. However, the yields of the wheat production practices selected exhibit relatively more negative correlation with cotton yields than the other possible wheat production practices, thereby reducing variability of profits. Thus, these practices are selected for their risk-reducing characteristics. Under the risk averse conditions, the lowest plant population for corn is used with all 258 acres of corn planted in the first planting week (2/12–2/18) using the earliest maturing variety. The reduction of corn yield variation in the selection of lower plant populations is consistent with statistical analysis of the biophysical model results. Cotton planting production decisions remained consistent with the risk neutral model. The cotton acreage is reduced, but the planting times are held to planting during the week of 3/26–4/1 (198 acres) and the week of 4/2–4/8 (259 acres) using the highest plant population. In the low-risk averse case, a 3 percent decrease in expected profits results when corn production is prohibited. When corn production was prohibited, the crop mix consisted of 150 acres of sorghum, 818 acres of wheat, and 532 acres of cotton.

Risk Analysis

Differing risk attitudes may change the desirability of corn production. Risk analysis is conducted by examining the effects of different risk aversion parameters. This is done by solving the production decision model repeatedly using Z values corresponding to confidence levels from the 50 percent (risk neutral) to the 90 percent level in 5 percent increments. The resultant expected profits, standard deviations of profits, and crop acreages are given in Table 2. A presentation of the production practices employed appears in Table 3. As the income confidence level is increased from 50 percent to 55 percent, there is no effect on the crop mix, but there is a change in the management practices employed (Table 3). The half corn/half cotton strategy changes at a confidence level of 60 percent. Wheat enters the solution at approximately 23 percent of total crop acreage planted, replacing corn which drops to about 27 percent of the acreage. As noted earlier, wheat possesses more stable and negatively correlated yields across years with the other crops, and thereby its production enables variability of expected profits to decrease. Cotton remains at half of the total land planted. As the confidence level increases beyond the 60-percent level, wheat acreage replaces both cotton and corn. Cotton acreage remains higher than the corn acreage from the 60 percent to the 90 percent risk-significance level. This dominance of cotton over corn is explained by the relatively higher profitability of cotton and by the lower coefficient of variation of cotton yields with respect to corn. Therefore, as risk aversion increases, the production of the relatively profitable cotton crop does not need to be decreased as much as corn production to reduce profit variability. The most conservative risk attitude (90 percent) results in the planting of only 1,364 of the available 1,500 acres.

TABLE 3. PLANTING TIME, PLANT POPULATION, AND MATURITY CLASS DECISIONS ASSOCIATED WITH DIFFERENT RISK AVERSION LEVELS

Production Practice Classification	Risk Significance Level								
	50[a]	55	60	65	70	75	80	85	90
	Acres Planted								
Corn Total	750	750	400	303	258	265	211	181	159
Plant Week 2/12–2/18	437	370	400	303	258	265	211	181	159
Plant Week 2/19–2/25	313	380	0	0	0	0	0	0	0
Low Population	0	487	400	303	258	265	211	181	159
Medium Population	0	263	0	0	0	0	0	0	0
High Population	750	0	0	0	0	0	0	0	0
Short Season	750	750	400	303	258	265	211	181	159
Sorghum Total	0	0	0	0	0	0	0	0	0
Wheat Total	0	0	350	645	785	845	958	1040	976
Plant Week 10/ 1–10/ 7	0	0	350	645	762	762	762	762	739
Plant Week 10/ 8–10/14	0	0	0	0	23	83	0	0	0
Plant Week 10/15–10/21	0	0	0	0	0	0	132	108	145
Plant Week 10/22–10/28	0	0	0	0	0	0	64	170	92
Low Population	0	0	350	645	691	223	196	278	237
Medium Population	0	0	0	0	93	622	762	762	739
Cotton Total	750	750	750	552	457	389	331	279	229
Plant Week 3/26–4/ 1	387	320	350	249	198	184	162	128	96
Plant Week 4/ 2–4/ 8	363	430	400	303	259	205	169	151	133
High Population	750	750	750	552	457	389	331	279	229

[a]See footnote a of Table 2.

Higher risk aversion levels than this simply lead to a proportional decrease in acreage along risk minimizing crop mix.

The effects of risk in terms of variance of profits and expected profits display the characteristic nonlinear properties in that increasing expected profits is only obtained by increasing variance. The relationship is relatively linear to expected profits of about $110,000. Thereafter, variance increases at an increasing rate as can be calculated from the expected profit and standard deviation results presented in Table 2.

Corn Price Analysis

Sensitivity of the crop mix to alterations in relative corn price changes is investigated. The production decision model is solved under corn price levels ranging from –20 percent to +50 percent of base price ($3.16/bu) in 10 percent increments using three risk levels.[4]

The corn price analysis results are given in Table 4. Expected profits and standard deviations increase as the corn price increases. These increases in expected profits are more dramatic the less risk averse the decision maker. As risk aversion increases, production practices selected, as well as expected profits and standard deviations, are less sensitive to corn price fluctuations.

The optimal crop mixes developed for the various corn prices suggest a close substitutability between corn and grain sorghum production. Given the high degree of similarity involved in the production of these crops in terms of resource usage and machinery operations, this substitutability is anticipated. Under risk neutral conditions, a 10 percent corn price decrease is accompanied by an entire replacement of corn with grain sorghum. At a 20 percent corn price decrease, corn drops completely from the solution and grain sorghum enters for both risk averse cases. Corn and grain sorghum appear simultaneously only under a 10 percent corn price decrease and high risk aversion.

As demonstrated in Table 4, corn price fluctuations have much greater impact the lower the aversion to risk. Percentages of farmland devoted to the various crops are more stable in the face of corn price alterations the greater the aversion to risk. Increased risk aversion causes the corn acreage to be set at risk-avoiding levels, indicating that higher risk

[4]Although commodity prices move together, varying only corn prices allows for analysis of changes in relative prices without explicit assumptions on how each individual commodity price increases or decreases.

Table 4. Expected Profits, Standard Deviation of Profits, and Planted Acreage Decisions for Various Corn Prices at Risk Neutral, Low Risk Averse, and High Risk Averse Levels

Section I : Risk Neutral Conditions (50% confidence Level)

Corn Price	Expected Profit	Standard Deviation of Profit	Planted Acreage: Corn	Grain Sorghum	Wheat	Cotton	Total Land Use
	Dollars		Acres				
2.528	159320	96959	0	750	0	750	1500
2.844	159320	96959	0	750	0	750	1500
3.160	170103	102899	750	0	0	750	1500
3.476	187739	116604	959	0	0	541	1500
3.792	211042	131395	1099	0	0	400	1500
4.108	235426	141151	1100	0	0	399	1500
4.424	260865	156853	1191	0	0	308	1500
4.740	286882	167401	1191	0	0	308	1500

Section II: Low Risk Averse Conditions (70% Confidence Level)

Corn Price	Expected Profit	Standard Deviation of Profit	Planted Acreage: Corn	Grain Sorghum	Wheat	Cotton	Total Land Use
	Dollars		Acres				
2.528	106569	44694	0	150	818	532	1500
2.844	106233	43803	208	0	785	506	1500
3.160	109742	44244	258	0	785	457	1500
3.476	115946	46070	301	0	774	425	1500
3.792	123586	48498	350	0	762	388	1500
4.108	130899	50562	369	0	762	369	1500
4.424	139228	53130	392	0	764	344	1500
4.740	146743	55232	403	0	779	318	1500

Section III: High Risk Averse Conditions (90% Confidence Level)

Corn Price	Expected Profit	Standard Deviation of Profit	Planted Acreage: Corn	Grain Sorghum	Wheat	Cotton	Total Land Use
	Dollars		Acres				
2.528	71618	25973	0	89	1094	254	1438
2.844	72182	26150	87	39	1038	246	1409
3.160	74697	26720	159	0	976	229	1364
3.476	77507	27323	181	0	937	206	1325
3.792	79534	27595	181	0	916	195	1293
4.108	81910	28035	181	0	912	184	1278
4.424	84378	28533	182	0	908	173	1264
4.740	86977	29102	184	0	903	161	1248

averse individuals are less responsive to changes in relative corn prices. Apland et al. report similar results.

Analysis of the Corn Production Enterprise-Corn Production Management Decisions

The base risk neutral model resulted in 750 acres of corn planted between weeks 2/12 and 2/19 of the highest population and earliest maturing variety. Analysis of the effects of different production management decisions is conducted holding the corn acreage at 750 acres so that the results are comparable. The first analysis restricts the planting period to various two-week periods. The planting periods used and economic results are presented in Table 5. This table also includes the percentages of expected profits relative to the risk neutral base case. Planting date has a substantial effect on profits with the expected profits consistently decreasing with later planting. Generally, an additional 5–6 percent decrease

TABLE 5. EXPECTED PROFITS, STANDARD DEVIATION OF PROFITS, AND PERCENT OF BASE PROFIT FOR SENSITIVITY ANALYSIS ON CORN PRODUCTION MANAGEMENT PRACTICES

Production Practice	Expected Profit $	Standard Deviation $	Expected Profit Percent of Base Profit
Planting Date 2/12-2/25	170103	102899	1.00
Planting Date 2/19-3/ 4	165259	102131	0.97
Planting Date 2/26-3/11	157302	101059	0.92
Planting Date 3/ 5-3/18	147701	101606	0.87
Planting Date 3/12-3/25	137813	102391	0.81
Planting Date 3/19-4/ 1	129500	104078	0.76
Planting Date 3/26-4/ 8	119921	111447	0.70
Low Population	162683	87438	0.96
Medium Population	166325	93367	0.98
High Population	170103	102899	1.00
Short Maturity Class	170103	102899	1.00
Medium Maturity Class	162220	117397	0.95
Full Maturity Class	152498	132883	0.90

in expected profits results for each week the planting period is pushed later into the year. These results reflect decreases in actual corn yield as planting date is delayed. Agronomists and farm management specialists familiar with corn production in the area agreed that earlier planting is more desirable, but the risk of frosts should be considered. Soil moisture stress and high temperatures during key physiological stages, such as tasseling, are likely agronomic explanations of these results. The results of the production management study indicate that planting date is the most important of the three production management decisions modeled.

Similar analyses were done for population and maturity classes (Table 5). Lower corn plant populations cause expected profits to decrease only slightly with the medium population causing profits to drop by 2 percent while a low population caused a 4 percent drop from the base expected profits resulting from the high population. These economic results are reinforced by agronomists and farm management specialists who believe corn yields are insignificantly different for the range of commonly used plant populations. Regarding maturity classes, income decreases with the planting of later maturing corn. Medium- and full-season classes result in 95 percent and 90 percent, respectively, of the base expected profits resulting with the short-season class. Agronomists did not feel comfortable with the maturity class results, but they mirror the biophysical simulator results. Further evaluation of the biophysical simulator in terms of its maturity class results is now underway. Fortunately, the production decision-making model selected only a single maturity class. Any biases introduced by the questionable maturity class results are therefore minimal.

SUMMARY AND CONCLUSIONS

Conducting a study under changing economic and agronomic conditions is often confounded by the lack of adequate production data. Biophysical simulation models were used here to overcome production data limitations. Integration of biophysical models and an economic decision-making model using mathematical programming allows for studies of agronomic/economic problems to be undertaken.

For the hypothetical Blacklands farm, a crop mix of half corn and half cotton production is selected under risk neutrality. Corn is an economically viable crop alternative in the Blacklands. The corn production practices selected include early planting, high population levels, and short season cultivars. Wheat production is the preferred means of reducing risk, replacing both corn and cotton as risk aversion is introduced. This finding is expected agronomically because winter wheat is exposed to less severe moisture conditions and temperatures than spring crops and thus has more stable yields. Risk was further reduced by the planting of low populations of corn and low populations of wheat to complement the higher cotton populations.

Risk neutral assumptions demonstrate greater sensitivity to corn price changes than risk aversion. As expected, corn acreage increases as corn price increases resulting in lower cotton production. This is observed under all risk levels examined, but with only slight decreases in wheat acreage under risk aversion. Low risk aversion showed greater sensitivity to changes in corn price than the higher risk aversion level. The analysis of the effects of corn price changes illustrates a high degree of substitutability between the production of corn and grain sorghum.

The sensitivity of profits to changing corn production practices are most prevalent in the case of planting date. A substantial decrease in expected profits results from later plantings of corn as a consequence of decreased yields. Altering corn population levels and maturity classes causes little change in expected profits. The economic analysis indicates that the economic feasibility of Blacklands corn production depends upon several factors including product prices, production practices, and attitude toward risk.

While the economic analysis does not explicitly include detailed modeling of the farm program, three implications can be drawn regarding those operating under the farm program. First, the economic model was analyzed without specific base acreage assumptions to provide an indication of the crop mix that is desirable in adjusting base acreage. Secondly, with both corn and grain sorghum being classified as feed grains for farm program purposes, the interchangeability of these two production enterprises in the model indicates that, at the price levels assumed, corn production is slightly more profitable than grain sorghum. However, under 10 percent or lower relative corn prices, grain sorghum is more desirable. Finally, the economic analysis of the corn production decisions of planting date, plant population, and maturity class applies to corn production regardless of whether or not it is under the farm program.

Potential limitations of the biophysical simulation models exist. Simulated corn yield responses to maturity class were felt to be incorrect by some agronomists and farm management specialists. Also, such factors as rotational effects, soil nutrients, fertilization practices, organic matter content, and pests are not modeled. Limitations of the economic decision-making model are also present. Marketing alternatives, explicit government program features, and financial planning considerations are excluded as is winter wheat grazing of cattle.

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APPENDIX: MATHEMATICAL SPECIFICATION OF THE ECONOMIC DECISION-MAKING MODEL

The economic decision-making model described in the text is depicted mathematically as shown in Figure A1. A description of the indices, variable names, and equations is provided in Figure A2.

(1) MAXIMIZE $\bar{Y} - \pi \sum_{y} 1/n\,(INC_y - \bar{Y})^2$

SUBJECT TO:

(2) $\sum_{c}\sum_{s}\sum_{d}\sum_{m} PROD_{csdm} \leq LAND$

(3) $\sum_{c}\sum_{s}\sum_{t \leq t_o}\sum_{e} OPER_{cso_f te} - \sum_{s}\sum_{t \leq t_o}\sum_{e} OPER_{c_o so_h te} \leq 0$ — for all c_o, t_o of o_h

(4) $\sum_{c}\sum_{s}\sum_{t}\sum_{e} OPER_{cso_f te} - \sum_{s}\sum_{t}\sum_{e} OPER_{c_o so_h te} \leq 0$ — for all c_o

(5) $\sum_{c}\sum_{s}\sum_{o} TUSE_{co}\, OPER_{csote} \pm TSUB_{te} \leq TTIM_t$ — for all t, e; $+TSUB$ if e = large tractor; $-TSUB$ if e = small tractor

(6) $-\sum_{o_1}\sum_{t \leq t_o}\sum_{e} OPER_{cso_1 te} + \sum_{o_2}\sum_{t \leq t_o}\sum_{e} OPER_{cso_2 te} \leq 0$ — for all c, s, o, t_o and o_1 such that o_1 precedes o_2, and all o_2 such that o_2 succeeds o_1

(7) $\sum_{t}\sum_{e} OPER_{cso_h te} - \sum_{d} PROD_{csdm} = 0$ — for all c, s, m

(8) $\sum_{c}\sum_{s}\sum_{d}\sum_{o}\sum_{t}\sum_{e} IUSE_{iedo}\, OPER_{csote} - PUR_i \leq 0$ — for all i

(9) $\sum_{c}\sum_{s}\sum_{d}\sum_{m} YLD_{psdmy}\, PROD_{csdm} - SALE_{py} \leq 0$ — for all p, y

(10) $-\sum_{i} IP_i\, PUR_i + \sum_{p} PP_p\, SALE_{py} - INC_y = 0$ — for all y

(11) $\sum_{y} 1/n\, INC_y - \bar{Y} = 0$

Figure A1. Mathematical Description of the Blacklands Crop Production Management Model.

Indices refer to the following:

- c — crop
- c_o — a particular crop
- s — sowing date
- d — plant population (density)
- m — maturity class
- o — operation
- o_f — first operation
- o_h — harvest operation
- o_1 — preceding operation
- o_2 — succeeding operation
- e — tractor size (agricultural equipment—large or small)
- t — time period
- t_o — time period of operation o
- i — input
- p — product
- y — state of nature (year)

Variables and parameters depict the following:

- PROD represents production activities
- OPER represents machinery operations
- TSUB represents tractor substitution
- PUR represents input purchases
- SALE represents product sales
- INC represents income by year
- $\bar{Y}$ represents expected income

- Π = risk aversion parameter
- n = number of states of nature
- LAND = allotment of total land available
- TUSE = tractor usage for operation o on crop c
- TTIM = allotment of tractor time available in period t
- IUSE = requirement of input i required to perform operation o on crop c of population d
- YLD = yield of product p under sowing date s, population d, maturity class m, and year y
- IP = price of input i
- PP = price of product p

Each equation represents the following components:

- Eq. 1 = objective function
- Eq. 2 = available land
- Eq. 3&4 = land sequencing rotation
- Eq. 5 = tractor time availability
- Eq. 6&7 = operation sequencing
- Eq. 8 = input balance
- Eq. 9 = product balance
- Eq. 10 = income balance
- Eq. 11 = expected income balance

Figure A2. Explanation of Indices, Variable Names, and Equations Used in the Blacklands Crop Production Management Model Mathematical Description.