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An Economic Analysis of a Corn-Soybean Crop Rotation Under Various Input Combinations in South Central Texas

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ABSTRACT

Eight input combinations of commercial fertilizer, insecticides, and herbicides on a corn-soybean crop rotation in the Brazos River Bottom of Texas are evaluated. Input combinations which do not fully utilize all three inputs are consistently ranked higher by all criteria as the preferred input strategy for the corn-soybean rotation system. These results, which indicate limited input crop rotations that fall somewhere between the extremes of conventional agricultural production and organic agriculture, deserve further attention as a possible production alternative.

Key Words: corn, limited input, soybean.

Use of agri-chemical production inputs is a subject of increasing concern and importance. Concerns include pesticide residue in foods (Buzby and Skees), contamination of surface and groundwater (Ritter, Scarborough, and Chirnside), and farm worker safety (Harper and Zilberman). These concerns have led to increased regulation of chemical inputs in agriculture. Regulation generally focuses on the principle of reducing the hazard by separating workers and consumers from the source of the chemicals in either time or space (Lichtenberg, Spear, and Zilberman). Regulatory measures restrict the use and timing of application of some agri-chemicals, such as the banning of 2-4-D and 2-4-5-T. Other regulations, such as requiring the use of protective clothing or restrictions on re-entry into areas where chemicals have been applied, affect the work place.

The proper use of agri-chemicals, however, remains a necessary component of U.S. commercial agriculture. Genetic advances, along with advances in the use of agri-chemicals, have provided the basis for the relatively cheap food supply in the United States. One possible way to address both the concerns over the use of agri-chemicals and the need for a stable food supply is through the use of cropping systems which reduce the use of some agri-chemicals. Johnson, Adams, and Perry suggest, for example, that reductions in nitrogen leaching could be achieved through better management of application rates and timing with little change in profits for intensively managed irrigated fields in the Columbia Basin. Other authors, however, suggest that broad policies which restrict nitrogen use to reduce nitrate pollution are likely to substantially impact producer income (Mapp et al.). In addi-

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tion to the concerns listed previously, the passage of the Federal Agricultural Improvement and Reform (FAIR) Act may also increase interest in reduced input agricultural production. Producers need to reevaluate their production practices in light of changing and decreasing government intervention in the agriculture sector.

One way to possibly reduce input usage is through crop rotations and production practices which restrict the use of some agri-chemicals. This study examines the desirability of eight input combinations of commercial fertilizer, insecticides, and herbicides on a corn-soybean crop rotation in the Brazos River Bottom of Texas. The Brazos River Bottom is located in Burleson County in South Central Texas, where cotton is the predominant crop. Corn and grain sorghum are the other two main crops grown in this area. For 1989–96, 53% of the acreage was planted in cotton. Corn planted acreage made up 31% of the total acreage; sorghum made up 16% of the acreage (Texas Crop Statistics). Over the past several years, soybean acreage has increased in the river bottom. Soybean is being used as a rotation crop and as a low input substitute for other higher input intensive crops. With soybean being a lower input intensive crop, producers may be substituting this crop for the higher input intensive crops for financial reasons. Soybean requires less operating capital and appears to provide a reasonable cash flow in the area.

Experimental plot data is used to analyze the desirability of the different fixed rotations and input combinations on both economic and production factors. Four criteria are used. First, crop budgets are developed to determine the expected profitability of each input combination. Second, cumulative probability density functions of yields for each crop and input combinations are examined. Next, the probability of achieving break-even yields is calculated. Finally, stochastic dominance is used to determine if net returns associated with one or more input combination dominates the other combinations.

Background

Economists have long been concerned with the optimal use of production inputs. Any review of this literature including sustainability would be a major undertaking. Rather, we briefly review the general types of data used in reduced input studies. Three types of data used in reduced input studies are actual farm, simulated, and experimental plot data. Actual farm studies compare organic and conventionally operated farms (Lockeretz et al.; Dobbs, Leddy, and Smolick). Mixed results concerning the advantages of organic *versus* conventional farming techniques are reported. A flaw in these studies is the small number of observations. Results indicate, however, that organic methods can be more profitable in particular circumstances and regions of the country (Cacek and Langner).

Simulated data are obtained by the use of crop growth simulation models. These simulation models estimate yields under conventional and organic operations. Conventional farming methods tend to be favored over organic methods, but results have been called into question because such models are unable to account for all interactions between pests, weather, and management practices (Diebel, Taylor, and Batie). Other studies such as Johnson, Adams, and Perry or Mapp et al. used crop growth simulation models as the basis for analyzing reduced input production systems. As noted earlier, results for these and similar studies vary in the impact of reduced input usage on profitability. Factors such as types of restriction placed on input usage, area of the country, and crop grown all appear to have an impact on profitability. Faeth incorporates, for example, USDA's EPIC model with a farm-level model to study different crop rotations and tillage practices on economic and resource accounting for farms in Nebraska and Pennsylvania. He concludes the pre-1995 farm program discouraged "... the adoption and generation of resource-conserving practices" (p. 98). Further conclusions indicated Pennsylvania farmers would switch to resource-conserving practices faster than Nebraska farmers

because resource costs are higher in Pennsylvania than in Nebraska.

Research plot data is the final general type of data used (Goldstein and Young). Commodity yields from different types of input combinations are measured and per-acre crop budgets are generated. Helmers, Langemeier, and Atwood used a test plot approach to look at a variety of cropping systems in east-central Nebraska. They set up thirteen crop systems that employed three crop rotation systems and three continuously grown crops that mimic current cropping practices. Income variability and the relative profitability of the different cropping and input combinations are examined. They found that row crop rotations had higher returns than continuously grown crops. Net returns on a reduced input system were similar to net returns on a rotation which used higher levels of fertilizer and herbicide. All rotation alternatives, with the exception of soybean, had returns that were less variable than continuous crops. They also found a corn-soybean rotation system was more stable, in terms of net returns, than growing the two crops separately. Helmers, Langemeier, and Atwood's study is similar to the work undertaken in the present study, in that both examine intermediate input combinations that fall between the extreme input mixes of conventional and organic farming practices. As with Helmers, Langemeier, and Atwood's study, experimental plot data is used here to examine the profitability of reduced input usage and the variability in yields and net returns.

Data and Procedures

Experimental plot data for the corn-soybean rotations under different input combinations used is an augmented data set that was first reported in Hons and Saladino. The augmented data set consists of four replications per year for each of eight input combinations for each crop from 1990 to 1997, resulting in 32 observations for every crop and input combination. A wide variety of weather conditions—including a drought year, 1996—is represented in the data set.

Hons and Saladino's experiment consisted of an alternating year rotation of corn and soybean. Plots of corn (or soybean) planted under a management strategy which utilized a particular input combination were planted the following year with soybean (corn) using the same management strategy. The eight input combinations are fertilizer, insecticide, and herbicide (FIH); fertilizer, insecticide, and no herbicide (FINH); fertilizer, no insecticide, and herbicide (FNIH); and fertilizer, no insecticide, and no herbicide (FNINH). The same insecticide and herbicide combinations were used in the no-fertilizer (NF) case resulting in NFIH, NFINH, NFNIH, and NFNINH. The construction of the field experiment imposes an unrealistic assumption on the economic analysis. Producers might not limit themselves to the same input management strategy for both crops. This data does, however, provide a useful starting point for examining the effects on profitability and risk of different reduced input combinations in a corn-soybean crop rotation. While direct comparisons of differing management strategies would be beyond the limits of the data available, results from the fixed rotations point to promising management combinations that warrant further investigation.

The Brazos River Bottom Research Farm is located approximately eight miles west of College Station, Texas. Soil at this site is a Weswood silt loam. Approximate annual rainfall is 39 inches, with April and May historically being the wettest months.

Planting occurred approximately the same time each year with some variability caused by weather and soil conditions. Corn was planted in late February/early March and harvested in late July/early August. Soybean planting occurred in early to mid-April and harvest occurred in mid-to-late August. Seeding rates were 26,406 seeds/acre for corn and 105,728 seeds/acre for soybean. Varieties planted were Pioneer 3170 for corn and Ring Around 452 for soybean. Planting occurred in prepared beds. During the growing season the plots were cultivated twice. Post-harvest activities for corn were stalk shredding, disking, and bed preparation; for soybean, disking and

bed preparation. The plots were generally disked three times post-harvest.

The inputs under consideration were either applied at the recommended level for each crop or were not applied at all. For example, corn either received a quantity of 112 pounds of nitrogen per acre or received no nitrogen at all. Soybean received either 45 pounds of nitrogen per acre or none at all. Insecticides and herbicides for each crop were administered in a similar fashion. The recommended level of fertilizer was determined from previous research work at the test site. Insecticides and herbicides were applied at their recommended label rates.

Over the course of the experimental studies, different inputs had to be used because of either a pesticide being removed from the market or the need for a specific type of insecticide to control a given pest infestation. In all years, for the corn plots receiving herbicides, both atrazine and metolachlor (Dual) were applied. Atrazine was applied at 2 quarts/acre, whereas metolachlor was applied at 1 quart/acre. On corn plots receiving insecticides at planting, the insecticide varied by year because of market availability. Terbufos (Counter) was used through 1993 for control of corn rootworm, while chlorpyrifos (Lorsban) was used in 1994, tefluthrin (Force) was applied in 1995 and 1997, and carbofuran (Furadan) was used in 1996. Terbufos was applied at a rate of 5.13 lbs/acre (20% active ingredient), chlorpyrifos was applied at a rate of 1 quart/acre, tefluthrin was applied at a rate of 6.5 pounds of material/acre, and carbofuran at 6.7 pounds of material/acre.

As with corn, the soybean plots receiving pesticides varied by year. Herbicides used on soybeans were alachlor (Lasso at 2 quarts/acre) plus imazaquin (Scepter 2.8 at ounces/acre) in 1990 through 1994, 1996, and 1997. In 1995, imazaquin at the above rate plus metolachlor (1 quart /acre) was used. Insecticide applications to soybean were based on field insect scouting and threshold densities (Bowling). As such, the insecticide used and number of applications varied by year. In 1990 through 1997, methyl parathion was used for control of three-cornered alfalfa hopper and southern green stink bug. Two applications of thiodicarb (Larvin) were used for looper control in 1991. Esfenvalerate (Asana XI) was used in 1994 through 1997 in place of thiodicarb. When used, methyl parathion was applied at 1 pint/acre, thiodicarb at 1 quart/acre, and esfenvalerate at 6 ounces/acre. The number of methyl parathion applications for 1990 through 1997 were one, five, four, five, two, two, zero, and one. Esfenvalerate was applied three times in 1994 and 1995, and once in both 1996 and 1997.

Because of the varying inputs by year, crop budgets for each observation are created by crop and input combination. Planting and chemical application costs, as well as all harvest and post harvest data, are from the Texas Custom Rate Statistics for 1992 (Texas Agricultural Statistical Service). In the budgets it is assumed, for simplicity, that the producer uses custom operators for all production operations and rents the land. Included in these budgets, in addition to the cost of obtaining and applying the previously mentioned inputs, are expenses for seeds and planting, harvest and hauling, pre- and post-harvest cultivation, and interest on operating expenses. Management is not included in the budgets. As such the budgets can be viewed as returns to management. Inclusion or exclusion of management opportunity cost would have had little impact on the analysis, because necessary management between the different rotations would vary little. Expected net returns and other economic criteria are then calculated assuming each observation is equally likely.

Three commodity price combinations are examined in the economic analysis to allow for a wide range of economic conditions. The low price combination is $1.75 per bushel for corn and $5.00 per bushel for soybean. The middle price combination is $2.50 for corn and $6.00 for soybean, whereas the high combination is $3.25 and $7.00. Input prices are obtained from local agri-chemical suppliers in the Brazos River Valley. In discussions with the agri-chemical sales representatives, it was learned that chemical and fertilizer prices had remained stable over the past few years, so no input price ranges are used.

Next, cumulative density functions (CDFs) for yields associated with each input combination are estimated for corn and soybean using Taylor's hyperbolic transformation. This transformation, in essence, provides a tractable equation for an estimated empirical distribution. The equation used to calculate the CDF is:

$$F(y) = .5 + .5 \tanh (v(y)),$$

where F(y) represents the CDF, v(y) is a polynomial function of yield, y, and tanh is the hyperbolic tangent function. Different polynomial functions involving the first three powers (linear, squared, and cubic) of yield are estimated. Schwarz's criteria is used to select the "best" functional form for each crop and input combination. Plots of the eight CDFs for each crop are provided to give an idea of the relative production risks associated with obtaining various yields under different input combinations. The probability of achieving break-even yields for each crop and price is then determined from the crop budgets and the estimated CDFs.

Finally, stochastic dominance is used to compare the distributions of net returns. For each price and input combination, a CDF for net returns is generated. These CDFs are compared using Cochran and Raskin's generalized stochastic dominance program version 3.0 to determine which, if any, input combinations dominate the other combinations. CDF's for net returns using the middle price levels are also presented to reinforce the stochastic dominance results.

Results

Condensed budgets for the various input combinations using the middle prices and expected yields are presented in Tables 1 and 2 for corn and soybean. In examining corn expected net returns, it is obvious the distribution is not symmetric. For input combinations whose expected net return is greater than zero, the median is over $20/acre higher than the expected value. When the expected value is negative, however, the median is over $13/acre less than the expected value. Standard deviations range from a low of $71 for NFINH to a high of $93 for FNIH. Patterns similar to the middle price are evident for the other two prices. At all prices, at least one observation per input combination resulted in a negative expected net return. Even if the drought year of 1996 is ignored, at least one observation results in a negative net return except under the highest price and the FINH and FNINH input combinations.

For soybean (Table 2), the difference between the mean and median net returns is not as pronounced. When compared to corn, the standard deviations of net returns are lower for soybean. Although not presented, in general, the coefficient of variation for soybean is smaller than for corn for the same input combination. Similar patterns of summary statistics presented in Table 2 are also found for the other two prices.

Net returns above variable costs for corn and soybean from the crop budgets for all possible input combinations and all three prices are presented in Table 3. When each crop is examined separately, corn has the highest expected net returns when only fertilizer is applied to the crop at all prices. For soybean, NFINH is the input combination with the highest expected net returns at the higher two prices and NFNINH has the highest expected net returns at the lowest price (Table 3). Between the two crops, soybean expected net returns are higher than the same input combinations for corn except for the FNINH input combination. This observation holds true for the low and middle price, but at the higher price corn expected net returns are higher when fertilizer is applied regardless of insecticide or herbicide application (Table 3). Because both crops were grown using the same input combinations in each plot, the most profitable input combination for the corn-soybean pairing is the most relevant net return for comparison purposes. For the complete corn-soybean rotation, FINH is the most profitable strategy at the higher two prices and FNINH at the lower price (Table 3). Because the no-nitrogen options lead to losses for corn, fertilizer is still seen as necessary in this crop ro-

Table 1. Condensed Expected Per Acre Corn Budgets for Various Input Combinations with Gross Income Calculated at a Corn Price of $2.50/bu

	FIH[a]	FINH	FNIH	FNINH	NFIH	NFINH	NFNIH	NFNINH
Gross Income	254.26	240.36	251.64	241.35	131.26	105.11	138.49	114.44
Pre-harvest								
Seed	23.57	23.57	23.57	23.57	23.57	23.57	23.57	23.57
Fertilizer, Insecticide, and Herbicide	47.47	23.97	35.77	12.27	35.20	11.70	23.50	0.00
Planting and Chemical Application	8.99	8.99	8.99	7.75	6.47	6.47	6.47	5.23
Cultivation	10.64	10.64	10.64	10.64	10.64	10.64	10.64	10.64
Interest[b]	4.08	3.02	3.55	2.44	3.41	2.36	2.89	1.78
Harvest								
Custom Harvest	14.38	14.38	14.38	14.38	14.38	14.38	14.38	14.38
Haul[c]	13.10	12.38	12.96	12.43	6.70	5.42	7.14	5.90
Post Harvest	29.99	29.99	29.99	29.99	29.99	29.99	29.99	29.99
Land Rental	52.68	52.68	52.68	52.68	52.68	52.68	52.68	52.68
Total Cost	204.90	179.62	192.54	166.15	183.10	157.20	171.25	144.16
Expected Net Revenue	49.36	60.74	59.11	75.20	−51.85	−52.09	−32.76	−29.72
Median Net Revenue	77.66	87.52	78.47	96.60	−67.97	−77.96	−46.56	−58.59
Standard Deviation	86.86	80.85	92.52	87.99	76.23	70.68	79.99	75.58
Maximum	165.77	169.07	195.01	211.70	129.55	157.84	226.91	206.22
Minimum	−146.24	−117.17	−140.71	−131.04	−148.65	−143.63	−158.02	−120.13

[a] FIH is fertilizer, insecticide, and herbicide; FINH is fertilizer, insecticide, and no herbicide; FNIH is fertilizer, no insecticide, and herbicide; FNINH is fertilizer, no insecticide, and no herbicide; NFIH is no fertilizer, insecticide, and herbicide; NFINH is no fertilizer, insecticide, no herbicide; NFNIH is no fertilizer, no insecticide, and herbicide; NFNINH is no fertilizer, no insecticide, and no herbicide.

[b] Interest expense is calculated at a 9% annual rate for pre-harvest expenses for 6 months.

[c] Haul expense is $0.1288/bu.

Table 2. Condensed Expected Per Acre Soybean Budgets for Various Input Combinations with Gross Income Calculated at a Soybean Price of $6.00/bu

	FIH[a]	FINH	FNIH	FNINH	NFIH	NFINH	NFNIH	NFNINH
Gross Income	264.87	261.96	230.77	202.24	261.97	255.30	219.40	213.49
Pre-harvest								
Seed	15.00	15.00	15.00	15.00	15.00	15.00	15.00	15.00
Fertilizer, Insecticide, and Herbicide	41.45	26.62	19.74	4.91	36.55	21.72	14.83	0.00
Planting and Chemical Application	20.58	20.58	8.99	7.75	18.06	18.06	6.47	5.23
Cultivation	10.64	10.64	10.64	10.64	10.64	10.64	10.64	10.64
Interest[b]	3.95	3.28	2.45	1.72	3.61	2.94	2.11	1.39
Harvest								
Custom Harvest	14.88	14.88	14.88	14.88	14.88	14.88	14.88	14.88
Haul[c]	8.39	8.30	7.31	6.40	8.30	8.08	6.95	6.76
Post Harvest	24.30	24.30	24.30	24.30	24.30	24.30	24.30	24.30
Land Rental	52.68	52.68	52.68	52.68	52.68	52.68	52.68	52.68
Total Cost	191.86	176.27	155.98	138.28	131.33	168.30	147.86	130.88
Expected Net Revenue	73.01	85.68	74.79	63.95	77.96	86.99	71.54	82.61
Median Net Return	82.70	96.76	76.91	64.76	74.04	96.30	78.94	85.18
Standard Deviation	66.01	65.73	70.00	66.64	67.72	56.86	66.41	78.99
Maximum	179.09	211.20	198.81	214.56	202.76	211.03	208.97	237.61
Minimum	−59.28	−49.82	−60.00	−92.70	−74.11	−35.86	−52.51	−69.03

[a] FIH is fertilizer, insecticide, and herbicide; FINH is fertilizer, insecticide, and no herbicide; FNIH is fertilizer, no insecticide, and herbicide; FNINH is fertilizer, no insecticide, and no herbicide; NFIH is no fertilizer, insecticide, and herbicide; NFINH is no fertilizer, insecticide, no herbicide; NFNIH is no fertilizer, no insecticide, and herbicide; NFNINH is no fertilizer, no insecticide, and no herbicide.

[b] Interest expense is calculated at a 9% annual rate for pre-harvest expenses for 6 months.

[c] Haul expense is $0.19/bu.

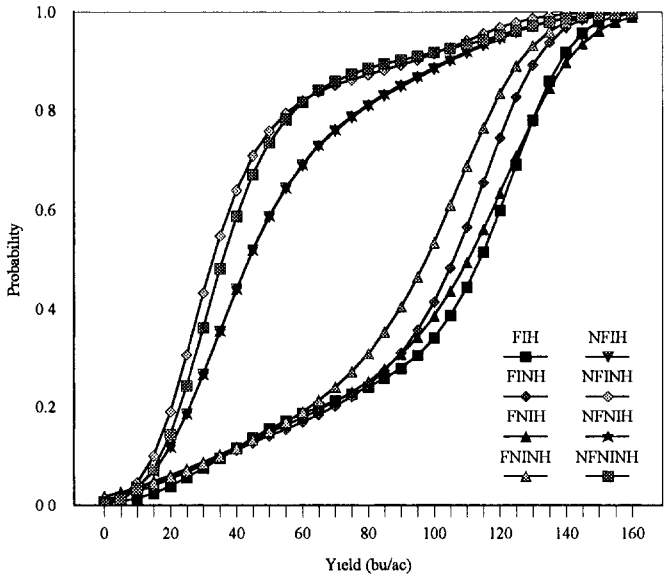

Figure 1. Cumulative Density Functions for Corn Yields Under Various Input Combinations

tation for overall profitability. The expected net returns vary by approximately $20/acre between the four input combinations which include fertilizer.

Graphs of CDFs for corn and soybean yields reveal interesting patterns for the relative production risk of the different input combinations. For corn (Figure 1), it is immediately apparent that input combinations which include fertilizer are generally superior to those that do not. For most yields, the probability of attaining that yield or greater is higher for input combinations which use fertilizer. Between the four input combinations which use fertilizer, the estimated CDFs are similar.

In contrast to the corn yield CDFs, those

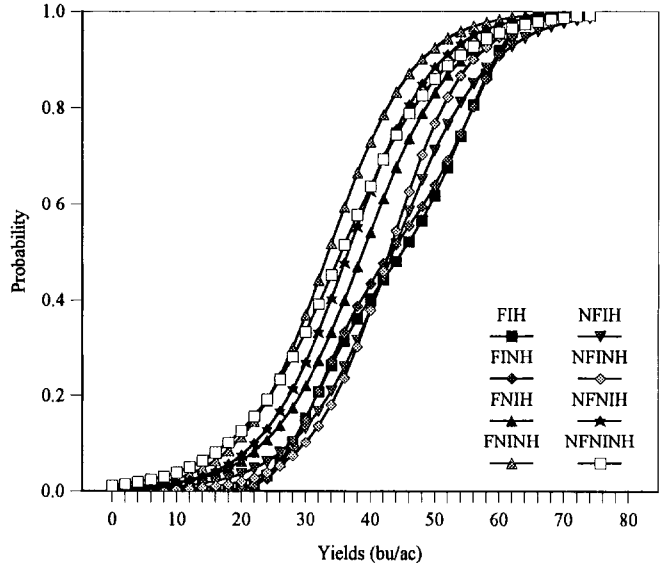

Figure 2. Cumulative Density Functions for Soybean Yields Under Various Input Combinations

Table 3. Expected Returns Above Variable Costs for Each Input Combination and Crop Rotation

	Corn		Soybeans		Corn-Soybean Total (2 years)	
Combination	Net Returns	Rank	Net Returns	Rank	Net Returns	Rank
			Low Price Combination			
FIH	−26.92	4	28.86	8	1.94	4
FINH	−11.37	2	42.02	3	30.65	2
FNIH	−16.38	3	36.33	4	19.95	3
FNINH	2.79	1	30.25	7	33.04	1
NFIH	−91.23	8	34.30	6	−56.93	8
NFINH	−83.62	7	44.44	2	−39.18	6
NFNIH	−74.31	6	34.97	5	−39.34	7
NFNINH	−64.05	5	47.03	1	−17.02	5
			Middle Price Combination			
FIH	49.36	4	73.01	6	122.37	4
FINH	60.74	2	85.68	2	146.42	1
FNIH	59.11	3	74.79	5	133.90	3
FNINH	75.20	1	63.95	8	139.15	2
NFIH	−51.85	7	77.96	4	26.11	8
NFINH	−52.09	8	86.99	1	34.90	7
NFNIH	−32.76	6	71.54	7	38.78	6
NFNINH	−29.72	5	82.61	3	52.89	5
			High Price Combination			
FIH	125.64	4	117.15	5	242.79	4
FINH	132.85	3	129.34	2	262.19	1
FNIH	134.60	2	113.26	6	247.86	2
FNINH	147.60	1	97.66	8	245.26	3
NFIH	−12.47	7	121.62	3	109.15	7
NFINH	−20.55	8	129.54	1	108.99	8
NFNIH	8.79	5	108.11	7	116.90	6
NFNINH	4.61	6	118.19	4	122.80	5

for soybean are less distinct (Figure 2). For soybean, the use of insecticide is a greater factor in determining the probability of achieving a yield for a particular input combination than the use of fertilizer. The CDFs of the four combinations using insecticides tend to be to the right of the remaining four CDFs. At best, the ranking of the remaining input combinations is fuzzy. The next least desirable input combinations use herbicide, but not insecticides, regardless of fertilizer application. Not using insecticides and herbicides leads to CDFs which are the least desirable for soybean, regardless of whether fertilizer is applied or not.

Break-even yields for corn and soybean under the three different price assumptions and eight input combinations are listed in Table 4. The rankings are based on the probability of obtaining a yield at or above the break-even yield. For example, for corn at the lower price, FINH and FNINH are the highest ranked input combinations with a probability of 43% of obtaining a yield at the break-even level or higher. Changing rankings indicates the CDFs for yields intersect between the break-even yields necessary at the different commodity prices. As with corn, for soybean there is a change in ranking among the input combinations between the prices. Probabilities of obtaining the

Table 4. Expected Break-even Yields and Associated Probabilities of Obtaining a Yield Equal to or Higher than the Break-even Yield for Each Crop and Input Combination

	Corn			Soybeans		
Combination	Yield	Probabability	Rank	Yield	Probability	Rank
		Low Price Combination				
FIH	126	0.28	4	40	0.60	8
FINH	111	0.42	2	37	0.66	6
FNIH	119	0.38	3	32	0.71	3
FNINH	102	0.43	1	29	0.67	5
NFIH	113	0.07	8	38	0.66	6
NFINH	97	0.09	6	35	0.77	1
NFNIH	106	0.09	6	31	0.71	3
NFNINH	89	0.10	5	27	0.74	2
		Middle Price Combination				
FIH	86	0.74	3	33	0.77	8
FINH	76	0.77	1	30	0.83	5
FNIH	81	0.74	3	27	0.85	2
FNINH	70	0.76	2	24	0.82	7
NFIH	77	0.20	6	32	0.83	5
NFINH	66	0.16	8	29	0.90	1
NFNIH	72	0.23	5	25	0.84	3
NFNINH	61	0.18	7	23	0.84	3
		High Price Combination				
FIH	66	0.80	4	28	0.88	6
FINH	57	0.84	1	26	0.93	2
FNIH	62	0.82	3	23	0.91	3
FNINH	53	0.84	1	20	0.88	6
NFIH	59	0.32	6	27	0.90	4
NFINH	50	0.24	8	25	0.95	1
NFNIH	55	0.36	5	22	0.90	4
NFNINH	46	0.31	7	19	0.88	6

break-even yields are higher for soybean than for corn for a given input combination and price.

To examine the risk associated with the net returns, second-degree stochastic dominance is applied to the distribution of net returns. For corn, the input combinations FINH, FNINH, and NFNINH second-order dominate all other input combinations at all prices. NFNINH is included in the dominate set because of the left-hand tail problem (Mjelde et al. p. 470–471) associated with second-order stochastic dominance. For soybean, the combinations of NFINH and NFNINH second order dominated at the lower price, whereas at the higher two prices NFINH second order dominates all other input combinations. Second-order dominance indicates which input combinations are preferred over other input combinations by risk averse decision makers. It is generally believed that most, if not all, decision makers are risk averse. In Figures 3 and 4, CDFs for net returns are presented for the middle price. These CDFs clearly show the left-hand tail problem associated with NFNINH and corn net returns. As expected, the CDFs closely follow the yield CDFs with two distinct groups for corn and similar CDFs for soybean.

Discussion and Conclusions

When the input combinations by crop and price are examined, the combinations of FINH, FNIH, and FNINH are consistently

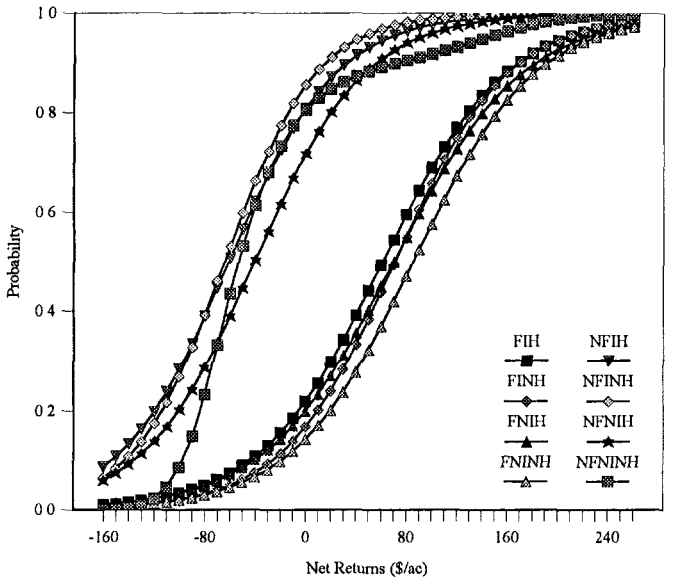

Figure 3. Cumulative Density Functions for Corn Net Returns Under Various Input Combinations for a Price of $2.50/bu

ranked in the top three by the different criterion for corn. The full input use combination, FIH, is only ranked in the top three by one criteria, break-even yield probability at the middle price. Admittedly, the difference between the top four input combinations is small. These results suggest two points. First, to grow corn profitability the crop must have nitrogen fertilizer applied. Second and more importantly, it appears that in the study area corn can be grown successfully with lower input usage: use either insecticides or herbicides, but not both, or use neither. Hons and Saladino found that the use of insecticides and herbi-

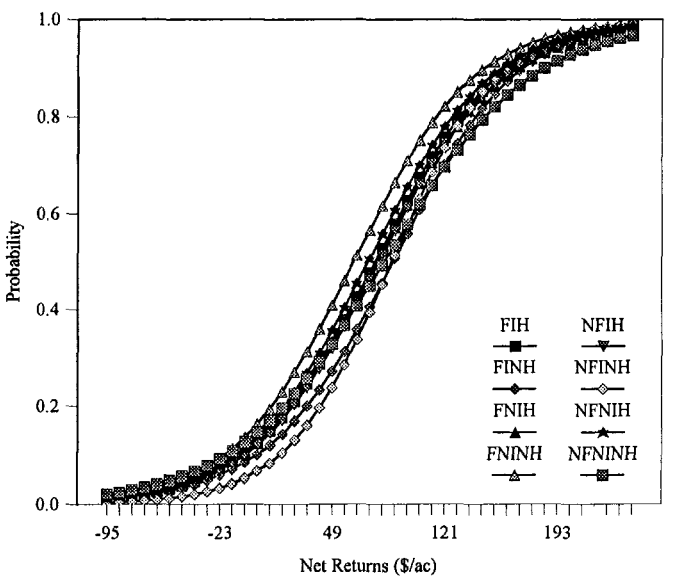

Figure 4. Cumulative Density Functions for Soybean Net Returns Under Various Input Combinations for a Price of $6.00/bu

cides had little significant effect on corn yields for the years 1990–93. The use of herbicides significantly decreased Johnsongrass populations, but did not affect either Texas Panicum or prostate spurge (the three main weed types observed). Nitrogen fertilization was, however, effective at controlling Texas Panicum and prostate spurge through shading by corn. The incidence of Johnsongrass did not adversely affect corn yields. These results remain consistent in the economic analysis of the longer-term data set. Mechanical control of weeds through cultivation in conjunction with the above discussion appeared to be adequate to preserve yields during the study period.

For soybean, input combinations which consistently ranked in the top three by the different criteria are NFINH, NFNINH, and FINH. These results suggest that soybean can profitably be raised without all three inputs and possibly without any of the inputs. Over all the study years at the lower two prices, soybean is more profitable than corn. At the higher price, corn grown with fertilizer is more profitable than soybean. In addition, during the drought year 1996, soybean profitability was much less impacted than corn. These findings may help explain the increasing number of acres being planted to soybean in the Brazos River Bottom. What remains to be determined is how much soybean acreage the infrastructure in the Brazos River Bottom can absorb.

The input combinations of FINH, FNIH, and FNINH are ranked highest when examining expected net returns over the two-year rotation. These combinations note the importance of nitrogen in the corn rotation. Two interesting points arise. First, limited input crop rotations—falling somewhere between the two extremes of conventional agricultural production—that utilize all three of the inputs, and organic agriculture, which strives to use none of these inputs, deserve further attention as possible production alternatives. Second, without external motivation it appears that the most desirable management practices would still involve chemicals that have the potential to cause harm to the environment and to humans.

It is important to remember that the input combinations used in this study are applied uniformly to both crops in the rotation. Individual rankings on input combinations for corn and soybean indicate that further study of mixed input strategies for the corn-soybean rotation is necessary. In particular, comparisons should be made between corn input combinations which use fertilizer and soybean input combinations which do not.

This study adds to the understanding of reduced input farming but a great deal of investigation is yet to be undertaken. The number of input combinations that could be analyzed between the two crops is limited by the study's design. A broader, more flexible experimental design would provide additional insight into the profitability of varying the use of inputs among crops in a rotation. Finally, only two quantities of each input—recommended amount or none at all—are used. This precludes a great deal of economic study. If all these shortcomings were incorporated into a field study, its relative size and complexity would make it difficult to manage and, more importantly, finance. The additional information gathered from this modified study relative to what has been done previously, however, might more than balance out these shortcomings.

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