ECONOMIC PROSPECTS FOR SPRINKLE IRRIGATING RICE IN TEXAS

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Abstract

The economic feasibility of investing in sprinkler irrigation technology for rice production is investigated using linear programming and capital budgeting to identify the net annual benefits and net present value, respectively. Groundwater and both flat rate and volumetrically priced surface water sources of irrigation water are analyzed. Under typical practices occurring in rice production operations in the Texas Rice Belt, sprinkler irrigation technology is not profitable at current water costs. Producers using volumetrically priced surface water have the greatest incentive to consider sprinkler irrigation, but water prices must increase by over 250 percent for the investment in a sprinkler irrigation system to become attractive. Yield reductions associated with sprinkle-irrigated rice are a significant disincentive. For equivalent flood- and sprinkle-irrigated rice yields, an increase in water prices of over 175 percent is required before the investment in a sprinkler irrigation system becomes economically feasible.

Key words: rice, linear programming, capital budgeting, sprinkler irrigation, technology, flood irrigation.

Water represents a major and necessary production expense for rice producers. Irrigation water must be pumped from the ground, purchased as surface water from canal companies, or pumped directly from surface water sources. Rising energy and well development/maintenance costs have increased the total cost of obtaining groundwater. Producers are indirectly affected when they purchase surface water. Rising costs experienced by canal companies are reflected in the price producers must pay to purchase the surface water necessary for crop production (Griffin et al.).

Water costs have contributed to a declining profit margin in recent years. The average total cost for rice irrigation water in Texas rose from $30.00 per acre in 1977 (USDA, 1977) to $73.58 per acre in 1982 (Griffin et al.). Irrigation water was responsible for 16 to 25 percent of variable costs and 11 to 17 percent of total costs associated with producing a rice crop in 1982 (USDA, 1982). The current poor profitability of rice production enhances the need for Texas and other southern rice producers to be economically efficient with respect to water as well as other production inputs.

Beyond satisfying rice water requirements, the primary purpose of the conventional flooding technique is to control weed growth (McCauley). Creating flooded conditions, however, consumes much more water than what is required for rice plant growth. In the Texas Rice Belt, for example, survey response estimates of water use on flood-irrigated rice range from 1.7 to 7.4 feet per acre (Griffin and Perry). These figures include, in varying proportions, water consumed by canal delivery systems and through field use. Through reduced evaporation, seepage, and tailwater losses, sprinkler irrigation can contribute to substantially lower water usage.

Initial research indicates sprinkler irrigation, as an alternative irrigation strategy, could be beneficial by: 1) reducing water use 50 to 80 percent from conventional methods, 2) reducing fuel expenses by decreasing well operating time, 3) conserving fuel by permitting many aerial fertilizer and chemical opera-

tions to be performed through the sprinkler system, 4) decreasing machinery costs because of a decrease in required land preparation, 5) reducing harvesting costs because of improved field conditions, 6) facilitating irrigation of alternative crops (e.g., soybeans), and 7) possibly reducing total labor requirements. The major deterrent to realizing the potential benefits of sprinkler irrigation is the large capital investment required to purchase a sprinkler system. Also, sprinkler irrigation may lead to lower rice yields and/or lower quality rice.

Both rice producers and agribusiness salesmen interested in merchandising sprinkler irrigation equipment in southern rice-producing states have expressed considerable interest in the economic feasibility of this technology. This paper presents the results of an interdisciplinary research study to evaluate the economic prospects of such a strategy over several alternative production regimes in the Texas Rice Belt.

ANALYTICAL APPROACH

Linear programming and capital budgeting are used conjunctively in this study. The linear programming model is a static, annual model for a profit-maximizing production program with sprinkler and/or flood irrigation as alternative technologies. Linear programming is well suited for evaluating production programs subject to a wide array of on-farm constraints and cost/price situations (Agrawal and Heady). These capabilities are significant because of the many diverse but interdependent cultural activities associated with flood and sprinkler technologies. After the linear programming model is used to identify the annual returns attributable to an investment in a sprinkler irrigation system, selected components of the resulting solutions are supplied to the capital budgeting model for use in investment analyses.

An economic evaluation of a new technology such as sprinkler irrigation for rice and/or soybeans has several dimensions. An analysis that fails to recognize differences in cultural operations between flood- and sprinkle-irrigated rice acreage, for instance, will fall short of identifying the potential merits of the new technology. Several such considerations should be incorporated into the analytical framework (i.e., differences in cultural operations, machinery and labor requirements, and water consumption, as well as crop yield and quality).

The majority of Texas rice acreage is grown in the Texas Rice Belt along the Gulf Coast (Figure 1). Currently, all rice acreage is grown
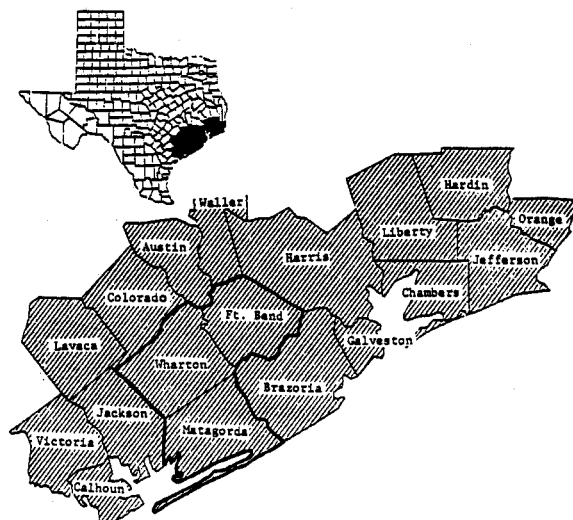

Figure 1. Texas Rice Belt and Study Area.

under a flooded culture, with irrigation water being either pumped from the ground, purchased as surface water from canal companies, or pumped directly from surface water sources. Observed differences in actual water use (1.7 to 7.4 feet per acre) and estimated minimal requirements for evapotranspiration, 2 feet per acre (Rice Farming), correspond to losses incurred in water delivery (evaporation, untended vegetation, burrowing rodents, and leaching) and field related losses (evaporation, leaching, and draining of excessive water required to maintain a flood over uneven fields) (Griffin and Perry; Luh). Sprinkler irrigation is conceived to be one possible approach[1] to reducing water use, primarily through alleviating the requirement of maintaining a flood and associated field leaching and draining of excess water. Due to the common practice of rotating land out of rice production once every two or three years and the frequent incidence of small, irregularly shaped fields, it is conjectured that a high pressure lateral sprinkler system designed to irrigate 100-125 acres is the most feasible

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[1]It is well recognized that a host of water management strategies exist to reduce the use of water in rice production. Research by Schulze documents the economics of replacing surface waterways with underground pipe. Other ongoing research activities in the South are directed towards investigating the concept of "pinpoint flooding" commonly observed in Louisiana (Pigg) and the economics of laser leveling and other land leveling techniques. The research reported herein only investigates sprinkler irrigation.

sprinkler technology for the region.

In Texas, rice is grown in rotation with several alternate crops, including grain sorghum, corn, cotton, wheat, and soybeans. The prevalence of soybeans as the basic rotation crop (Sij) prompted their inclusion in this study as the alternative crop. The linear programming model developed for this study, TEAMARC (Technical and Economic Assessment Model for Alternative Rice Cultures), is designed to represent rice/soybean production practices occurring in the Texas Rice Belt. Although flooded rice and dryland soybeans dominate as cultural practices in this region, TEAMARC can be used to evaluate alternative technologies, such as sprinkler irrigation on rice and/or soybeans.

The primary objective of developing

nent is comprised of a group of activities and constraints. TEAMARC includes alternatives for land acquisition, labor acquisition, machinery capacities, cultural operations, planting, harvesting, irrigation water acquisition, input purchasing, interest on capital, government programs, and output sales. The manner in which each group of activities in the model affects major categories of resource constraints is illustrated in Figure 2. In the diagram, a negative sign associated with an activity and resource constraint implies that the activity supplies some amount of that resource to the resource row. A positive sign implies the activity uses or consumes some amount of the resource or row constraint.

The objective function in TEAMARC is designed to maximize revenues above vari-

|			ACTIVITIES									
CONSTRAINT	Right hand side	Sign of constraint	Acquire land	Acquire labor	Machinery field capacities	Cultural operations	Plant	Harvest	Water	Acquire variable inputs	Interest on capital	Sell output
Objective											−	+
Cashflow	0	=	−	−	−	−		−		+	−	
Land	+	≤	−			+/−	+/−	+/−				
Labor	+	≤		−	+							
Machinery	+	≤			+							
Field operations	0	≤			−	+	+	+				
Intermediate resource transfer	0	≤				+/−	+/−	+/−				
Water resources and charges	+	≤						+	−			
Variable input requirements	0	≤						+		−		
Rice and soybeans	0	≤						−				+

Source: Parker, P. 40.

Figure 2. Structure of the TEAMARC Linear Programming Model Designed for Representing Texas Rice Belt Rice/Soybean Production and Marketing Activities and Annual Returns to Sprinkler Irrigation as Opposed to Flood Irrigation Technology.

TEAMARC was to provide a means of identifying additional annual revenues attributable to sprinkler irrigation relative to flood irrigation, subject to typical land, labor, machinery, and other variable input restrictions. Because TEAMARC was designed to represent typical rice/soybean farming situations, the model's activity flow (Figure 2) and internal components represent activities commonly performed by an individual rice/soybean producer in the Texas Rice Belt. Each column and row heading in Figure 2 represents a major component of TEAMARC—each compo-

able costs. Sales of rice and soybeans are the only positive sources of income available.[2] In order for rice and soybean sales to occur, land preparation activities must take place, levees must be built, planting must occur, irrigation water and other variable inputs must be acquired and allocated, and harvest of the crop must be completed. The linear programming framework of TEAMARC allows for simultaneous consideration of all activities necessary to produce and sell rice and soybean crops while recognizing resource constraints. To do so, TEAMARC consists of over 900 rows and over 1100 columns.

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[2]Positive income is also generated through government farm program activities. Government programs within TEAMARC, however, generate income only if a crop is produced. Such programs, therefore, are not considered a separate source of income but income generated as a result of production.

The capital budgeting model employed in this study, CAPBUD, was previously developed by Pajestka et al. The net present value approach of capital budgeting is used in CAPBUD to identify the present value of future returns minus the cost of the investment (Weston and Brigham, p. 403). General features of CAPBUD which facilitate its application to economic analysis of capital investments such as sprinkler irrigation technology are 1) recognition of uneven annual cash flows accruing to the investment, 2) allowance for multiple assets to comprise the total investment package, with each asset possibly having a different useful life, 3) accounting for automatic replacement of assets whose useful life expires prior to the end of the planning horizon, 4) recognition of several alternative financing arrangements, 5) accounting for tax-related aspects of net returns accruing to the capital investment, and 6) explicit accounting of differential real rates of increase in individual assets' capital costs and general operating costs during the specified planning horizon. A more detailed specification of the individual variables and form of the modelling equation included within CAPBUD are presented in Appendix A.
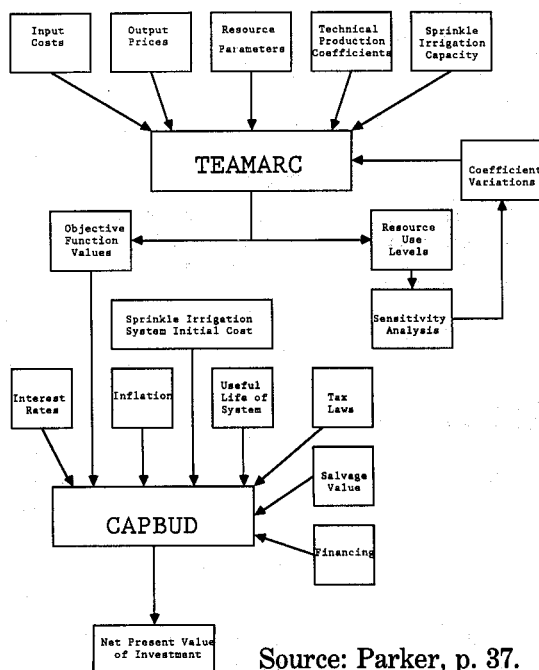
Source: Parker, p. 37.

Figure 3. Flow Chart for TEAMARC and CAPBUD.

The Linear Programming/Capital Budgeting Relationship

The principal purpose of interfacing the linear programming model (TEAMARC) and the capital budgeting model (CAPBUD) is to identify net benefits associated with the sprinkler system investment. The major classifications of parameter specifications and important linkages for the two analytical models are illustrated in Figure 3.

The detailed structure of TEAMARC is sufficient to account for several of the benefits provided by the sprinkler technology: reduced water, fuel, labor, and machinery costs, as well as the opportunity to irrigate soybeans. Reduced harvesting costs due to improved field conditions are also endogenous. Fertilizers and chemicals are assumed to be applied conventionally (aerially) rather than through the sprinkler system. By using TEAMARC to evaluate two production scenarios, one assuming the availability of a sprinkler irrigation system as well as conventional flood irrigation and another assuming only conventional flood irrigation, the potential annual benefits of a sprinkler irrigation system can be identified. This value and information on useful life of sprinkler systems, financing arrangements, tax laws, interest rates, inflation, and sprinkler irrigation system costs are required for analysis within the capital budgeting model.

CASE SITUATION

Using this analytical framework, the economic merits of employing sprinkler irrigation technology are examined for a case farm situation in the Texas Rice Belt. Because different areas employ different farming practices, a narrower study region is desirable. The study region chosen is an area west of Houston in the El Campo/Bay City/Katy triangle including portions of Wharton, Matagorda, and Fort Bend counties (Figure 1).

Farm Characteristics

A typical 800 acre rice/400 acre soybean, full-owner situation is assumed, with some additional acreage available for government farm program compliance. The 2:1 rice/soybean acreage ratio is considered to be typical of farming operations in the study area (Perry et al.; Stansel, 1983–1984). Only a full-owner situation is investigated inasmuch as the full net benefits of investing in the water-saving technology of sprinkler irrigation accrue to the

owner/operator. The net benefits associated with such a capital investment by a tenant producer are generally less and depend on the specific share arrangements with respect to both revenue and input costs. However, the design of TEAMARC permits the evaluation of full-owner, share-tenant, and cash-tenant situations, either individually or in combination.

As depicted in Figure 2, the modelling specification within TEAMARC is highly detailed. Attention is focused on known differences in cultural operations, input requirements, and yield levels (Bowling; Eastin; McCauley; Turner; Sij; Stansel, 1982; Whitney) between flood- and sprinkle-irrigated rice production systems and between dryland and sprinkle-irrigated soybean production systems. Complete documentation of the study assumptions are provided by Parker.

A central feature of TEAMARC is the division of the cropping year into 21 consecutive time periods. Field operations (various land preparation activities, planting, and harvest-

ing) are required to be performed sequentially. Available field time (which is weather dependent), machinery capacities, and labor resources vary by period. The characteristics of these 21 time periods and associated possible cultural operations are indicated in Table 1.

As discussed by Parker, the emphasis within TEAMARC is to identify multiple planting/harvesting date combinations and associated harvested yields, recognizing implicit differences in scheduling cultural operations between flood and sprinkler irrigation technologies. An optimum harvest date for each planting period exists with a variation from this date causing a reduction in yield (Gerlow). For many reasons (e.g., a large number of acres maturing at the same time, machinery limitations, and weather), producers may be unable to harvest during the optimum period. TEAMARC allows for harvest in the period subsequent to the optimum but with a reduction in yield.

Based on experimental field trials, it is

TABLE 1. CRITICAL TIME PERIODS POTENTIAL CULTURAL OPERATIONS OCCURRING WITHIN TEAMARC FOR TEXAS RICE BELT RICE AND SOYBEAN PRODUCTION, 1985–1994

Time period	Calendar dates	Possible field operations
1	10/1–10/15	Disc, LP[a], FC[b] harvest rice and sobybeans
2	10/16–10/31	Disc, LP, FC, harvest rice
3	11/1–11/14	Disc, LP, FC, harvest soybeans and rice
4	11/15–12/31	Disc, LP, FC, harvest soybeans
5	1/1–2/28	Disc, LP, FC
6	3/1–3/15	Disc, LP, FC, LC[c], ditch[d], plant rice
7	3/16–3/31	Disc, LP, FC, LC, ditch, plant rice
8	4/1–4/14	Disc, LP, FC, LC, ditch, plant rice
9	4/15–4/30	Disc, LP, FC, LC, ditch, plant rice
10	5/1–5/15	Disc, LP FC, LC, ditch, plant rice and soybeans
11	5/16–6/15	Disc, LP, FC, ditch, plant soybeans, SC[e]
12	6/16–7/8	Disc, LP, FC, ditch, plant soybeans, harvest rice, SC, LR[f]
13	7/9–7/16	Disc, LP, FC, ditch, plant soybeans, harvest rice, SC, LR
14	7/17–7/23	Disc, LP, FC, ditch, plant soybeans, LR, harvest rice, SC
15	7/24–7/31	Disc, LP, FC, LR, harvest rice, SC
16	8/1–8/7	Disc, LP, FC, LR, harvest rice
17	8/8–8/15	Disc, LP, FC, LR, harvest rice
18	8/16–8/23	Disc, LP, FC
19	8/24–8/30	Disc, LP, FC
20	9/1–9/7	Disc, LP, FC
21	9/8–9/30	Disc, LP, FC, harvest rice and soybeans

[a]LP = landplane
[b]FC = field cultivate
[c]LC = levee construction
[d]Ditch = construction of drainage ditches within the field
[e]SC = soybean cultivation
[f]LR = levee reconstruction

[g]The observed differences between flood-irrigated and sprinkle-irrigated yields in experimental research plots may be attributable, at least in part, to the failure to satisfy the rice plant's transpiration requirements on a timely basis. Some of the experimental research with sprinkler irrigation on Texas rice occurred during seasons with above average temperatures and solar radiation. As a result, the sprinkler system was unable to deliver sufficient water to meet transpiration requirements, and some blanking occurred in the seed head. Morphological modifications of the rice plant under non-flood (e.g., sprinkler) culture may also be partially responsible for the yield loss. Because farm managers will have to deal with these same problems, it is appropriate to include a yield penalty for sprinkle-irrigated rice. As part of this study, the sensitivity of results to yields were evaluated by assuming equivalent yields for sprinkle-irrigated and flood-irrigated rice, and these results will be presented in a forthcoming section.

assumed sprinkle-irrigated rice yields are 84 percent of flood-irrigated rice yields.[3] Based on available experimental information, this assumption appears to present a best case setting (McCauley et al.; Westcott and Vines). Soybean yields are assumed invariant with respect to planting/harvest dates but differ for dryland versus sprinkle-irrigated production.[4] Dryland soybean yields are assumed to be 15 bushels per acre, while sprinkle-irrigated soybeans yield 26 bushels per acre (Sij).

Because the key benefit of investing in sprinkler technology is associated with water cost savings, substantial detail is included within TEAMARC to account for availability of water resources and costs, either on a $/acre-inch basis (from groundwater or surface water sources) or a $/acre basis (from a surface water source). Differences in water requirements, on a per-time-period basis, are expressly recognized between flood- and sprinkle-irrigated rice. Labor requirements also differ between the two rice irrigation regimes and between dryland and irrigated soybeans. While Parker provides more detail, a general assessment is that sprinkle-irrigated rice uses 57 percent less irrigation water and 60 percent less labor than does flood-irrigated rice.

Physical/Financial Aspects of Sprinkler Irrigation System

Sprinkler irrigation system costs vary greatly with brand names and system size, among other factors. This study assumes a 1897 foot, linear move, Valley sprinkler system designed to irrigate 115 acres.[5] The cost of the completed system is $85,406 and the useful life is 10 years (1985–1994) with an assumed salvage value of $8,540. It is assumed that 100 percent of the sprinkler system's purchase price is borrowed for 365 days at a nominal annual interest rate of 14.5 percent.

During each year of the 10-year financing period, the borrower pays all of the interest accrued over 365 days plus a 10 percent reduction in the principal amount originally borrowed.

Variable operating expenses such as fuel and labor costs associated with operating the sprinkler irrigation system are included in TEAMARC. Annual insurance premiums and repair (maintenance) costs, however, are specified within CAPBUD. Annual insurance costs are assumed to be 1.5 percent of the current market value of the system during every year of the 10-year planning horizon. Annual operating and repair costs are $200 in years one and two with a linear escalation thereafter to $1000 in the tenth year (Golden).

It is assumed that the purchased sprinkler technology is depreciated under the 1982 Accelerated Cost Recovery System (ACRS) (Prentice-Hall, pp. 288–89).[6] With the investment having a useful life of 10 years, it is also assumed that the investment is fully depreciated over 10 years under the 1982 "straight-line ACRS" schedule. Furthermore, due to the relatively high cost of financing in the early years, nothing is expensed under "Section 179 Expensing," allowing use of 100 percent of the qualified investment amount in calculating investment tax credit. Maximum allowable investment tax credit is claimed, thereby requiring the initial tax basis to be reduced by 50 percent of the claimed investment tax credit prior to calculating annual depreciation.

An investor's effective tax rate affects the net present value of a capital investment by determining the amount of tax savings associated with depreciation and financing interest expenses as well as affecting the annual net after-tax cash flows. *Doane's Agricultural Report* indicates that "under the current law, 25 percent of all farmers fall into tax brackets above 25 percent, 26 percent are in brackets from 16 percent to 25 percent, and 49 percent

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[4]TEAMARC has two harvest periods (optimum and an alternate) for each soybean planting date. Although not employed in the study reported here, this feature of TEAMARC accommodates potential uses of the model in which delayed harvesting may discount soybean yields.

[5]The sprinkler system assumed in this study is not an endorsement of that system but simply represents a sprinkler irrigation technology appropriate for the study region.

[6]Since this research was conducted, the Tax Reform Act of 1986 has been enacted. In general, it is perceived that the basic assumptions made in this and the next text paragraph provide a conservative basis of analysis that is not significantly altered by the new tax legislation. With respect to the assumed 10 year depreciation schedule, the new 10 year alternate MACRS depreciation option is comparable. The elimination of investment tax credit in the new legislation results in a slight relative disadvantage for capital investments such as a sprinkler irrigation system. The new tax act also revises the marginal tax bracket structure, resulting in potential marginal tax rates of 15, 20, and 33 percent. A majority of potential affected rice producers could fall in the 28 percent bracket as opposed to the previously assumed 20 percent rate. The likely net effect of such an increased marginal tax rate would be a lowered net present value relative to the presented analyses. Consequently, the results in this paper should be viewed as conservative in nature, but also as slightly optimistic regarding capital investments in a sprinkler irrigation system when one considers the 1986 tax legislation.

are under 16 percent" (p.1). For this study, the producer's marginal tax rate is assumed to be 20 percent.

The choice of discount rate is an important but subjective assumption for this analysis. A discount rate has three components: real time value of money, risk, and inflation (Penson and Lins, p. 107). No inflation is assumed in this study. A 6 percent real rate of interest plus a risk premium of 5 percent is assumed, resulting in an overall discount rate of 11 percent. Assuming a 20 percent marginal tax bracket, this level of before-tax return is comparable to what one could earn in a high risk municipal bond (Hopkin).

RESULTS

Initially, the economics of investing in sprinkler technology were investigated for representative water costs associated with the three primary potential sources of rice irrigation water: $1.98 per acre-inch for groundwater (approximately $69.00 and $33.00 per acre for flood- and sprinkle-irrigated rice, respectively), $2.50 per acre-inch for volumetrically priced surface water (approximately $87.00 and $41.00 per acre for flood- and sprinkle-irrigated rice, respectively), and approximately $60.00 and $48.00 per acre for flood- and sprinkle-irrigated rice, respectively, for flat rate priced surface water. Groundwater costs are representative for the region and are derived from Griffin et al. Many canal companies operate in the study region. Some employ volumetric pricing, but flat rate pricing is prevalent. The costs used in this analysis are representative. The results of these analyses are presented in Table 2.

Annual returns associated with sprinkler irrigation as identified by TEAMARC are negative for both groundwater and flat rate priced surface water situations, indicating the losses in revenues related to reduced yields were greater than the savings linked to use of the sprinkler technology. Negative annual net benefits obviously preclude the need for capital budgeting analyses. Annual net benefits are positive for the volumetrically priced surface water situations (recall that volumetrically priced surface water was approximately 25 percent more expensive than groundwater). The margin of net benefits associated with the sprinkler technology was not of sufficent magnitude to make the investment economically feasible when considered within a capital budgeting context, however, as indicated in Table 2.

Sensitivity Analyses—Higher Water Costs

Predominant emphasis for sensitivity analyses is directed towards determining the level of water costs necessary for the investment in sprinkler irrigation to be profitable. For this purpose, the current costs of water from the three possible sources of water are increased by 10, 25, 50, 75, 100, 200, 300, and 400 percent, and analyses are performed for each situation. Graphical representation of TEAMARC and CAPBUD results for groundwater, flat rate priced surface water, and volumetrically priced surface water are provided in Figure 4.

Based on these sensitivity results, groundwater costs must increase 368 percent above current levels (with all other costs fixed) before annual net benefits are sufficient to create a positive net present value (Figure 4, panels a and b). An acre-inch of groundwater, therefore, must cost approximately $9.26 before the investment in sprinkler irrigation technology is economically feasible. Although an analysis yielding a positive net present value does indicate that the potential invest-

TABLE 2. ECONOMIC FEASIBILITY OF INVESTING IN SPRINKLER IRRIGATION TECHNOLOGY FOR RICE PRODUCTION IN TEXAS, 1985–1994[a]

| Water source | Water costs | | Annual net benefits for sprinkle irrigation | Net present value of sprinkle irrigation |
	Flood	Sprinkle		
	($/acre)			
Groundwater	69.00	33.00	$ − 303	b
Flat rate priced surface water	60.00	48.00	− 4,983	b
Volumetrically priced surface water	87.00	41.00	1,144	$ − 75,063

[a]These results are based on 1984 water costs and a 1200 acre, fully owned western Texas Rice Belt farm with 800 acres of rice and 400 acres of soybeans. Other specifics of the case farm situation analyzed are provided in Parker.

[b]Because annual net benefits are negative, it is unnecessary to utilize CAPBUD to calculate the net present value of investing in sprinkler irrigation—the investment is clearly economically infeasible.
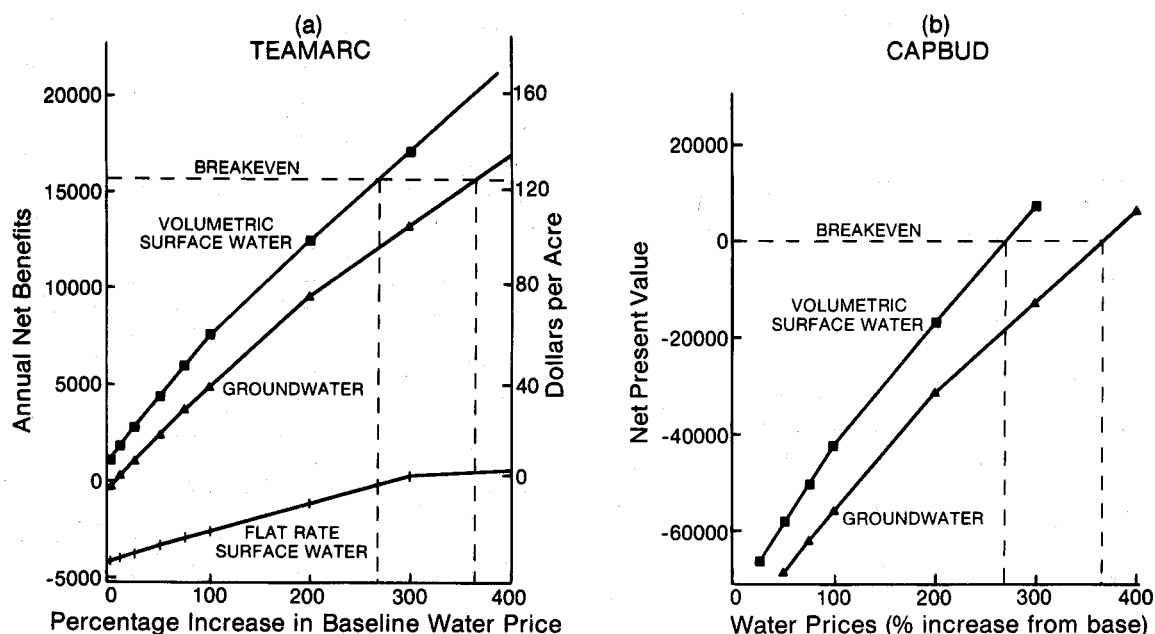
Figure 4. Annual Net Benefits and Net Present Value for Alternative Water Price Increases.

ment is profitable, this finding may be overshadowed by another important factor associated with the investment—before- and after-tax cashflows (both positive and negative) attributable to the investment for each year of the planning horizon.

Although the NPV may be positive, the system does not generate enough cash inflows (cost savings) in certain years to cover system operating costs and principal and interest payments associated with the chosen financing arrangement. During negative net cash flow years, therefore, cash from some other source (e.g., another facet of the farm, outside farm income, or additional borrowing) is required. Because of negative cashflow during particular periods, there may be grounds for rejecting the investment even though the NPV is positive. As an example, annual cashflow summary is presented in Table 3 for a situation where groundwater costs are increased 400 percent from the base.

As noted in Figure 4, the sensitivity analyses suggest water prices for flat rate priced surface water must increase approximately 283 percent for any positive annual net benefits above operating costs to occur.

Even at the 400 percent increase level, NPV is still highly negative, and the corresponding graph does not fall within the range depicted in panel b of Figure 4. Volumetric surface water prices must increase 270 percent before NPV is positive (Figure 4, panels a and b).

Sensitivity Analyses—Equivalent Flood- and Sprinkle-Irrigated Rice Yields

In the base scenario of this study, it is assumed rice grown under sprinkler irrigation produces significantly lower yields (16 percent) than that grown under flood irrigation. Sprinkler yield reductions are responsible for revenue losses, which cannot be overcome easily through cost savings associated with a decrease in water use. With the currently modelled yield reductions, therefore, sprinkler irrigation technology is not economical unless water prices are increased greatly. An additional set of sensitivity results were derived for the groundwater source situation, assuming comparable yields between flood- and sprinkle-irrigated rice. Levels of annual returns and the NPV of investing in the sprinkler irrigation technology for both sets of yield assumptions are con-

Year	Net before-tax Cash Flow	Net after-tax Cash Flow
1985	$ – 5,577	$ 3,669
1986	– 4,236	– 2,825
1987	– 3,012	– 2,170
1988	– 1,797	– 1,523
1989	– 594	– 560
1990	597	392
1991	1,777	1,174
1992	2,944	2,107
1993	4,095	3,028
1994	14,572	11,410

[a]These values are for a groundwater source situation with water costs increased 400 percent above base 1985 levels.

trasted in Figure 5. Only the groundwater setting is considered in this sensitivity analysis (as well as the forthcoming one) in order to keep the discussion manageable. The groundwater scenario was chosen because (1) the baseline analysis demonstrated sprinkler irrigation is an extremely poor option for flat rate surface water sources and (2) groundwater sources are much more prevalent in Texas than are volumetric surface water sources.

From these results, it is evident that less of a water price increase is necessary for a positive NPV to occur when flood- and sprinkle-irrigated rice yields are equal. When yields are equal, groundwater costs must be increased 176 percent above assumed current levels (i.e, from $1.98 to $5.46 per acre-inch).

Sensitivity Analyses—Rice/Soybean Rotation

Under the baseline conditions, it was assumed that dryland soybeans will be grown one year out of three on all fields. To satisfy this constraint, it was implicitly assumed that the sprinkler system was mobile, in the sense that is was always employed for rice—never soybeans. To accommodate situations where the sprinkler system must be used on the same field year after year, soybeans grown under sprinkler irrigation should be considered. Net annual benefits associated with a two year rice-one year soybean rotation (with both crops being sprinkle-irrigated) for differing levels of groundwater costs are presented in Table 4, assuming soybeans are the first crop in the rotation. Except for the rotation all baseline conditions are maintained. Negative and positive values in Table 4 are associated with the incremental changes between sprinkler and flood irrigation, as measured by successive runs of TEAMARC. The negative values are related to water price and rotation, with soybeans grown in years 1, 4, 7, and 10.

It is assumed that the sprinkler technology will only be used when anticipated annual net returns are positive. Accordingly, at the 0
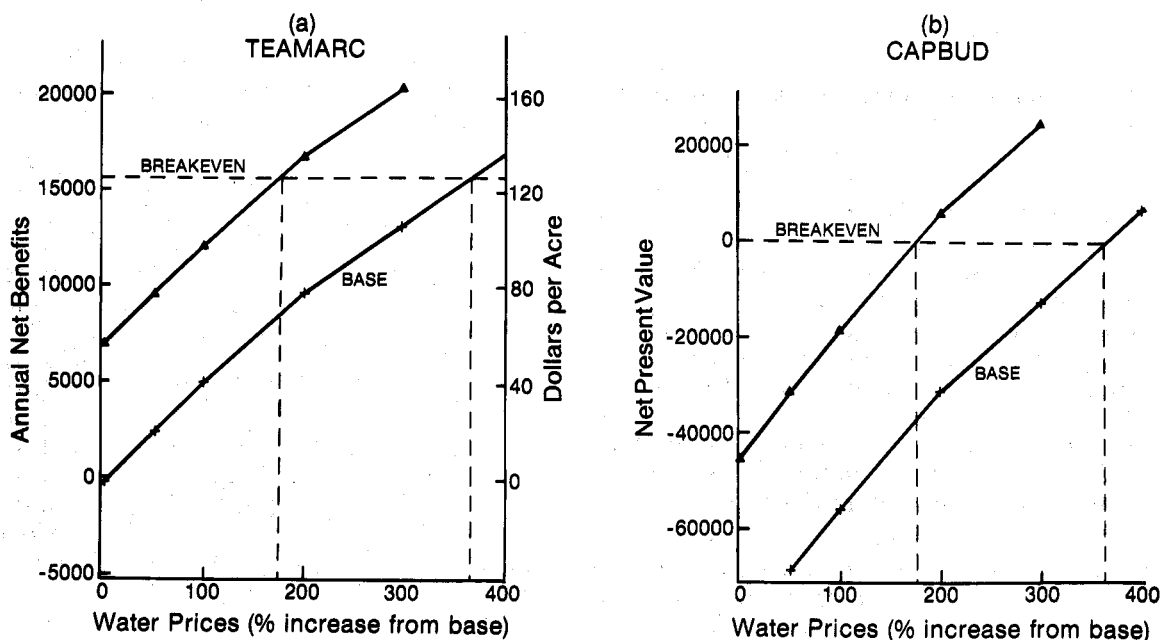

Figure 5. Annual Net Benefits and Net Present Value for Groundwater Price Increases (Base Situation and Equal Flood-and Sprinkle-Irrigated Rice Yields).

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level of water price increases, the negative returns to sprinkle-irrigating rice were set to zero in the capital budgeting analysis, assuming the producer would continue with flood irrigation. Similarly, for high water costs, it was assumed the producer would revert to dryland soybeans and leave the sprinkler system idle. Net present values for this production scenario are illustrated in Figure 6.

With a rice/soybean crop mix, the net present value of investing in a sprinkler irrigation

offset to some degree by the decreasing annual net benefits for soybeans as groundwater costs increase. The tradeoff is such that the net present value simply does not become positive even if groundwater costs increase to $9.90 per acre-inch.

SUMMARY AND CONCLUSIONS

The results obtained from using TEAMARC and CAPBUD for the case farm

TABLE 4. NET ANNUAL BENEFIT STREAMS ASSOCIATED WITH A TWO YEAR RICE/ONE YEAR SOYBEAN CROP MIX

Water Price Increases (%)	Year									
	1	2	3	4	5	6	7	8	9	10
0	4,184	− 303[a]	− 303	4,184	− 303	− 303	4,184	− 303	− 303	4,184
10	3,882	294	294	3,882	294	294	3,882	294	294	3,882
25	3,430	1,091	1,091	3,430	1,091	1,091	3,430	1,091	1,091	3,430
50	2,690	2,393	2,393	2,690	2,393	2,393	2,690	2,393	2,393	2,690
75	1,935	3,691	3,691	1,935	3,691	3,691	1,935	3,691	3,691	1,935
100	1,196	4,859	4,859	1,196	4,859	4,859	1,196	4,859	4,859	1,196
200	− 1,792	9,576	9,576	− 1,792	9,576	9,576	− 1,792	9,576	9,576	− 1,792
300	− 4,780	13,162	13,162	− 4,780	13,162	13,162	− 4,780	13,162	13,162	− 4,780
400	− 7,769	16,820	16,820	− 7,769	16,820	16,820	− 7,769	16,820	16,820	− 7,769

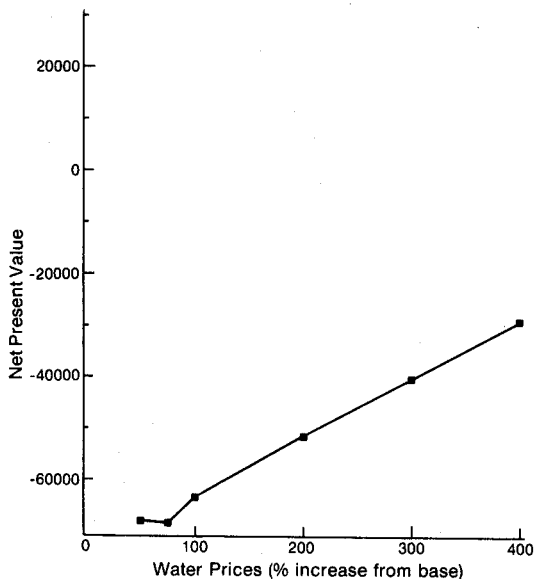[a]A negative value within this table is entered as 0 in CAPBUD.

Figure 6. Net Present Value Associated with Groundwater Price Increases and a Two Year Rice/One Year Soybean Crop Mix for Sprinkler Irrigation in Texas, 1985–1994.

situation reveal a number of conclusions of interest to Texas Rice Belt rice/soybean producers. First, under typical practices occurring in rice production operations in the Texas Rice Belt, sprinkler irrigation technology is not profitable and generally leads to losses in net annual returns. Yield reductions associated with rice produced under the sprinkler system create losses in revenues that are not overcome by water, fuel, labor, and machinery cost savings.

Second, of the three methods of acquiring water currently available to Texas rice producers, only surface acre-inch water (purchased for $2.50 per acre-inch) creates any net benefits above variable operating costs (excluding the costs of purchasing the system) when sprinkler irrigation technology is employed. As real irrigation water prices rise, therefore, users of surface acre-inch water have the greatest incentive to incorporate sprinkler irrigation into their rice program.

Third, under current rice production technologies (flood-irrigated rice yields being greater than sprinkle-irrigated yields), irrigation water prices must increase by a significant amount for sprinkler irrigation to become profitable. Depending on water source, water prices must increase to four to five times current prices before the net present value of a

system does not become positive even with a 400 percent increase in groundwater costs. Increasing annual net benefits associated with rice produced under sprinkler irrigation are

sprinkler system becomes positive. If technologies change (e.g., sprinkle-irrigated rice yields equal flood-irrigated rice yields), the incentive to incorporate sprinkler technology occurs at much lower levels of water price increases. Losses in revenues from reductions in yields are no longer a factor. Under these circumstances, groundwater costs must increase by 176 percent before sprinkler irrigation becomes profitable.

Finally, results indicate sprinkler irrigation for a rice/soybean cropping program is not profitable and does not become economically attractive even with a five-fold increase in groundwater prices. The decrease in annual returns associated with soybeans when water costs increase offsets some of the increasing annual returns associated with rice.

In summary, under current technologies and irrigation water prices, sprinkler irrigation technology is not economical for rice/soybean production in the Texas Rice Belt. Increasing irrigation water costs tend to improve feasibility results, but, for the most part, the increase must be large before sprinkler irrigation can become profitable. It should be noted that this analysis was conducted in a static framework, with limited attention directed to the variability of yields, prices, and water input requirements. As noted by Boggess and Amerling, variance in yields and water input requirements can be of significant consequence when evaluating irrigation technologies. This study acknowledges the impacts of alternative weather events through a sensitivity analysis (a) assuming equivalent yields between sprinkle- and flood-irrigated rice and (b) including a 5 percent risk premium as a component of the discount rate used in the capital budgeting procedure. Lack of more complete experimental data prohibited application of the procedure suggested by Boggess and Amerling. Regarding variance in prices (Boggess et al.), it was considered acceptable to ignore this issue in recognition of the target price concept in place in the current Farm Bill and the historically high rate of rice producer participation in the farm program—greater than 80 percent in Texas since 1982 (Grant).

This study demonstrates the value of conducting economic analyses as part of ongoing physical and/or biological research in agricultural experiment stations. The specifics of net benefits associated with adopting new or alternative technologies are largely unknown and often oversold unless economics evaluation is administered. In fact, this study provides an example of what could be accomplished prior to implementation of costly field experiments in that it identifies what will have to occur before sprinkler irrigation is economically feasible for rice producers in Texas. While the economic literature is well marked with *ex post* applied studies, there is sufficient room for improvement in the realm of *ex ante* feasibility analyses to complement the planning activities of agricultural experiment station administrations attempting to allocate scarce research resources.

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APPENDIX A

The specific application of the model in this study utilizes the net present value of the investment over its useful life, employing the following general capital budgeting formulation (Pajestka et al., pp. 15–17):

$$NPV = -\sum_{I=1}^{NBR} \sum_{K=1}^{NA(I)} [DPAY_{I,K}(1 + ATROR_{(FIRST(I,K)-1)})^{-(FIRST(I,K)-1)}]$$

$$-\sum_{I=1}^{NBR} \sum_{K=1}^{NA(I)} \sum_{J=L(I,K)}^{M(I,K)} [(PRIN_{I,J} + (TOTINT_{I,J}(1 - TAXB_J)))(1 + ATROR_J)^{-J}]$$

$$-\sum_{I=1}^{NBR} [LOBAL_{I,N}(1 + ATROR_N)^{-N}]$$

$$+\sum_{J=1}^{N} [(1 - TAXB_J)BENINV_J(1 + ATROR_J)^{-J}]$$

$$+\sum_{I=1}^{NBR} \sum_{K=1}^{NA(I)} \sum_{J=L(I,K)}^{N(I,K)} [(1 - TAXB_J)AINC_{I,J}(1 + ATROR_J)^{-J}]$$

$$-\sum_{I=1}^{NBR} \sum_{K=1}^{NA(I)} \sum_{J=L(I,K)}^{N(I,K)} [(1 - TAXB_J)(AFIXCT_{I,J} + AVARCT_{I,J})(1 + ATROR_J)^{-J}]$$

$$-\sum_{I=1}^{NBR} \sum_{K=1}^{NA(I)} \sum_{J=L(I,K)}^{N(I,K)} [OLABCT_{I,J}(1 + ATHOR_J)^{-J}]$$

$$+\sum_{I=1}^{NBR} \sum_{K=1}^{NA(I)} [INVCRD_{I,FIRST(I,K)}(1 + ATROR_{FIRST(I,K)})^{-FIRST(I,K)}]$$

$$-\sum_{I=1}^{NBR} \sum_{K=1}^{NA(I)} [RCAPIC_{I,LAST(I,K)}(1 + ATROR_{LAST(I,K)})^{-LAST(I,K)}]$$

$$+\sum_{I=1}^{NBR} \sum_{K=1}^{NA(I)} [TAXB_{FIRST(I,K)}(S179EX_{I,FIRST(I,K)})(1 + ATROR_{FIRST(I,K)})^{-FIRST(I,K)}]$$

$$+\sum_{I=1}^{NBR} \sum_{K=1}^{NA(I)} \sum_{J=L(I,K)}^{N(I,K)} [TAXB_J(ADEP_{I,J})(1 + ATROR_J)^{-J}]$$

$$-\sum_{I=1}^{NBR} [TAXB_N(DISPOS_I)(1 + ATROR_N)^{-N}]$$

$$+\sum_{I=1}^{NBR} (SVAL_I(1 + ATROR_N)^{-N}],$$

where

NPV = net present value of an investment with a planning horizon of N years, consisting of NBR assets and NA(I) replacement periods for asset I,

I = asset type,

NBR = number of assets comprising the investment,

K = replacement period,

$NA(I)$ = number of replacement periods in planning horizon for asset I,

J = year of planning horizon,

N = length of planning horizon in years,

$FIRST_{I,K}$ = the first year of asset I's replacement in period K,

$LAST_{I,K}$ = the last year of asset I's replacement in period K,

$DPAY_{I,K}$ = downpayment made on the acquisition cost or replacement cost of asset I in replacement period K,

$ATROR_J$ = after-tax discount rate in year J,

$M_{I,K}$ = years asset I is financed in replacement period K,

$L_{I,K}$ = first year of asset I's replacement in period K,

$N_{I,K}$ = last year of asset I's replacement in period K,

$PRIN_{I,J}$ = principal payment on asset I in year J,

$TOTINT_{I,J}$ = total interest/financing charges on outstanding debt in year J, associated with asset I's acquisition,

$TAXB_J$ = average tax bracket of the business in year J,

$LOBAL_{I,N}$ = unpaid principal balance on asset I in final year of planning horizon (N),

$BENINV_J$ = additional income/cost saving benefits in year J associated directly with the investment as a whole,

$AINC_{I,J}$ = additional income/cost saving benefits in year J associated specifically with asset I, not included above,

$AFIXCT_{I,J}$ = fixed costs (propery taxes, insurance and housing) associated with asset I in year J,

$AVARCT_{I,J}$ = variable costs (hired labor, fuel, repairs, maintenance, supplies, and interest on operating capital) associated with asset I in year J,

$OLABCT_{I,K}$ = value of owner/operator labor on asset I in year J,

$INVCRD_{I,FIRST(I,K)}$ = investment tax credit on asset I that can be taken in year FIRST(I,K) of replacement period K,

$RCAPIC_{I,LAST(I,K)}$ = investment tax credit recaptured on asset I, to be added to tax liability in year LAST(I,K) of replacement period K,

$S179EX_{I,FIRST(I,K)}$ = Section 179 expensing taken on asset I in year FIRST(I,K) of replacement period K,

$ADEP_{I,J}$ = regular depreciation claimed on asset I in year J,

$DISPOS_I$ = taxable disposal value of asset I, consisting of depreciation recaptured and/or Section 179 expensing recaptured and/or taxable portion of capital gain, or capital loss, and

$SVAL_I$ = salvage/terminal/market value of asset I in final year of planning horizon (N).