ADOPTION OF WATER-CONSERVING IRRIGATION TECHNOLOGIES IN THE CENTRAL HIGH PLAINS

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ADOPTION OF WATER-CONSERVING IRRIGATION

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HIGH PLAINS

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PREFACE

This study was conducted to determine how field, farm, and irrigator characteristics affect the adoption of water-conserving irrigation technologies in the Central High Plains. Water-conserving irrigation technologies such as surge-flow furrow systems, low pressure center pivot systems, and low energy precision application (LEPA) systems have the potential to increase the life of the High Plains aquifer and to reduce the likelihood of environmental damage from nitrates and pesticides. Researchers and policy makers may be interested in the factors that lead to voluntary adoption of water-conserving irrigation technologies and the locations where such technologies have the highest or lowest probabilities of being adopted.

The specific objectives of this research were to (a) identify the most important factors affecting the adoption of water-conserving irrigation technologies, and (b) predict irrigation method adoption probabilities for different field, farm, and irrigator characteristics in the Central High Plains. Multinomial logit models were used to achieve these objectives. The multinomial logit models were estimated using data collected by a mail survey from irrigators in Southwest Kansas and the Northern Texas Panhandle. Parameter estimates of the multinomial logit models were used to identify important factors affecting the adoption of water-conserving irrigation technologies and the to estimate the probabilities of adopting furrow, improved furrow, sprinkler, and LEPA irrigation in the Central High Plains.

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CHAPTER I

INTRODUCTION

Overview of the Study

The Central High Plains region consists of 48,500 square miles in Colorado, Kansas, New Mexico, Oklahoma, and Texas (Luckey et al., 1986). Wheat, grain sorghum, corn, and alfalfa hay are the dominant crops produced in the region. Due to wide fluctuations in rainfall, crop production within the region is highly dependent on irrigation water. The primary source of irrigation water is the Ogallala Formation, an aquifer underlying most of the High Plains region.

Precipitation is the major source of recharge for the High Plains aquifer system. About 75 percent of the precipitation falls during April through September (McGrath and Dugan, 1993). Persistent wind and high summer temperatures during this period cause high rates of evaporation. Thus, most of the water that enters the soil during this period is returned to the atmosphere by evapotranspiration, and little precipitation is available to recharge the aquifer (Weeks, 1986). The demand for irrigation water often exceeds the amount of recharge from precipitation in many parts of the High Plains aquifer (Gutentag et al., 1984). Thus, many areas in the High Plains have experienced significant water-level declines.

Water-level changes that occurred in the High Plains during the predevelopment to 1980 period and during the 1980 to 1991 period are presented in Table 1. Predevelopment refers to the period prior to irrigation development. From predevelopment to 1980, the High Plains experienced a net water-level decline. Water-level declines within the High Plains during this period were closely associated with the development of irrigation, which generally proceeded south-to-north. The greatest declines were observed in Texas where irrigation first developed in the early 1940s. Large declines were also observed in Oklahoma, Kansas, New Mexico, and Colorado, which began irrigation in the 1950s. Nebraska, South Dakota, and Wyoming experienced little change in water-levels during the predevelopment to 1980 period. Irrigation development began much later in these states relative to the rest of the region.

Water-level declines continued throughout the 1980s. During the 1980 to 1991 period, the High Plains experienced a net decline of -1.42 feet. However, the rate of water-level decline during this period was smaller than the rate of decline observed prior to 1980. The average annual water-level change for this period was -0.13 feet, compared to an average annual water-level change of -0.33 feet during predevelopment to 1980. Reduced rates of decline were observed in Texas, Oklahoma, and New Mexico, while increased rates of decline were observed in Kansas and Colorado.

There are several reasons why the rate of water-level decline was reduced in the High Plains. One reason is that precipitation during the 1980 to 1991 period was generally above normal for most of the region (McGrath and Dugan, 1993). Thus conditions were favorable for increased recharge of the aquifer and smaller irrigation

TABLE 1

AREA-WEIGHTED WATER-LEVEL CHANGES FOR STATES IN THE HIGH PLAINS FROM PREDEVELOPMENT TO 1980 AND FROM 1980 TO 1991

	Area-Weighted Water-Level Changes (feet)			
	Predevelopment to 1980		1980 to 1991	
State	Total	Annual Average [a]	Total	Annual Average
Colorado	-4.2	-0.16	-3.15	-0.29
Kansas	-9.9	-0.40	-6.21	-0.56
Nebraska	0.0	0.00	0.23	0.02
New Mexico	-9.8	-0.28	-2.27	-0.21
Oklahoma	-11.3	-0.38	-0.11	-0.01
South Dakota	0.0	0.00	-0.74	-0.07
Texas	-33.7	-0.96	-1.65	-0.15
Wyoming	0.0	0.00	2.92	0.27
High Plains	-9.9	-0.33	-1.42	-0.13

[a] Predevelopment to 1980 averages were calculated by dividing the total area-weighted water-level changes by the number of years from predevelopment to 1980. Predevelopment for Colorado and Kansas was assumed to be 1955, predevelopment for Oklahoma and the entire High Plains region was assumed to be 1950, and predevelopment for Texas and New Mexico were assumed to be 1945.

Source: Timothy McGrath and Jack T. Dugan's Water-Level Changes in the High Plains Aquifer -- Predevelopment to 1991. U.S. Geological Survey, Water-Resources Investigations Report No. 93-4099, 1993.

requirements. Advancements in irrigation technology also contributed to the reduced rate of decline (Musick et al., 1988; Musick et al., 1990; McGrath and Dugan, 1993). The use of center pivot systems expanded throughout the High Plains during the 1970s and 1980s (Nieswiadomy, 1988; Lichtenberg, 1989; Musick et al., 1988; Musick et al., 1990). Center pivot technology made it possible to irrigate areas where topography or soils were unsuited for furrow irrigation. Surge-flow furrow technologies and LEPA (Low Energy Precision Application) sprinkler systems also appeared during the 1980s (Musick et al., 1988; Musick et al., 1990). These technologies were designed to apply water more evenly throughout the field and reduce water losses to runoff and/or percolation.

Economic considerations also contributed to the reduction in the rate of water-level decline. Declining water levels lead to increased pump lifts and reduced well yields (Gutentag et al., 1984). These factors, other things equal, increase pumping costs and reduce the profitability of irrigated agriculture. High energy prices in the 1970s and low crop prices in the 1980s exacerbated the effects of increased pump lifts and led to cropland being shifted away from irrigated crops to nonirrigated crops in many parts of the High Plains (Mapp, 1988; Masud and Lacewell, 1990; McGrath and Dugan, 1993). Thus, the reduction in the rate of water-level decline may in part be due to a reduction of irrigated cropland area during the 1980s. Expansion in irrigated cropland also peaked by 1980 in many parts of the High Plains (McGrath and Dugan, 1993). Few large areas suited for irrigation remain to be developed. Irrigation development continued to expand until after 1980 in parts of the Central High Plains (Kastner et al., 1989; McGrath and Dugan, 1993). This may explain why the rate of decline in water-levels increased during the 1980 to 1991 period for Kansas and Colorado.

Description of the Study Area

This research focuses on two subregions in the Central High Plains: Southwest Kansas and the Northern Texas Panhandle. The subregions are similar in terms of crops produced, rainfall, and cropland field slope. Irrigated and dryland acres by crop are shown for both subregions in Table 2. At least 50 percent of the total cropland in both subregions is irrigated. Corn and alfalfa require large amounts of water and are grown almost exclusively under irrigated conditions, while wheat and grain sorghum require less water and are grown under both irrigated and dryland conditions. Cropland production occurs generally on nearly level slopes within either subregion, while annual precipitation in both subregions ranges from 16 to 21 inches (Mapp et al., 1994).

Soil Types in Southwest Kansas and the Northern Texas Panhandle

Principal dryland and irrigated cropland soils by soil group and soil type are presented for Southwest Kansas and the Northern Texas Panhandle in Table 3 and Table 4, respectively. The tables demonstrate differences in soil type between the two subregions. Cropland acres are primarily composed of silty loam soils in Southwest Kansas, while cropland acres in the Northern Texas Panhandle are primarily silty clay loam or fine sandy loam in texture. In terms of soil groups, the Northern Texas Panhandle has a higher percentage of low percolation ("heavy") soils

TABLE 2

1992 IRRIGATED AND DRYLAND ACRES BY CROP, SOUTHWEST KANSAS AND THE NORTHERN TEXAS PANHANDLE

Southwest Kansas [a]	Irrigated Acres	Dryland Acres	Total Acres	Percent Irrigated
Corn	563,600	0	563,600	100
Wheat	539,500	1,283,500	1,823,000	29.6
Sorghum	206,300	219,800	426,100	48.4
Alfalfa	135,800	0	135,800	100
Other	58,100	0	58,100	100
Total	1,503,300	1,503,300	3,006,600	50.0
Texas Panhandle [b]	**Irrigated Acres**	**Dryland Acres**	**Total Acres**	**Percent Irrigated**
Corn	292,700	0	292,700	100
Wheat	412,200	666,100	1,078,300	38.2
Sorghum	156,800	66,200	223,000	70.3
Alfalfa [c]	15,900	0	15,900	100
Other	4,000	0	4,000	100
Total	881,600	732,300	1,613,900	54.6

[a] Counties in Southwest Kansas include Finney, Ford, Grant, Hamilton, Haskell, Kearny, Meade, Morton, Seward, Stanton, and Stevens.

[b] Counties in the Northern Texas Panhandle include Dallam, Hansford, Hartley, Hutchinson, Lipscomb, More, Ochiltree, Roberts, and Sherman.

[c] Alfalfa acres for the Northern Texas Panhandle were obtained from the Texas Water Development Board's Surveys of Irrigation in Texas: 1958, 1964, 1968, 1974, 1978, 1984, and 1989.

Sources: 1993 Kansas Farm Facts and 1992 Texas Crop Statistics.

TABLE 3

PRINCIPAL DRYLAND AND IRRIGATED CROPLAND SOILS AND APPROXIMATE ACREAGE BY SOIL GROUP AND SOIL TYPE IN SOUTHWEST KANSAS

Soil Groups	Soil Group Definition	Soil Types in Group	Acres by Soil Type	Acres by Soil Group	Percent of Total
Group I	High crop yields	Harney silty loam	379,111	602,310	9.6
	Low percolation volume	Goshen silty loam	78,033		
		Roxbury silty loam	74,536		
		Bridgeport clay loam	56,723		
		Missler silty clay loam	13,907		
Group II	Low crop yields	Richfield silty loam	2,313,541	3,127,687	49.7
	Medium percolation volume	Wiley silty loam	279,170		
		Baca clay loam	252,497		
		Campo silty clay loam	146,554		
		Spearville silty loam	117,843		
		Wakeen silty loam	18,082		
Group III	Medium crop yields	Ulysses silty loam	1,637,157	2,215,823	35.2
	Low percolation volume	Keith silty loam	253,436		
		Uly silty loam	197,846		
		Satanta loam	127,384		
Group IV	Low crop yields	Vona loamy fine sand	191,944	348,613	5.5
	High percolation volume	Dalhart loamy fine sand	114,175		
		Pratt loamy fine sand	25,489		
		Las clay loam	11,347		
		Las Animas silty loam	5,658		
		Total Acres	6,294,433	6,294,433	100.0

Source: Harry P. Mapp, Daniel J. Bernardo, George J. Sabbagh, Samuel Geleta, K. Bradley Watkins, Ronald L. Elliott, and John F. Stone. Impacts of Agricultural Production Practices on the Quantity and Quality of Groundwater in the Central High Plains. Final Report, U.S. Geological Survey, Washington, D.C., November 1991.

TABLE 4

PRINCIPAL DRYLAND AND IRRIGATED CROPLAND SOILS AND APPROXIMATE ACREAGE BY SOIL GROUP AND SOIL TYPE IN THE NORTHERN TEXAS PANHANDLE

Soil Groups	Soil Group Definition	Soil Types in Group	Acres by Soil Type	Acres by Soil Group	Percent of Total
Group I	High crop yields	Sherm silty clay loam	685,539	1,911,576	52.0
	Negligible percolation volume	Sherm clay loam	621,553		
	High runoff volume	Pullman silty clay loam	302,590		
		Pullman clay loam	261,034		
		Darrouzett silty clay loam	40,860		
Group II	Medium crop yields	Dallam fine sandy loam	329,730	794,638	21.6
	High percolation volume	Dallam loamy fine sand	294,630		
	Low runoff volume	Perico fine sandy loam	101,500		
		Dalhart fine sandy loam	58,578		
		Perico loamy fine sand	10,200		
Group III	High crop yields	Dumas loam	204,689	519,156	14.1
	Low percolation volume	Gruver loam	131,500		
	Medium runoff volume	Gruver clay loam	84,960		
		Richfield silty clay loam	60,747		
		Gruver silty clay loam	37,260		
Group IV	Low crop yields	Sunray clay loam	232,026	452,106	12.3
	High percolation volume	Sunray loam	149,836		
	High runoff volume	Ulysses silty clay loam	55,054		
		Ulysses clay loam	15,190		
		Total Acres	3,677,476	3,677,476	100.0

Source: Harry P. Mapp, Daniel J. Bernardo, George J. Sabbagh, Samuel Geleta, K. Bradley Watkins, Ronald L. Elliott, and John F. Stone. Impacts of Agricultural Production Practices on the Quantity and Quality of Groundwater in the Central High Plains. Final Report, U.S. Geological Survey, Washington, D.C., November 1991.

(66.1 percent versus 44.8 percent in Southwest Kansas) and a higher percentage of high percolation ("light") soils (33.9 percent versus 5.5 percent for Southwest Kansas). Thus, the Northern Texas Panhandle has a wider diversity of soil types than Southwest Kansas.

<u>Average Depth to Water and Water-Level Changes for Southwest Kansas and the Northern Texas Panhandle</u>

The average depths to water and the distribution of water-level changes from predevelopment to 1980 and from 1980 to 1991 by county and subregion for Southwest Kansas are shown in Table 5. 56 percent of the area in Southwest Kansas had water-level declines during the predevelopment to 1980 period. 40 percent of Southwest Kansas experienced water-level declines between 10 to 50 feet, while 16 percent experienced water-level declines of 50 feet or more. Water-level declines were greatest in Grant, Haskell, and Stanton counties, which had the largest average depths to water in 1990.

The amount of area experiencing water-level declines in Southwest Kansas increased to 61 percent during the 1980s. 29 percent of the area in Southwest Kansas experienced water-level declines between 5 and 20 feet, while nearly a third of Southwest Kansas experienced water level declines greater than 20 feet. The area of decline increased in Southwest Kansas primarily because groundwater irrigation (e.g., irrigated acres) continued to expand until after 1980 (Kastner et al., 1989; McGrath and Dugan, 1993).

The average depths to water and the distribution of water-level changes from predevelopment to 1980 and from 1980 to 1991 by county and subregion for the Northern Texas Panhandle are presented in Table 6. Comparison of Table 5 to Table 6 reveals that water is much deeper in the Northern Texas Panhandle than in Southwest Kansas. The average depth to water for the Northern Texas Panhandle in 1990 was 272.9 feet. Every county but one for which depth to water data were available had average depths to water in excess of 200 feet, while two counties (Ochiltree and Hartley) had average depths to water greater than 300 feet. More area in the Northern Texas Panhandle also had water-level declines during the predevelopment to 1980 period. 61 percent of the Northern Texas Panhandle had water-level declines between 10 and 50 feet and 20 percent had declines of 50 feet or more. Most of the water-level decline occurred in Sherman, Hansford, Moore, and Ochiltree counties.

The area of water-level decline in the Northern Texas Panhandle was reduced during the 1980 to 1991 period. 52 percent of the area in the Northern Texas Panhandle had little to no water-level decline, while only 14 percent experienced a decline greater than 20 feet. Much of the reduction in the rate of water-level decline observed in the Northern Texas Panhandle can be explained by reduced irrigated area and improvements in irrigation systems and management practices (Musick et al., 1990). The next section will provide evidence for this argument.

TABLE 5

AVERAGE DEPTH TO WATER AND DISTRIBUTION OF WATER-LEVEL CHANGES (PREDEVELOPMENT TO 1980 AND FROM 1980 TO 1991) BY COUNTY FOR SOUTHWEST KANSAS

		Percentage of Area Within Each Water-Level Change Interval [b]							
		Predevelopment to 1980.				1980 to 1991			
County	1990 Average Depth to Water (feet) [a]	Little to no decline	-10 to -50 feet	-50 to -100 feet	More Than -100 feet	Little to no decline	-5 to -10 feet	-10 to -20 feet	More Than -20 feet
Finney	112.4	3	81	14	2	29	11	5	55
Ford	93.3	91	9	0	0	43	22	33	2
Grant	240.1	0	9	74	17	0	8	6	86
Gray	127.0	30	70	0	0	14	11	25	50
Hamilton	90.8	80	20	0	0	88	3	2	7
Haskell	254.2	0	67	33	0	0	0	25	75
Kearny	120.8	35	57	8	0	60	7	4	29
Meade	115.8	71	29	0	0	60	10	10	20
Morton	124.5	56	44	0	0	52	17	25	6
Seward	179.6	55	45	0	0	36	23	27	14
Stanton	197.2	12	25	57	6	30	7	18	45
Stevens	159.7	45	44	11	0	17	14	47	22
Region	144.5	44	40	14	2	39	11	18	32

[a] Represents the average depth to water by county for January, 1991. Averages were calculated using well measurement data from James E. Mitchell, John Woods, Thomas J. McClain, and Robert W. Buddemeier's January 1993 Kansas Water Levels and Data Related to Water-Level Changes, Kansas Geological Survey, Technical Series No. 4, 1994.

[b] Modified from pages 20 and 28 of Timothy McGrath and Jack T. Dugan's Water-Level Changes in the High Plains Aquifer -- Predevelopment to 1991, U.S. Geological Survey, Water-Resources Investigations Report no. 93-4099, 1993.

TABLE 6

AVERAGE DEPTH TO WATER AND DISTRIBUTION OF WATER-LEVEL CHANGES (PREDEVELOPMENT TO 1980 AND FROM 1980 TO 1991) BY COUNTY FOR THE NORTHERN TEXAS PANHANDLE

		Percentage of Area Within Each Water-Level Change Interval [b]							
		Predevelopment to 1980.				1980 to 1991			
County	1990 Average Depth to Water (feet) [a]	Little to no decline	-10 to -50 feet	-50 to -100 feet	More Than -100 feet	Little to no decline	-5 to -10 feet	-10 to -20 feet	More Than -20 feet
Dallam	---	61	34	5	0	33	10	21	36
Hansford	269.0	0	56	44	0	27	22	48	3
Hartley	311.6	25	72	3	0	42	29	21	8
Hutchinson	297.8	0	100	0	0	59	10	12	19
Lipscomb	151.2	45	55	0	0	100	0	0	0
Moore	297.7	0	63	37	0	42	2	25	31
Ochiltree	313.0	0	75	25	0	50	32	18	0
Roberts	---	15	85	0	0	97	0	3	0
Sherman	254.8	0	24	76	0	30	17	28	25
Region	272.9	19	61	20	0	52	14	20	14

[a] Represents the average depth to water by county for January, 1991. Averages were calculated using well measurement data from North Plains Water News, Vol. 35, No. 2, North Plains Underground Water Conservation District No. 2, April 1991.

[b] Modified from pages 20 and 28 of Timothy McGrath and Jack T. Dugan's Water-Level Changes in the High Plains Aquifer -- Predevelopment to 1991, U.S. Geological Survey, Water-Resources Investigations Report no. 93-4099, 1993.

Irrigated Acres by Method of Water Delivery for Southwest Kansas and the Northern Texas Panhandle

Furrow and sprinkler irrigation are the two major methods of water delivery in both subregions. Furrow irrigation is a broad category referring to all methods of water delivery that depend on gravity flow to move water down furrows. This category includes open ditch, gated pipe, surge-flow, and cablegation systems. Sprinkler irrigation refers to all water delivery methods that spray water onto the field through nozzles attached to a network of pressurized pipe. Water delivery methods falling into this category include center pivot sprinklers, hand move sprinklers, side roll sprinklers, and low energy precision application (LEPA).

The amounts of irrigated acres, furrow acres, and sprinkler acres observed in the Northern Texas Panhandle during the years of 1958, 1964, 1969, 1974, 1979, 1984, and 1989 are presented in Table 7. Considerable irrigation development occurred in the Northern Texas Panhandle from 1958 to 1979. During this period, total irrigated acres expanded by nearly 1.1 million acres. Total irrigated acres declined by 32 percent from 1979 to 1989. The decline was associated with low crop prices, increased pump lifts, and increased per unit energy costs which contributed to shifts of acres out of irrigation or to crops such as wheat and sorghum which use less water (Mapp, 1988). Furrow acres accounted for the majority of acres removed from irrigated production, primarily because of the low water application efficiency (e.g., the percent of applied water actually used by the plant) associated with traditional furrow systems (Musick et al., 1990).

Sprinkler acres increased throughout the 1958 to 1989 period both in terms of

TABLE 7

IRRIGATED ACRES, FURROW ACRES, AND SPRINKLER ACRES FOR THE NORTHERN TEXAS PANHANDLE, 1958, 1964, 1969, 1974, 1979, 1984, AND 1989*

Year	Irrigated Acres	Furrow Acres	Percent Furrow	Sprinkler Acres	Percent Sprinkler
1958	317,820	316,420	99.6	1,400	0.4
1964	628,865	609,840	97.0	19,025	3.0
1969	1,141,864	1,056,225	92.5	85,639	7.5
1974	1,287,833	1,115,441	86.6	172,392	13.4
1979	1,382,193	1,062,522	76.9	319,671	23.1
1984	1,087,257	698,063	64.2	389,194	35.8
1989	933,789	490,932	52.6	442,866	47.4

* Counties in the Northern Texas Panhandle include Dallam, Hansford, Hartley, Hutchinson, Lipscomb, More, Ochiltree, Roberts, and Sherman.

Source: Texas Water Development Board's Surveys of Irrigation in Texas: 1958, 1964, 1969, 1974, 1979, 1984, and 1989.

total acres irrigated and the percent of acres irrigated. The rise in sprinkler acres was due largely to the introduction of the center pivot system in the late 1960s (Nieswiadomy, 1988; Musick et al., 1988). Center pivot systems became popular because of their high water application efficiencies, which allowed them to be used on sandy or hilly fields (Nieswiadomy, 1988; Musick et al., 1988). Center pivot systems also became popular because they used only one-fourth the labor required by furrow or hand move sprinkler systems (Nieswiadomy, 1988).

The amounts of irrigated acres, furrow acres, and sprinkler acres observed in Southwest Kansas during the years of 1978, 1982, and 1990 are presented in Table 8. Although fewer years of information are available for Southwest Kansas, some direct comparisons can still be made between the two subregions. Total irrigated acres in Southwest Kansas peaked much later than in the Northern Texas Panhandle. The peak appears to have occurred either in 1982 or shortly thereafter. Irrigated acres declined from 1982 to 1990. This information supports the view that irrigation development continued to expand in Southwest Kansas after 1980. However, irrigation development appears to have ended some time after 1982. Sprinkler acres in Southwest Kansas increased by 39 percent, while furrow acres declined 28 percent during the 1978 to 1990 period. Thus, the system usage trends that occurred in the Northern Texas Panhandle also occurred in Southwest Kansas.

TABLE 8

IRRIGATED ACRES, FURROW ACRES, AND SPRINKLER ACRES FOR SOUTHWEST KANSAS, 1978, 1982, 1989*

Year	Irrigated Acres	Furrow Acres	Percent Furrow	Sprinkler Acres	Percent Sprinkler
1978	1,795,768	1,315,038	73.2	480,730	26.8
1982	1,820,265	1,240,678	68.2	579,587	31.8
1990	1,611,192	940,801	58.4	670,391	41.6

* Counties in Southwest Kansas include Finney, Ford, Grant, Hamilton, Haskell, Kearny, Meade, Morton, Seward, Stanton, and Stevens.

Source: 1978 and 1982 data from the Kansas Irrigation Survey. 1990 data from the Southwest Kansas Groundwater Management District No. 3, Garden City, Kansas.

Saturated Thickness in Southwest Kansas and the Northern Texas Panhandle

Irrigated acres, the proportion of furrow and sprinkler acres, and the distribution of saturated thickness by county and subregion in Southwest Kansas are presented in Table 9. Saturated thickness represents the zone of water-bearing permeable sands and gravels that make up the aquifer. Low saturated thickness translates into low well yields (Weeks, 1986). Generally, if saturated thickness is less than 35 feet, the remaining water is not economically recoverable (Kromm and White, 1992). Thus, saturated thickness is a measure of water availability.

17 percent of the area in Southwest Kansas had little to no saturated thickness in 1980. Most of this area was located in Hamilton county, which had the smallest number of irrigated acres in 1990 (28,841 acres). Meade, Kearney, Stanton, Ford, and Gray also had area with little to no saturated thickness in 1980. Five percent of the area in Southwest Kansas had a saturated thickness between 400 and 600 feet. Most of this area was located in Stevens county. Seward and Finney county also had areas of saturated thickness between 400 and 600 feet.

Saturated thickness appears to be positively related to furrow usage and negatively related to sprinkler usage. Counties with large areas of saturated thickness between 200 and 600 feet tended to have the largest furrow percents in 1990, while counties with large areas of saturated thickness between 0 and 100 feet tended to have the largest sprinkler percents in 1990. There were exceptions to the rule. All of Stevens county had a saturated thickness between 200 and 600 feet in 1980. However, furrow and sprinkler acres were about equal for Stevens county in 1990. Thus, water availability does not appear to be the only factor affecting furrow and

TABLE 9

IRRIGATED ACRES, PERCENT OF FURROW AND SPRINKLER ACRES, AND DISTRIBUTION OF SATURATED THICKNESS BY COUNTY FOR SOUTHWEST KANSAS

				Percentage of Areas Within Each Saturated Thickness Interval, 1980 [b]				
County	1990 Irrigated Acres [a]	1990 Percent Furrow [a]	1990 Percent Sprinkler [a]	Little to None	Less than 100 feet	100 to 200 feet	200 to 400 feet	400 to 600 feet
Finney	251,588	46.4	53.6	0	36	32	23	9
Ford	95,080	25.4	74.6	8	84	8	0	0
Grant	149,161	58.7	41.3	0	0	28	72	0
Gray	198,805	38.8	61.2	6	38	17	39	0
Hamilton	28,841	65.9	34.1	82	15	3	0	0
Haskell	218,468	85.4	14.6	0	0	0	100	0
Kearny	101,273	48.4	51.6	25	41	17	17	0
Meade	126,320	78.8	21.2	35	23	0	42	0
Morton	55,688	81.6	18.4	0	31	38	31	0
Seward	112,542	61.2	38.8	0	0	0	81	19
Stanton	143,753	71.7	28.3	25	17	33	25	0
Stevens	129,673	49.3	50.7	0	0	0	60	40
Region	1,611,192	58.4	41.6	17	28	14	35	5

[a] Modified from unpublished data from the Southwest Kansas Groundwater Management District No. 3, Garden City, Kansas, March 1991.

[b] Modified from page 21 of Timothy McGrath and Jack T. Dugan's Water-Level Changes in the High Plains Aquifer -- Predevelopment to 1991, U.S. Geological Survey, Water-Resources Investigations Report No 93-4088, 1993.

sprinkler usage in Southwest Kansas.

Irrigated acres, the proportion of furrow and sprinkler acres, and the distribution of saturated thickness by county and subregion in the Northern Texas Panhandle are presented in Table 10. All area in the Northern Texas Panhandle had at least some saturated thickness in 1980. However, none of the area in the Northern Texas Panhandle had a saturated thickness greater than 400 feet. Thus, the Northern Texas Panhandle has a smaller variability of saturated thickness than Southwest Kansas.

Saturated thickness again appears to be positively related to furrow usage and negatively related to sprinkler usage. Counties in the Northern Texas Panhandle with large areas of saturated thickness between 200 and 400 feet tended to have larger furrow percents, while counties with large areas of saturated thickness less than 200 feet tended to have larger sprinkler percents. Again, there were exceptions to the rule. 67 percent of Moore county had less than 200 feet of saturated thickness in 1980. However, Moore county had more furrow than sprinkler acres in 1990. Thus, other factors besides water availability appear to affect the use of furrow and sprinkler irrigation in the Northern Texas Panhandle.

Summary of the Study Area

The previous sections demonstrate that Southwest Kansas and the Northern Texas Panhandle differ in soil types, depth to water, and variability of saturated thickness. Also, the previous sections indicate that soil types, depth to water, and saturated thickness vary spatially within the two subregions. Both subregions

TABLE 10

IRRIGATED ACRES, PERCENT OF FURROW AND SPRINKLER ACRES AND DISTRIBUTION OF SATURATED THICKNESS BY COUNTY FOR THE NORTHERN TEXAS PANHANDLE

				Percentage of Area Within Each Saturated Thickness Interval, 1980[b]				
County	1989 Irrigated Acres [a]	1989 Percent Furrow [a]	1989 Percent Sprinkler [a]	Little to None	Less than 100 feet	100 to 200 feet	200 to 400 feet	400 to 600 feet
Dallam	204,515	5.5	94.5	0	33	50	17	0
Hansford	136,550	93.3	6.7	0	0	25	75	0
Hartley	151,900	22.9	77.1	0	38	52	10	0
Hutchinson	35,000	88.6	11.4	0	42	11	47	0
Lipscomb	17,680	18.6	81.4	0	0	67	33	0
Moore	161,100	77.6	22.4	0	50	17	33	0
Ochiltree	70,737	90.2	9.8	0	0	33	67	0
Roberts	8,316	67.1	32.9	0	0	11	89	0
Sherman	148,000	60.0	40.0	0	0	22	78	0
Region	933,798	52.6	47.4	0	19	33	47	0

[a] Modified from the Texas Water Development Board's Surveys of Irrigation in Texas - 1958, 1964, 1969, 1974, 1979, 1984, and 1989, Report No. 329, January 1991.

[b] Modified from page 21 of Timothy McGrath and Jack T. Dugan's Water-Level Changes in the High Plains Aquifer -- Predevelopment to 1991, U.S. Geological Survey, Water-Resources Investigations Report No 93-4088, 1993.

experienced changes in irrigation practices during the 1980s. Irrigated area began to decline in both subregions due to a combination of increased pump lifts, low crop prices, and high energy costs which reduced the profitability of irrigated agriculture in the two subregions. The decline in irrigated area began slightly later in Southwest Kansas because of continued groundwater development during the early 1980s.

Furrow irrigated area in both subregions declined during the 1980s, while sprinkler irrigated area increased. Sprinkler area increased primarily because of expanded use of center pivot systems, which apply water more efficiently than furrow systems and can be used on sandy or hilly terrain or in areas with low saturated thickness. Furrow irrigated area declined because of the low water application efficiency of the traditional furrow system. Thus, furrow irrigation became unsuitable in areas experiencing major groundwater declines or in areas with low saturated thickness.

Problem Statement

Water-conserving irrigation technologies such as surge-flow furrow systems, center pivot sprinkler systems and LEPA systems have been identified as being partially responsible for the reduction in the rate of water-level decline in the High Plains during the 1980s (Musick et al., 1988; Musick et al., 1990; McGrath and Dugan, 1993). Thus, these technologies have the potential to increase the life of the High Plains aquifer in areas where water-level declines have been most severe. Little is known about the factors leading to the adoption of such technologies in the High Plains. Several studies have shown that physical characteristics such as soil type and field slope influence the adoption of water-conserving irrigation technologies (Caswell and Zilberman, 1986; Lichtenberg, 1989; Negri and Brooks, 1990; Dinar and Yaron, 1990). Other studies have shown that the adoption of agricultural technologies is influenced by characteristics of the decision maker, such as the decision maker's age and education level (Rahm and Huffman, 1984; Pulter and Zilberman, 1988). However, these studies were not concerned with the adoption of new irrigation technologies. Information sources may also affect the irrigator's adoption decision. However, the effect of information sources on irrigation technology adoption has not been explored in the literature.

Locational differences substantially affect the adoption of water-conserving irrigation technologies in the High Plains. Kromm and White (1990) found that irrigator attitudes about the usefulness of specific water-saving irrigation technologies and management practices varied considerably across the High Plains region. The authors concluded that spatial distribution of information flows, aquifer characteristics, socioeconomic characteristics, or conservation attitudes explained much of the variation in system preferences.

The previous sections have demonstrated that soil types, pump lifts, and water availability (saturated thickness) vary considerably across the Central High Plains region alone. A better understanding of the spatial characteristics affecting irrigation technology adoption in the Central High Plains should help researchers target locations where water-conserving irrigation technologies will most likely be adopted. For example, the likelihood of adopting sprinkler over furrow systems may depend partially on soil type. If the relationship between irrigation technology adoption and soil type can be established, and if locations of specific soil types are known within the region, then unique sprinkler and furrow adoption probabilities can be predicted for different locations based on soil type. Additional spatial factors such as field slope and pump lift can also be incorporated into the irrigation technology adoption model, thus allowing for irrigation technology adoption predictions based on a combination of spacial factors (e.g predictions based on soil type, pump lift, and field slope).

Policy makers concerned with the effects of nitrate and pesticide pollution resulting from irrigated production should also be interested in the spatial factors affecting irrigation technology adoption in the Central High Plains. Adoption of water-conserving irrigation technologies by agricultural producers will often reduce runoff and percolation and will also reduce the likelihood of environmental damage from nitrates and pesticides (Mapp et al., 1994). Policy makers may want to know where water-conserving irrigation technologies have the highest or lowest probability of being adopted. Such information would help policy makers develop incentive policies that promote the use of water-conserving irrigation technologies in areas where adoption of such technologies is least probable.

Research Objectives

The goal of this research is to determine how spacial factors affect the adoption of water-conserving irrigation technologies in the Central High Plains. The specific objectives of this study are as follows:

1. Identify the most important factors affecting the adoption of water-conserving irrigation technologies in the Central High Plains; and

2 Predict irrigation method adoption probabilities for different field, farm, and irrigator characteristics in the Central High Plains.

Irrigation Methods Under Study

This study groups irrigation system types into four irrigation methods: (1) furrow; (2) improved furrow; (3) sprinkler, and (4) LEPA. These irrigation methods are unique in terms of method of water delivery, water application efficiency, and energy required to deliver water to the plant.

Furrow technologies deliver water by either open ditch or gated pipe. Open ditch systems use siphon tubes to move water from the irrigation ditch to the field. Gated pipe supplies water to the furrow using a series of openings in a supply pipe. Furrow technologies deliver large amounts of water to a field at relatively infrequent intervals. The water application efficiency of furrow systems is generally lower than that of sprinkler systems and ranges from 35 to 70 percent (Negri and Hanchar, 1989). However, the water application efficiency of furrow systems approaches that of sprinkler systems on soils with high water holding capacity. Thus, furrow systems are usually placed on heavy textured and leveled soils (Caswell and Zilberman, 1986).

Improved furrow technologies are gated pipe systems that have been modified to control the flow of water running down the furrows or to capture runoff at the end of the field. Surge-flow systems, cablegation systems, and gated pipe systems with tailwater recovery pits are included in this category. Surge-flow furrow systems deliver water to the furrow in timed releases through surge valves. The initial surge of water forms a water seal on the soil permitting the next surge of water to travel further down the furrow. Cablegation delivers water automatically and sequentially using a plug attached to a cable inside the supply pipe. The rate at which water is supplied to a particular furrow is at a maximum initially and then gradually declines as the plug travels down the pipe. Tailwater recovery pits capture field runoff in pits dug in low-lying areas of the farm and recirculate the water to the top of the field. Water application efficiency for improved furrow systems typically ranges from 75 to 85 percent (Negri and Hanchar, 1989).

Sprinkler systems combine equipment (spray nozzles, drop tubes, etc.) and energy in the form of pressurization to distribute water uniformly throughout the field. Water delivery methods in this category include hand move sprinklers, side roll sprinklers, linear move sprinklers, and high and low pressure center pivot sprinklers. Center pivot systems are used on more acres in the Central High Plains than the other sprinkler systems. Center pivot systems supply water from the pivot point (center of the field) to a pipeline suspended on mobile towers, and the mobile towers rotate slowly around the pivot point. High pressure center pivots operate at pressures ranging from 45 to 100 pounds per square inch, while low pressure center pivots operate at pressures ranging from 15 to 45 pounds per square inch (Negri and Hanchar, 1989).

Sprinkler technologies apply water in smaller amounts and at more frequent intervals than furrow systems. This method of water application reduces the potential for water percolation out of the root zone and makes more water available for plant uptake. Thus, sprinkler technologies are more likely than furrow technologies to be placed on sandy or hilly fields. The water application efficiency of center pivot systems ranges from 70 to 85 percent, while the water application efficiency of the other sprinkler technologies ranges from 55 percent to 80 percent (Negri and Hanchar, 1989).

LEPA is a sprinkler technology that distributes water directly to the furrow at very low pressure (4 to 10 pounds per square inch) through drop tubes and emitters located 2 to 4 inches above the furrow (Lyle and Bordovsky, 1983). Direct application of water to the furrow also cuts down on water evaporation. The system is usually combined with improved agronomic land practices, such as furrow diking and planting in a circle, to fully utilize rainfall and reduce runoff (Fipps and New, 1990). The water application efficiency for LEPA technology can be as high as 99 percent (Lyle and Bordovsky, 1983). In addition, field trials indicate that crop yields are consistently higher with LEPA than with conventional center pivot technology (Fipps and New, 1990).

Summary of Procedures

Multinomial logit models are used to predict the probability of irrigation method adoption in the Central High Plains. Multinomial logit models relate the log odds of a particular choice being made to attributes or characteristics of the decision maker and are used in situations where the decision maker has three or more discrete alternatives from which to choose. In this study, the decision maker is assumed to choose between furrow, improved furrow, sprinkler, and LEPA irrigation. The estimated coefficients of the multinomial logit models are used to determine important factors that significantly affect the likelihood of adopting water-conserving irrigation technologies. The coefficients are also used to predict irrigation method adoption probabilities for different field characteristics (e.g., sandy versus clay soils) different irrigator characteristics (e.g., age, education, etc.), and different farm characteristics (number of wells per farm, percent of irrigated cropland rented, etc.).

The multinomial logit models are estimated using data collected by a mail survey from irrigators in Southwest Kansas and the Northern Texas Panhandle. Survey respondents provided information about the types of systems used on their farming operations and the field characteristics (soil type, field slope, etc.) associated with each system. Respondents also provided individual information about themselves, their farming operations, and the information sources they use when making irrigation technology adoption decisions. Three multinomial logit models are estimated for this study; one for the entire Central High Plains, one for Southwest Kansas, and one for the Northern Texas Panhandle.

CHAPTER II

REVIEW OF THE IRRIGATION SYSTEM ADOPTION LITERATURE

The purpose of the chapter is to provide the reader with an understanding of how irrigation system adoption research is typically conducted and to demonstrate how this study differs from previous research. The chapter begins with a brief history of technological adoption research and continues by summarizing theoretical and empirical irrigation system adoption studies found in the literature. The chapter concludes with an explanation of how this study differs from previous irrigation system adoption studies.

Adoption of Agricultural Technologies

Early work on technological adoption in agriculture focused on the pattern of adoption over time, or diffusion. These studies generally found empirically that the diffusion curve is sigmoid or s-shaped. Researchers usually explained the s-shaped pattern as a function of communication.

Rogers (1962) characterized diffusion as a continuous innovativeness dimension and partitioned this dimension into five adopter categories: 1) innovators; 2) early adopters; 3) early majority; 4) late majority; and 5) laggards. Innovators were described as young, wealthy, risk takers who remained close to scientific information sources and freely interacted with other innovators. Early adopters were characterized as opinion leaders or role models with high social status. Early majority adopters were described as individuals who adopted innovations only after peers adopted them. Late majority adopters were characterized as individuals who needed overwhelming pressure from peers before adoption could take place. Finally, laggards were characterized as individuals who were highly dependent on tradition and who used friends, neighbors, and relatives as their main sources of information.

Mansfield (1961) described diffusion as a process of imitation among firms. The rate of imitation was defined as the speed at which a new innovation spreads from one firm to another. Mansfield used ordinary least squares to estimate the rate of imitation of twelve innovations for four American industries. The author found that the rate of imitation was a decreasing function of the size of investment required for the innovation and an increasing function of both the innovation's profitability and the proportion of firms adopting the innovation.

Griliches (1957) conducted the first econometric study of diffusion. He estimated logistic functions of hybrid seed corn diffusion by state and crop reporting district in the United States using ordinary least squares. Griliches found cross-sectional variation in the parameters of the logistic diffusion functions. He attributed this variation to locational differences in the profitability of hybrid corn adoption.

Jarvis (1981) analyzed the diffusion of improved pastures in Uruguay. A logistic function was used to predict the path of improved pasture diffusion and the ceiling of pasture diffusion (or the point in time when the diffusion process ceases). Jarvis incorporated beef and fertilizer prices into the rate of improved pasture diffusion. Thus, Jarvis was the first investigator to express the rate of diffusion of a single innovation as a function of economic variables.

Technology diffusion studies are often criticized for not having a firm theoretical foundation in microeconomic theory (Caswell, 1991). This criticism is raised because diffusion studies are concerned with the shape of the diffusion curve and fail to account for individual decision making by farmers. More recent agricultural technology adoption studies focus on the determinants of adoption rather than the shape of the diffusion curve. The following is a sample of such studies.

Hiebert (1974) argued that the decision to adopt modern agricultural technologies is enhanced by "learning" under uncertainty. Learning was defined as a collection of information about the probability distribution of output from the modern technology. Hiebert asserted that the probability of adopting a modern agricultural technology was positively related to 1) the stock of information pertaining to the modern technology and 2) the skill of the farmer (e.g., the farmer's ability to decode and analyze the information).

Feder and O'Mara (1981) argued that fixed costs are a deterrent to the adoption of modern technologies by small acreage farmers. The authors defined fixed costs as the monetary and time cost required to obtain essential information about the modern technology, the time cost associated with the transport of inputs required by the modern technology, and the transaction costs of obtaining loans from credit institutions burdened by "red tape". With no fixed costs, the authors demonstrated that the modern technology would always be adopted by both small and large acreage farmers regardless of risk attitude. If fixed costs existed, the modern technology would first be partially adopted by large acreage farmers who experimented with the modern technology. Large acreage farmers would increase their rate of adoption and eventually shift to full acceptance. Small acreage farmers would begin to adopt the modern technology once enough information had been gathered to reduce the degree of uncertainty to an acceptable level.

Rahm and Huffman (1984) investigated the effects of human capital investments (e.g., education, experience, and the use of extension and media information sources) on the decision to adopt reduced tillage. The authors used farm-level data from a sample of Iowa farm operators to estimate the probability of reduced tillage adoption and the efficiency of reduced tillage adoption decisions. Efficiency of adoption was measured as the difference between the actual outcome of the adoption decision and the predicted probability of adoption. The authors found that human capital variables enhanced the efficiency of the farmer's decision to adopt reduced tillage.

Lee and Stewart (1983) investigated the effects of landownership on minimum tillage adoption. The authors used a logit model to predict minimum tillage adoption rates for full-owner operators, part-owner operators, and non-operator landlords in the Corn Belt Region. The authors found that full-owner operators and landowners with small farm size had lower minimum tillage adoption rates than other groups.

Pulter and Zilberman (1988) investigated the factors affecting computer and computer software adoption by farmers in Tulare County, California using logit models. The authors found that the likelihood of computer adoption increased with farm size and education level but decreased with age. The likelihood of computer software ownership was also found to be positively related to farm size and education level.

Irrigation System Adoption Studies

Irrigation system adoption research can be classified as being either normative or positive (Caswell, 1991). Normative studies use economic theory to indicate what "should" be obtained. Such models are usually based on an engineering approach and compute profits, water use, etc., based on assumed parameters for production functions, costs, and irrigation system efficiencies. Positive studies try to analyze what people are actually doing rather than what they should be doing. Such models are generally econometric; they seek to identify the factors that affect the adoption of new technologies and assess the importance of these factors to the adoption decision. Although the two research methods differ, they are nevertheless related. Hypotheses developed by conceptual normative analysis can be tested using positive analysis. The two methods typically lead to the same conclusions (Caswell, 1991).

Normative Irrigation System Adoption Studies

Several irrigation system adoption studies have been conducted using the normative method. Some of these studies are theoretical in nature and try to set forth the conceptual framework behind the irrigator's decision to adopt new irrigation technologies.

Caswell and Zilberman (1986) introduced a theoretical framework that provided conditions for the selection of water-conserving (modern) irrigation technologies over water-intensive (traditional) irrigation technologies. Their model incorporated irrigation technology characteristics (e.g., labor cost, system cost, and irrigation effectiveness) with physical characteristics (e.g., land quality and well depth) to explain when water-conserving irrigation technologies were most likely to be adopted. Under the assumption that the farmer chooses the irrigation technology with the largest per acre quasi-rent, the authors demonstrated that water-conserving irrigation technologies were more likely to be adopted in locations with low land quality and deep wells.

Lichtenberg (1989) developed a theoretical model to explain how land quality and irrigation technology choice affect cropland allocation. Under the assumption of profit maximization and in the absence of land quality-augmenting technologies, Lichtenberg showed that lands with unique qualities will be allocated to the most profitable crop. The introduction of a land-quality augmenting technology such as sprinkler irrigation will result in an exogenous shift in the profitability of the crop grown on lower quality land. This exogenous shift will be much smaller for high quality land. Thus, the introduction of sprinkler irrigation should result in an expansion of acreage of the most profitable crop and a simultaneous reduction of acreage of less profitable crops.

Caswell et al. (1990) expanded the theoretical irrigation system adoption framework introduced by Caswell and Zilberman (1986) by including a pollution function. The authors theorized that water not used by the crop may be a source of environmental damage in the form of either runoff or percolation. Thus, they made the assumption that water-conserving irrigation technologies result in lower levels of pollution than water-intensive irrigation technologies. The authors demonstrated that charging a high tax for each unit of pollution produced by irrigation could encourage owners of high quality land to switch to water-conserving irrigation technologies and encourage owners of low quality land to remove such land from irrigated production.

Other system adoption studies using the normative method are empirical. These studies generally analyze the monetary benefits achieved from improving the water application efficiency of the current technology in place and the monetary benefits of switching to a more water-conserving irrigation technology. The following is a sample of such studies.

Lee et al. (1985) used a recursive linear programming model to evaluate the net benefits associated with improving the distribution efficiency of irrigation systems in the Texas High Plains. Net benefits were derived for two situations: 1) improving the distribution efficiency of the current system; and 2) shifting from either furrow to sprinkler or from furrow to low energy precision application (LEPA). The net benefits for each situation were analyzed under a base scenario (high water availability and average crop prices), a low crop price scenario, and a low water availability scenario. The authors concluded from their analysis that substantial benefits can be achieved by simply improving the application efficiency of an irrigation system currently in place. The authors also found that benefits from improved application efficiency are dramatically reduced under both low crop prices and low water availability.

Hornbaker and Mapp (1988) combined a grain sorghum growth stage model with a dynamic risk-neutral recursive programming model to analyze the potential water savings from adopting irrigation scheduling and low pressure center pivot technology. Three different sprinkler technologies were analyzed: 1) high pressure center pivot; 2) low pressure center pivot; and 3) LEPA. The results showed that LEPA technology allowed the farm operator to apply less water per application and resulted in yields and net returns that were higher and less variable than those of high or low pressure center pivot technologies.

Coupal and Wilson (1990) investigated the economic feasibility of adopting surge-flow irrigation in Arizona based upon the breakeven price of irrigation water and the net present value of investing in surge-flow irrigation. Three scenarios were analyzed: 1) the farmer is developing new agricultural land and must choose between either open ditch technology or surge-flow technology; 2) the farmer replaces the existing ditch system with surge-flow (which also requires investment in gated pipe); and 3) the farmer adapts the existing gated pipe system to surge-flow. Surge-flow was found to be profitable when developing new land (Scenario 1) or when gated pipe was already in place (Scenario 3). However, surge-flow was found to be unprofitable when converting from open ditch irrigation. Since most irrigators in Arizona use ditch systems, the authors concluded that very little surge-flow adoption would take place in the state.

Letey et al. (1991) evaluated five different irrigation systems (furrow, subsurface drip, hand-moved sprinkler, linear-moved sprinkler, and LEPA) based on system costs, crop yields, and irrigation uniformity (e.g., a measure of how evenly water is made available to plants throughout the field). The five systems were evaluated for cotton production in the San Joaquin Valley of California. The results of the study indicated that furrow systems were more profitable than sprinkler systems when the amount of drainage water from irrigation was unconstrained or when drainage water disposal was costless. LEPA systems with an irrigation uniformity of at least 90 percent were found to provide the highest profitability when drainage water disposal costs were imposed.

Positive Irrigation System Adoption Studies

Most of the empirical system adoption work using the positive method is recent. Empirical work on irrigation system adoption is generally limited by a lack of data, particularly time series data (Caswell, 1991). Nevertheless, several empirical system adoption studies have been completed, and these studies generally confirm the hypotheses generated using the normative method.

Caswell and Zilberman (1985) were probably the first to conduct an econometric analysis of irrigation technology adoption. Their study used multinomial logit models to estimate the log odds of adopting sprinkler and drip technology versus using the traditional furrow technology in the Central Valley of California. The authors collected irrigation system land use data via questionnaires sent to farm advisers from six counties in the San Joaquin Valley. Data were obtained from 97 subregions. The dependent variables of the multinomial logit models were the log odds of adopting sprinkler technology versus furrow technology and the log odds of adopting drip technology versus furrow technology based upon the shares of each technology within each subregion. The explanatory variables were water cost savings, a groundwater/surface water dummy variable, a set of county (location) dummy variables, and a set of crop dummy variables.

Water cost savings were found to be important in the adoption of sprinkler and drip technologies. Such a result was expected, since sprinkler and drip technologies apply water more efficiently than furrow technologies. Groundwater users were found to be more likely to adopt sprinkler and drip technologies than were surface water users. This result was also expected, since surface water users are supplied by water districts that generally gear their water distribution systems to the traditional technology (furrow). Crop differences were found to be influential in the adoption of sprinkler and drip technologies. Specifically, nut tree crops were found to benefit from such technologies. Finally, county location was for the most part insignificant in the adoption of sprinkler and drip irrigation. However, the locational effect was more significant for drip than for sprinkler technology.

Nieswiadomy (1988) investigated irrigation input substitution for Texas High Plains irrigators during the 1970s. Nieswiadomy estimated partial elasticities of substitution for such inputs as water, labor, center pivot systems, furrow systems, and wheel roll systems. The results indicated that irrigators reduced their water usage in response to higher pumping costs during the 1970s. A likely cause was the rise of center pivot usage and a decline in furrow usage within the region. Center pivot irrigation was found to be a substitute for furrow irrigation, a complement to wheel roll irrigation, and possibly a complement to labor.

Lichtenberg (1989) used a multinomial logit regression model to determine the important factors leading to the diffusion of center pivot technology in the Northern High Plains. Six crops were analyzed for a sample of 22 counties in western Nebraska. The log of the ratio of harvested acreage of each crop to dryland acreage was regressed on a quadratic function of expected own-crop price, expected hay price, estimated center pivot system cost, and average county land quality using weighted least squares. Land quality was measured as the county-wide average available water capacity in the top six feet of soil. Lichtenberg's results showed a strong tie between land quality and the adoption of center pivot technologies in the Northern High Plains. Specifically, Lichtenberg found that center pivot adoption in the Northern High Plains has allowed for substitution of irrigated corn for both grain sorghum and small grains on lower quality lands.

Kromm and White (1990) surveyed 709 irrigators from ten counties in Kansas, Nebraska, Oklahoma, and Texas to determine the frequency of adoption of water-conserving irrigation technologies and management practices in the High Plains. The results indicated that irrigators' perceptions about the value of converting to more water conserving irrigation technologies or management practices vary across the High Plains. Location (e.g., the irrigator's county of residence) was found to be the leading factor explaining this variation. The authors concluded that the spatial distribution of other characteristics such as information flows, aquifer characteristics, socioeconomic characteristics, or conservation attitudes may explain why some practices are used in one place but not in another.

Dinar and Yaron (1990) used OLS to estimate both grove area equipped with modern technologies and the speed of adoption of modern technologies by citrus producers in Israel and Gaza. The authors used a cross-section data base with information on the use of six irrigation technologies in Israel. Their sample included 209 owner operated groves. Grove area and speed of adoption of modern irrigation systems (e.g., the time lag between the introduction of a given technology into the market and its adoption by the grower) were regressed against water price, grove age, farm area, a water quality variable, a pair of soil texture variables (e.g., heavy and light soils), a rootstock variable, a water quota variable, an experience variable, a farm organization dummy variable, and a regional dummy variable. Land quality was found to be a significant factor in the adoption of modern irrigation technologies. Specifically, Dinar and Yaron found that modern technologies were more likely to be adopted on lighter soils than on heavy soils.

Negri and Brooks (1990) used two binomial logit models to estimate the probability of adopting sprinkler systems and tailwater recovery systems. The authors obtained farm-level system usage data from the 1984 Farm and Ranch Irrigation Survey (FRIS) and county-level land quality data from the National Resource Inventory (NRI) to conduct their analysis. The explanatory variables for each model were the price of water, the price of labor, the number of irrigated acres, a surface water dummy variable, a set of climate variables, a set of soil characteristic variables, and a set of regional dummy variables. The dependent variables were the share of irrigated acreage using sprinkler systems and tailwater recovery systems, respectively.

Their results indicated that land quality characteristics have the greatest impact on selection probabilities. Farms consisting of soils with low water-holding capacity were more likely to adopt sprinkler irrigation, supporting the hypothesis that sprinklers are land quality augmenting. The probability of adopting sprinklers varied positively with total rainfall and inversely with growing degree days and growing season length. Soil slope was found to have the greatest impact on the probability of adopting sprinklers. Water cost, labor cost, and irrigated acreage were also significant determinants of technological adoption. However, their impact was relatively small compared to soil texture, soil slope, and climate.

Shrestha and Gopalakrishnan (1993) used a simultaneous equation model consisting of a discrete choice probit model and two yield rate equations for furrow and drip irrigation to analyze the choice of drip irrigation in Hawaii's sugar industry. Their study utilized field observation panel data from four plantations on the Hawaiian Islands for the period 1975 through 1986. The dependent variable for the discrete choice model was a zero/one binary variable representing the choice of drip irrigation (one if drip irrigation is used and zero otherwise), while the dependent variables for the yield rate equations were tons of sugar per acre produced under furrow and drip irrigation. The explanatory variables for the discrete choice model were perceived yield difference, difference in expected water use, year, field size, a plantation dummy, soil type, annual temperature, and field gradient. The explanatory variables for the two yield rate equations were water used, fertilizers applied, field acreage, plant cycle, age of crop at harvest, crop variety, harvesting month, soil order, water holding capacity, annual temperature, field gradient, and a plantation dummy.

The results of the discrete choice model indicated that perceived yield difference and expected water savings are very important in the choice of drip irrigation. However, both soil types analyzed in the study (one with good water-holding capacity and one with poor water-holding capacity) were equally important in the choice of drip irrigation, implying a contradiction to the theory that drip is more likely to be adopted in poor-quality lands. The authors concluded that water conservation is important in the early years of drip adoption, but perceived yield increases take priority over water savings during later years of drip adoption.

The results of the two yield rate equations tended to conform to previous expectations. The net effect of applied water was significant under drip irrigation but not under furrow irrigation due to drip's higher water application efficiency. Water-holding capacity and flatness of field were significant factors contributing to yield under furrow irrigation but insignificant under drip irrigation. This result was also expected, since drip is more suitable than furrow irrigation for use on soils with steep slope and poor water holding capacity.

Conclusions of the Normative and Positive Irrigation System Adoption Studies

The general findings of the theoretical normative studies are that water-conserving irrigation technologies are more efficient at applying water and should be more likely than furrow technologies to be used in areas with sandy soils, in areas with steep slopes, or in areas with deep pump lifts. The general findings of the empirical normative studies are that monetary benefits from water savings do exist when shifting to water-conserving irrigation technologies, but substantial monetary benefits can also be achieved by simply improving the water application efficiency of the current system in place. Normative studies indicate the tendency of adoption. That is, they can explain the conditions for which the adoption of water-conserving irrigation technologies is most likely. However, normative studies cannot be used to predict the level of adoption, since they estimate such things as profit levels and not behavior (Caswell, 1991).

The findings of the positive studies conform to those of the normative studies. The results of the positive studies indicate that water-conserving irrigation technologies are more likely than furrow technologies in areas with light sandy soils, in areas with steep slopes, or in areas where irrigation water is expensive. Many of the positive studies use econometric probability models. The parameters of such models can be used to predict the level (or probability) of adoption associated with specific irrigation technologies.

None of the positive studies identify factors affecting LEPA adoption. Several studies deal with adoption of drip irrigation for perennial tree fruits and specialty crops (Caswell and Zilberman 1985, Dinar and Yaron, 1990, Shrestha and Gopalakrishnan, 1993). However, LEPA is also an efficient irrigation method that is superior to either furrow or other sprinkler delivery methods in water application efficiency and energy savings (Lyle and Bordovsky, 1983). Row crop studies such as Negri and Brooks (1990) and Lichtenberg (1989) make no distinction between different sprinkler types. However, LEPA is distinctly different from other sprinkler technologies.

Irrigation system adoption studies have also ignored the effects of information sources on the irrigator's decision to adopt water-conserving irrigation technologies. Kromm and White (1991) addressed this issue for water-conserving management practices. They used the results from their High Plains survey to identify the most widely used and accepted information sources among irrigators when choosing water saving management practices. Their findings indicated interpersonal contacts such as friends, neighbors, and county agricultural agents had little impact on the irrigator's decision to adopt water saving practices. Such sources of information were considered less reliable relative to past personal experience, university extension services, private agricultural consulting firms, trade magazines, and local groundwater districts.

This study addresses factors affecting LEPA adoption and the effects of information sources on the adoption decision, both of which were ignored in earlier irrigation system adoption studies. Multinomial logit models are estimated using survey data from irrigators in Southwest Kansas and the Northern Texas Panhandle. The multinomial logit models are then used to predict the probability of adopting furrow, improved furrow, sprinkler and LEPA irrigation. Information sources are incorporated into the multinomial logit models as explanatory variables. The next chapter provides the theoretical framework behind the multinomial logit model and describes how data were collected for this study.

CHAPTER III

METHOD OF ANALYSIS

Economic models which predict the likelihood of choosing one alternative over another are called "discrete choice" or "limited dependent variable" models. Such models work with a limited number of discrete alternatives and seek to describe choice behavior in terms of probability. That is, they relate the conditional probability of a particular choice being made to various explanatory factors or attributes that include characteristics of the decision maker (Judge et al., 1985).

This chapter explains how one such discrete choice model, the multinomial logit model, is employed to predict the probability of adoption of water conserving irrigation technologies in the Central High Plains. The chapter discusses the theory behind the multinomial logit model and describes how the model is estimated and used to predict irrigation method adoption probabilities. The chapter also explains the survey procedures used for data collection in this study.

Theoretical Framework for the Multinomial Logit Model

Irrigators are assumed to make adoption decisions based upon an objective of utility maximization. Assume the irrigator wishes to irrigate a certain field and has a binary choice between two irrigation methods: (1) furrow; and (2) sprinkler. Denote a technology index j so that $j = 1$ for furrow irrigation and $j = 2$ for sprinkler irrigation, and denote a utility function that ranks the irrigator's preferences for these irrigation methods as follows:

$$U_{ij} = U\ (\ R_{ij}\ ,\ A_{ij}\ )\ , \tag{3.1}$$

where

U_{ij} = The irrigator's utility from using irrigation method j on field i;

R_{ij} = a vector of moments that describe the distribution of net returns for irrigation method j on field i including adoption costs; and

A_{ij} = a vector of other attributes associated with irrigation method j.

The variables R_{ij} and A_{ij} are unobserved and unavailable, but a linear relationship can be postulated between the utility derived from irrigation method j and vectors of physical and irrigator characteristics as follows:

$$U_{ij} = \beta_{j0}' + \beta_{j1}'C_i + \beta_{j2}'Q_i + \beta_{j3}'S_i + \epsilon_{ij} \tag{3.2}$$

$$i = 1, \ldots, I\ ; \qquad j = 1, 2$$

where

U_{ij} = The irrigator's utility from using irrigation method j on field i;

C_i = a vector of physical characteristics associated with field i (e.g., soil type, slope, etc.);

Q_i = a vector of irrigator and farm characteristics (e.g., age, education, number of wells on the farm, etc.) that affect the technology choice on field i;

S_i = a vector of information sources (e.g., irrigation dealers, private consulting firms, extension, etc.) that affect the technology choice on field i;

ϵ_i = a zero mean random disturbance term representing unobserved characteristics; and

$\beta'_{j0}, \beta'_{j1}, \beta'_{j2}, \beta'_{j3}$ = vectors of parameters to be estimated.

For simplicity of presentation let X_i represent the vectors C_i, Q_i, and S_i, and let β_j represent the vectors β'_{j0}, β'_{j1}, β'_{j2}, and β'_{j3} in (3.2) so that $U_{ij} = X_i'\beta_j + \epsilon_{ij}$. The irrigator will choose the method of irrigation that provides the largest utility. Thus, the irrigator will choose sprinkler irrigation (j = 2) over furrow irrigation (j = 1) on field i if $U_{i1} < U_{i2}$. The probability of choosing sprinkler irrigation on field i is as follows:

$$
\begin{aligned}
(3.3) \qquad P_{i2} &= Prob\ (U_{i1} < U_{i2}) \\
&= Prob\ (\ X_i'\beta_1 + \epsilon_{i1} \ < \ X_i'\beta_2 + \epsilon_{i2}\ ) \\
&= Prob\ [\ (\epsilon_{i1} - \epsilon_{i2}) \ < \ X_i'(\beta_2 - \beta_1)\ ] \\
&= Prob\ [\ \alpha_i \ < \ X_i'(\beta_2 - \beta_1)\ ] \\
&= F\ [\ X_i'(\beta_2 - \beta_1)\ ]\ ,
\end{aligned}
$$

where α_i represents the difference ($\epsilon_{i1} - \epsilon_{i2}$) and $F\ [\ X_i'(\beta_2 - \beta_1)\ ]$ represents the cumulative distribution function of α_i evaluated at $X_i'(\beta_2 - \beta_1)$.

Estimation of F depends on the distribution of α_i. The two most commonly used distributions for F are the cumulative normal and the cumulative logistic. If the cumulative normal distribution is chosen, then the binomial probit model is used, and if the cumulative logistic is chosen, then the binomial logit model is used. There is very little difference between the two models (Judge et al., 1988; Pindyck and Rubinfeld, 1981). Under the logit model, the cumulative distribution function for P_{i2} is as follows:

$$(3.4) \qquad P_{i2} = F\,[\,X_i'(\,\beta_2 - \beta_1\,)\,] = \frac{1}{1 + e^{-[\,X_i'(\,\beta_2 - \beta_1\,)\,]}}\,.$$

Equation (3.4) is the cumulative logistic distribution function.

The binomial logit model can be derived from (3.4) in the following manner. First multiply both sides of (3.4) by $1 + e^{-[X_i'(\beta_2 - \beta_1)]}$ to get

$$(3.5) \qquad (\,1 + e^{-[\,X_i'(\,\beta_2 - \beta_1\,)\,]}\,)\,P_{i2} = 1\,.$$

Dividing both sides of (3.5) by P_{i2} and subtracting 1 leads to

$$(3.6) \qquad e^{-[\,X_i'(\,\beta_2 - \beta_1\,)\,]} = \frac{1}{P_{i2}} - 1 = \frac{1 - P_{i2}}{P_{i2}} = \frac{P_{i1}}{P_{i2}}\,.$$

By definition, $e^{-[X_i'(\beta_2 - \beta_1)]} = 1 \,/\, e^{[X_i'(\beta_2 - \beta_1)]}$, so

$$(3.7) \qquad \frac{P_{i1}}{P_{i2}} = \frac{1}{e^{[X_i'(\beta_2 - \beta_1)]}} .$$

Inverting both sides of **(3.7)** and taking natural logs gives

$$(3.8) \qquad \ln\left(\frac{P_{i2}}{P_{i1}}\right) = X_i'(\beta_2 - \beta_1) ,$$

where $\ln(P_{i2}/P_{i1})$ represents the natural logarithm of the observed odds ratio of choosing sprinkler over furrow irrigation. Equation **(3.8)** is the binomial logit model.

The multinomial logit model is similar to the binomial logit model except the former assumes that the decision maker has three or more alternatives from which to choose. The multinomial logit model assumes that ϵ_{ij} in **(3.2)** are independently and identically distributed with Weibull density functions (Judge et al., 1985; Domencich and McFadden, 1975). The Weibull density function has the same general bell shape as the normal density function, but is skewed, with a thinner left tail and a thicker right tail (Domencich and McFadden, 1975). The Weibull distribution has two significant properties: (1) the difference between two independent Weibull random variables (e.g., $\epsilon_{i1} - \epsilon_{i2}$ in **(3.3)** above) is again a Weibull random variable; and (2) the difference between two Weibull random variables has a logistic distribution (Domencich and McFadden, 1975). This leads to the multinomial logit model (Judge et al., 1985).

Under the multinomial logit model, the probability of using irrigation method j

on field i can be expressed as follows:

$$(3.9) \qquad P_{ij} = \frac{e^{X_i'(\beta_j - \beta_1)}}{\sum_{j=1}^{J} e^{X_i'(\beta_j - \beta_1)}} ,$$

which is the general form of the cumulative logistic distribution function. The general form of the multinomial logit model is identical to that of the binomial logit model and is estimated as follows:

$$(3.10) \qquad \ln\left(\frac{P_{ij}}{P_{il}}\right) = X_i'(\beta_j - \beta_1) , \qquad j = 2, \ldots, J.$$

Estimation of the Multinomial Logit Model

Both the binomial logit model in **(3.8)** and the multinomial logit model in **(3.10)** require some sort of normalization to identify their parameters. The normalization rule used most often is to assume that $\beta_1 = 0$. With this normalization accomplished, the multinomial logit model for this study can be expressed as follows:

$$(3.11) \qquad \ln\left(\frac{P_{i2}}{P_{i1}}\right) = X_i'\beta_2 = \beta_{20} + \beta_{21}'C_i + \beta_{22}'Q_i + \beta_{23}'S_i$$

$$\ln\left(\frac{P_{i3}}{P_{i1}}\right) = X_i'\beta_3 = \beta_{30} + \beta_{31}'C_i + \beta_{32}'Q_i + \beta_{33}'S_i$$

$$\ln\left(\frac{P_{i4}}{P_{i1}}\right) = X_i'\beta_4 = \beta_{40} + \beta_{41}'C_i + \beta_{42}'Q_i + \beta_{43}'S_i$$

where the subscripts 1, 2, 3, and 4 represent furrow irrigation, improved furrow irrigation, sprinkler irrigation and LEPA irrigation, respectively; $\ln(P_{i2}/P_{i1})$, $\ln(P_{i3}/P_{i1})$, and $\ln(P_{i4}/P_{i1})$ are the natural log of the odds of choosing improved furrow over furrow irrigation, sprinkler over furrow irrigation, and LEPA irrigation over furrow irrigation, respectively; (β_{10}, β_{20}, β_{30}; $\beta'_{21},\ldots,\beta'_{43}$) are the estimated parameters of the multinomial logit model; and C_i, Q_i, and S_i are the characteristic vectors described in (3.2) above.

Elements of the J - 1 equations in (3.11) can be used to estimate the probabilities of adoption associated with the four irrigation methods. These equations plus the requirement that adoption probabilities must sum to one for every field observation determine the probabilities uniquely (Schmidt and Strauss, 1975). The probability of adopting furrow irrigation (P_{i1}) is determined as follows:

$$(3.12) \qquad P_{i1} = \frac{1}{1 + \sum_{j=2}^{4} e^{X_i'\beta_j}}, \qquad j = 1,$$

and the probabilities of adopting improved furrow, sprinkler, and LEPA irrigation (P_{ij}) are determined as follows:

$$(3.13) \qquad P_{ij} = \frac{e^{X_i'\beta_j}}{1 + \sum_{j=2}^{4} e^{X_i'\beta_j}}, \qquad j = 2, 3, 4 ,$$

where X_i represents C_i, Q_i, and S_i, and β_j represents β_2, β_3 and β_3 in **(3.11)**.

Other comparisons can also be derived from the equations in **(3.11)** (Schmidt and Strauss, 1975). For example, parameters for the natural log of the odds of choosing sprinkler over improved furrow irrigation ($\ln(P_{i3}/P_{i2})$), LEPA over improved furrow irrigation ($\ln(P_{i4}/P_{i2})$), and LEPA over sprinkler irrigation ($\ln(P_{i4}/P_{i3})$), can be derived as follows:

$$(3.14) \qquad \ln\left(\frac{P_{i3}}{P_{i2}}\right) = (\beta_{30} - \beta_{20}) + (\beta_{31}' - \beta_{21}')C_i + (\beta_{32}' - \beta_{22}')Q_i + (\beta_{33}' - \beta_{23}')S_i$$

$$\ln\left(\frac{P_{i4}}{P_{i2}}\right) = (\beta_{40} - \beta_{20}) + (\beta_{41}' - \beta_{21}')C_i + (\beta_{42}' - \beta_{22}')Q_i + (\beta_{43}' - \beta_{23}')S_i$$

$$\ln\left(\frac{P_{i4}}{P_{i3}}\right) = (\beta_{40} - \beta_{30}) + (\beta_{41}' - \beta_{31}')C_i + (\beta_{42}' - \beta_{32}')Q_i + (\beta_{43}' - \beta_{33}')S_i$$

Data Development

Data for this study were collected using a mail questionnaire survey. The survey was divided into two sections. The first section asked for specific data about the irrigator, the irrigator's farm operation, and the sources of information used by the irrigator when adopting irrigation technologies or management practices. The second section asked for information about the types of systems used on the irrigator's farm operation and the field characteristics associated with each system. Much work went into the actual development of the irrigation survey prior to its first mailing. Early versions of the survey were examined by irrigation experts to determine if the survey's questions were appropriate and understandable (Earls, 1994; Elliott, 1994; Frost, 1994; Gollehon, 1994; Hodges, 1994; Kizer, 1994; and Piatt, 1994). A copy of the irrigation survey is provided in Appendix A.

Central High Plains irrigators were randomly sampled from a pair of irrigator mailing lists. One mailing list came from the Southwest Kansas Groundwater Management District Number 3 headquartered in Garden City, Kansas and represented a composite of landowners and water use correspondents (primarily tenants) with irrigation water rights within the Southwest Kansas groundwater district (Frost, 1994). The other mailing list came from the North Plains Underground Water Conservation District Number 2 headquartered in Dumas, Texas and represented names and addresses of people receiving the quarterly news letter North Plains Water News (Piatt, 1994). Addresses of non-irrigators were deleted from both lists, leaving a total of 2350 possible irrigators in the Southwest Kansas list and 1435 possible irrigators in the Northern Texas Panhandle list. Forty percent of the possible irrigators within each list were randomly sampled leaving a total sample size of 1513 mailing addresses (940 in Southwest Kansas and 573 in the Northern Texas Panhandle).

The survey was conducted from mid-March to late-May, 1994 and followed mailing procedures outlined by Christenson (1975). The initial mailing of the survey occurred during the first full week of March, 1994. Each irrigator was sent a survey form, a cover letter explaining the need for the survey, and a postage paid return envelope. A different cover letter was used for each subregion. Copies of both cover letters are provided in the Appendix A.

Approximately three weeks after the initial mailing, a reminder post card was sent to all surveyed irrigators who had not yet responded. The post card referred to the initial mailing and purpose of the survey. It also encouraged a prompt response from each survey recipient. A copy of the post card reminder is provided in the Appendix A. A second and final reminder was sent approximately three weeks after the first. The final reminder included a cover letter, a postage paid return envelope, and an additional copy of the survey form in case the first was lost or misplaced. The reminder cover letter was similar to that used in the initial mailing except the reminder letter explained the need for a representative sample from each region and the importance of the irrigator's completed response.

A summary of the total number of surveys mailed and returned in both Central High Plains subregions is provided in Table 11. Nearly 45 percent of the total mailed surveys were returned. Of those returned, 50.4 percent were unanswered and 11.4 percent were unusable. Unanswered surveys represented non-farmers and farmers who were retired, no longer irrigating crops, or deceased. Unusable surveys were typically surveys answered by landlords not directly involved in the management of irrigated crops on their land. 38 percent of the returned surveys were usable, and the usable surveys represented nearly 17 percent of the total surveys mailed.

TABLE 11

MAILING AND RESPONSE SUMMARY FOR THE 1994 CENTRAL HIGH PLAINS IRRIGATION SURVEY, SOUTHWEST KANSAS AND THE NORTHERN TEXAS PANHANDLE

Survey Region	Total Surveys Mailed	Total Mailing Percentage	Total Surveys Returned to Sender*	Total Returned Surveys	Total Unanswered Surveys	Total Unusable Surveys	Total Usable Surveys	Usable Surveys as a Percentage of Total Returned	Usable Surveys as a Percentage of Total Mailed
Southwest Kansas	940	62.13	8	416	162	63	191	45.91	20.32
Texas Panhandle	573	37.87	14	259	178	15	66	25.48	11.52
Total	1513	100	22	675	340	78	257	38.07	16.99

* Surveys returned to sender were surveys with no available forwarding address or surveys with incomplete mailing addresses.

CHAPTER IV

IRRIGATION METHODS USED IN THE CENTRAL HIGH PLAINS AND EXPLANATORY VARIABLES USED IN THE ANALYSIS

The purpose of this chapter is to provide the reader with knowledge about the different irrigation methods used in the Central High Plains and to describe the explanatory variables used in the multinomial logit model presented in Chapter III. The chapter is divided into two sections. The first section presents irrigation system usage data by irrigation method (e.g., furrow, improved furrow, sprinkler, and LEPA) from irrigators in Southwest Kansas and the Northern Texas Panhandle. The second section presents the explanatory variables used in the multinomial logit analysis and describes how each variable is hypothesized to affect irrigation method adoption in the Central High Plains.

Irrigation System Types by Irrigation Method

Chapter I defined the four irrigation methods used in the Central High Plains: (1) furrow; (2) improved furrow; (3) sprinkler; and (4) LEPA. Responses to Question C1 of the Central High Plains Irrigation Survey were used to group irrigation system data by irrigation method. Question C1 asked irrigators to identify every irrigation system used on their farm operations. To keep the length of the survey manageable, irrigators with more than eight systems were asked to report for only eight. Irrigators were required to designate each system as being one of ten system types, ranging from open ditch systems to LEPA systems. The ten system types were later grouped into four alternative irrigation methods in the following manner:

Furrow: Includes open ditch systems (with and without tailwater recovery pits) and gated pipe systems without any additional improvements, such as surge-valves, cablegation, or tailwater recovery pits.

Improved Furrow: Includes all gated pipe systems with surge-valves, cablegation, and/or tailwater recovery pits.

Sprinkler: Includes side roll sprinklers, hand move sprinklers, linear move sprinklers, and high and low pressure center pivots.

LEPA: Includes all low energy precision application systems.

Total Systems by Irrigation Method

The numbers of systems by irrigation method for Southwest Kansas and the Northern Texas Panhandle are presented in Table 12. Both subregions have similar furrow and sprinkler system percentages. However, the Southwest Kansas sample has

TABLE 12

NUMBER OF IRRIGATION SYSTEMS BY IRRIGATION METHOD IN SOUTHWEST KANSAS AND THE NORTHERN TEXAS PANHANDLE, 1994 CENTRAL HIGH PLAINS IRRIGATION SURVEY

Irrigation Method	Southwest Kansas Systems	System Percent	Texas Panhandle Systems	System Percent	Total Systems	System Percent
Furrow[a]	85	13.6	39	16.3	124	14.3
Improved Furrow	136	21.7	29	12.1	165	19.0
Sprinkler[b]	319	50.8	111	46.3	430	49.6
LEPA	87	13.9	61	25.4	148	17.1
Total	627	100	240	100	867	100

[a] Gated pipe systems account for 91.8 and 82.1 percent of the total furrow systems in Southwest Kansas and the Northern Texas Panhandle, respectively. The remaining systems are open ditch technologies.

[b] Low pressure center pivot systems account for 86.2 and 92.8 percent of all sprinkler systems in Southwest Kansas and the Northern Texas Panhandle, respectively. The remaining sprinkler systems are primarily high pressure center pivot systems.

a higher percentage of improved furrow systems, while the Northern Texas Panhandle sample has a higher percentage of LEPA systems. These numbers indicate different system preferences for LEPA and improved furrow irrigation within the two subregions.

Several explanations are possible for this difference in system preference. One is based upon the physical characteristics of soil types in the two subregions. The Northern Texas Panhandle has a greater extreme in soil types. Nearly two thirds of cropland area in the Northern Texas Panhandle is composed of silty clay loam soils with high runoff potential, while the remaining one third is composed of sandy soils or soils with high percolation potential (see Chapter I, Table 4). Soil types are more uniform throughout Southwest Kansas. Cropland acres in Southwest Kansas are primarily composed of silty loam soils with medium to low percolation volume. LEPA irrigation is used in conjunction with field management practices that catch rainfall and reduce runoff (Fipps and New, 1990). LEPA is also better suited for use on sandy soils than furrow irrigation. Thus, the higher incidence of LEPA adoption in the Northern Texas Panhandle may be due in part to the greater extreme in soil types observed in this subregion.

A second explanation is based on the difference in depths to water between the two subregions. The average depth to water is larger in the Northern Texas Panhandle than in Southwest Kansas (see Chapter I, Tables 5 and 6). Thus, the cost of pumping groundwater should be higher for irrigators in the Northern Texas Panhandle. The combination of high water application efficiency with low operating pressures makes LEPA an energy saving alternative to other irrigation technologies

(Lyle and Bordovsky, 1983; Fipps and New, 1990). Thus, deeper pump lifts in the Northern Texas Panhandle may explain in part why LEPA is used more extensively in this subregion.

Other explanations are concerned with the irrigator's knowledge of the LEPA concept (e.g., awareness about its design and its benefits). The LEPA concept was first introduced in the Texas Panhandle in 1981 (Fipps and New, 1990). Thus, irrigators in this region may be more familiar with LEPA and less averse to using it on their farms. Also, field trials in the Texas Panhandle show that LEPA crop yields are generally higher than those of other water delivery methods (Fipps and New, 1990; Lyle and Bordovsky, 1983). Higher yields often translate into increased profit. The potential for increased profit plus a greater general knowledge about benefits associated with energy and water savings may explain in part why LEPA adoption is more prevalent in the Texas Panhandle.

Total Acres by Irrigation Method and Crop

Total irrigated acres by crop and irrigation method for Southwest Kansas and the Northern Texas Panhandle are presented in Table 13 and Table 14, respectively. The data in Tables 13 and 14 were calculated using information collected from Question C10 of the Central High Plains Irrigation Survey. Sprinkler and furrow irrigation are first and third in terms of the total share of irrigated acres in both subregions. However, the order is reversed for LEPA and improved furrow irrigation. LEPA acres form the second largest share of total irrigated acres in the Northern Texas Panhandle, while improved furrow acres form the second largest

TABLE 13

IRRIGATED ACRES BY IRRIGATION METHOD AND CROP IN SOUTHWEST KANSAS, 1994 CENTRAL HIGH PLAINS IRRIGATION SURVEY

Irrigation Method	Corn Acres	Percent Corn Acres	Wheat Acres	Percent Wheat Acres	Sorghum Acres	Percent Sorghum Acres	Alfalfa Acres	Percent Alfalfa Acres	Other Acres	Percent Other Acres	Total Acres	Percent Total Acres
Furrow	8,014	12.5	7,077	16.6	3,088	22.7	415	6.1	454	9.2	19,048	14.4
Improved Furrow	20,509	32.0	14,462	33.9	3,913	28.8	297	4.3	1,111	22.5	40,292	30.5
Sprinkler	25,708	40.1	16,208	38.0	5,725	42.1	5,029	73.3	2,330	47.2	55,000	41.6
LEPA	9,917	15.5	4,887	11.5	874	6.4	1,118	16.3	1,039	21.1	17,835	13.5
Subregion Total	64,148	100	42,634	100	13,600	100	6,859	100	4,934	100	132,175	100

TABLE 14

IRRIGATED ACRES BY IRRIGATION METHOD AND CROP IN THE NORTHERN TEXAS PANHANDLE, 1994 CENTRAL HIGH PLAINS IRRIGATION SURVEY

Irrigation Method	Corn Acres	Percent Corn Acres	Wheat Acres	Percent Wheat Acres	Sorghum Acres	Percent Sorghum Acres	Alfalfa Acres	Percent Alfalfa Acres	Other Acres	Percent Other Acres	Total Acres	Percent Total Acres
Furrow	3,518	11.5	6,635	19.4	1,438	23.9	25	3.7	430	15.1	12,046	16.2
Improved Furrow	3,625	11.9	4,002	11.7	1,360	22.6	0	0.0	175	6.2	9,162	12.3
Sprinkler	11,182	36.6	12,745	37.2	2,426	40.3	658	96.3	1,735	61.1	28,746	38.7
LEPA	12,196	40.0	10,905	31.8	791	13.2	0	0.0	500	17.6	24,392	32.8
Subregion Total	30,521	100	34,287	100	6,015	100	683	100	2,840	100	74,346	100

share of total irrigated acres in Southwest Kansas. Once again, one can see different system preferences between the two subregions; LEPA is perceived to be more important than improved furrow irrigation in the Northern Texas Panhandle, while improved furrow is perceived to be more important than LEPA irrigation in Southwest Kansas. Wheat and corn are the major irrigated crops in both subregions. Most corn and wheat acres in Southwest Kansas are irrigated using improved furrow and sprinkler systems, while most corn and wheat acres in the Texas Panhandle are irrigated using sprinkler and LEPA systems. Sorghum acres are irrigated using both furrow and sprinkler methods while alfalfa is predominately irrigated using sprinkler systems.

Irrigation Method Combinations in the Central High Plains

The numbers of irrigators by irrigation method combination and the average numbers of systems used by method in each combination are reported for Southwest Kansas and the Northern Texas Panhandle in Table 15 and Table 16, respectively. Respondents in both subregions use on average 1.5 different irrigation methods on their farming operations. At least 53 percent of respondents in both subregions use only one irrigation method. Nearly 39 percent of respondents in the Southwest Kansas use two irrigation methods, while over 42 percent of respondents in the Northern Texas Panhandle use two irrigation methods on their farming operations. Tables 15 and 16 give the impression that few respondents use three irrigation methods. However, these results may be slightly misleading, because respondents were asked to report for only eight systems. Thus, the percent of respondents using

TABLE 15

NUMBER OF IRRIGATORS BY IRRIGATION METHOD COMBINATION AND AVERAGE NUMBER OF IRRIGATION SYSTEMS USED BY IRRIGATION METHOD WITHIN EACH COMBINATION IN SOUTHWEST KANSAS, 1994 CENTRAL HIGH PLAINS IRRIGATION SURVEY

					Average Number of Systems Used by Method in Each Combination			
Combinations:	Irrigation Methods in Combinations:	Number of Responces	Percent of Sample	Percent by Combination	FURR	IFUR	SPRK	LEPA
Four Method Combination	FURR, IFUR, SPRK, LEPA [a]	1	0.5	0.5	1.0	1.0	1.0	1.0
Three Method Combinations	IFUR, SPRK, LEPA	4	2.1	6.8	0.0	1.3	1.0	2.0
	FURR, SPRK, LEPA	3	1.6		1.0	0.0	1.3	1.0
	FURR, IFUR, LEPA	1	0.5		1.0	1.0	0.0	1.0
	FURR, IFUR, SPRK	5	2.6		1.4	2.0	2.4	0.0
Two Method Combinations	FURR, IFUR	3	1.6	38.7	1.0	1.3	0.0	0.0
	FURR, SPRK	20	10.5		1.3	0.0	2.2	0.0
	FURR, LEPA	4	2.1		1.5	0.0	0.0	1.0
	IFUR, SPRK	31	16.2		0.0	1.6	2.0	0.0
	IFUR, LEPA	12	6.3		0.0	2.3	0.0	2.8
	SPRK, LEPA	4	2.1		0.0	0.0	5.5	1.3
Use Only One Method	FURR	25	13.1	53.9	1.6	0.0	0.0	0.0
	IFUR	20	10.5		0.0	1.9	0.0	0.0
	SPRK	51	26.7		0.0	0.0	3.4	0.0
	LEPA	7	3.7		0.0	0.0	0.0	4.6
	Total	191	100	100	1.4	1.8	2.7	2.4

[a] FURR = furrow irrigation, IFUR = improved furrow irrigation, SPRK = sprinkler irrigation, and LEPA = LEPA irrigation.

TABLE 16

NUMBER OF IRRIGATORS BY IRRIGATION METHOD COMBINATION AND AVERAGE NUMBER OF IRRIGATION SYSTEMS USED BY METHOD WITHIN EACH COMBINATION IN THE NORTHERN TEXAS PANHANDLE, 1994 CENTRAL HIGH PLAINS IRRIGATION SURVEY

					Average Number of Systems Used in Each Combination			
Combinations:	Irrigation Methods in Combinations:	Number of Responces	Percent of Sample	Percent by Combination	FURR	IFUR	SPRK	LEPA
Four Method Combination	FURR, IFUR, SPRK, LEPA [a]	0	0.0	0.0	0.0	0.0	0.0	0.0
Three Method Combinations	IFUR, SPRK, LEPA	0	0.0	4.5	0.0	0.0	0.0	0.0
	FURR, SPRK, LEPA	1	1.5		1.0	0.0	1.0	6.0
	FURR, IFUR, LEPA	0	0.0		0.0	0.0	0.0	0.0
	FURR, IFUR, SPRK	2	3.0		2.0	1.5	2.5	0.0
Two Method Combinations	FURR, IFUR	1	1.5	42.4	3.0	1.0	0.0	0.0
	FURR, SPRK	8	12.1		1.8	0.0	2.0	0.0
	FURR, LEPA	4	6.1		1.3	0.0	0.0	1.3
	IFUR, SPRK	6	9.1		0.0	2.0	2.2	0.0
	IFUR, LEPA	5	7.6		0.0	1.6	0.0	2.4
	SPRK, LEPA	4	6.1		0.0	0.0	4.0	3.0
Use Only One Method	FURR	10	15.2	53.0	1.2	0.0	0.0	0.0
	IFUR	5	7.6		0.0	1.0	0.0	0.0
	SPRK	15	22.7		0.0	0.0	4.0	0.0
	LEPA	5	7.6		0.0	0.0	0.0	5.2
	Total	66	100	100	1.5	1.5	3.1	3.2

[a] FURR = furrow irrigation, IFUR = improved furrow irrigation, SPRK = sprinkler irrigation, and LEPA = LEPA irrigation.

three irrigation methods could be slightly higher than reported in Tables 15 and 16.

Respondents using only sprinkler systems and respondents using both improved furrow and sprinkler systems account for the largest response percents in Southwest Kansas. Sprinkler irrigators use an average of 3.4 systems while improved furrow and sprinkler irrigators use an average of 1.6 improved furrow systems and 2 sprinkler systems. Respondents using only sprinkler irrigation and respondents using only furrow irrigation account for the largest response percents in the Northern Texas Panhandle. Sprinkler irrigators use an average of 4 systems, while furrow irrigators use an average of 1.2 systems in the Northern Texas Panhandle.

Explanatory Variables Used in the Analysis

Explanatory variables for this study can be placed into three categories: (1) physical characteristics; (2) irrigator and farm characteristics; and (3) information sources. Each category was briefly defined in Chapter III. The following sections describe the variables within each category and explain how each variable is hypothesized to affect irrigation technology adoption in the Central High Plains.

Physical Characteristic Variables

Physical characteristic variables refer to the general characteristics of the field on which each irrigation system is placed. This category includes land quality variables, a pump lift variable, a well yield variable, and an acres per well variable.

Land Quality Variables: Several studies have established that land quality has a strong influence on technology adoption (Caswell and Zilberman, 1986;

Lichtenberg, 1989; Negri and Brooks, 1990; Dinar and Yaron, 1990). Lichtenberg defines land quality as a series of attributes (e.g., fertility, water-holding capacity, topography, and depth of topsoil) that affects crop productivity. Two of the most influential attributes affecting irrigation technology choice are water-holding capacity and topography. Water-holding capacity is a measure of the soil's ability to hold and store water for plant uptake, while topography refers to the terrain of the field (e.g., flat versus rolling or hilly land). This study uses soil and field slope as proxies for water holding-capacity and topography, respectively.

Water-holding capacity varies by soil type. Sandy fields have a lower water holding-capacity relative to either loam or clay fields. Furrow irrigation is inappropriate on sandy fields because applied water percolates before it flows the entire length of the furrow. Sprinkler systems are better suited for sandy fields because water is applied in smaller amounts at frequent intervals. This method of water application reduces the potential for water percolation and makes more water available for plant uptake. Thus sprinkler technologies meet the water needs of the plant and are often referred to in the literature as land quality-augmenting technologies (Lichtenberg, 1989).

Question C8 of the Central High Plains Irrigation Survey asked irrigators to identify the predominant soil type irrigated by every system operated on their farm. The numbers of irrigation systems by irrigation method and soil type for Southwest Kansas and the Northern Texas Panhandle are shown in Table 17 and Table 18, respectively. Sandy loam, loam, and clay loam are the primary soil types irrigated in both subregions. Furrow and improved furrow systems are generally used on loam

TABLE 17

NUMBER OF IRRIGATION SYSTEMS BY IRRIGATION METHOD AND SOIL TYPE IN SOUTHWEST KANSAS, 1994 CENTRAL HIGH PLAINS IRRIGATION SURVEY

Soil Type	Irrigation Method									
	Furrow	Percent Furrow	Improved Furrow	Percent Improved Furrow	Sprinkler	Percent Sprinkler	LEPA	Percent LEPA	Total	Percent Total
Sand	1	1.2	1	0.7	64	20.3	2	2.3	68	10.9
Sandy Loam	26	30.6	39	28.7	150	47.5	36	41.4	251	40.2
Loam	38	44.7	60	44.1	74	23.4	25	28.7	197	31.6
Clay Loam	18	21.2	36	26.5	24	7.6	24	27.6	102	16.3
Clay	2	2.4	0	0.0	4	1.3	0	0.0	6	1.0
Total	85	100	136	100	316	100	87	100	624	100

TABLE 18

NUMBER OF IRRIGATION SYSTEMS BY IRRIGATION METHOD AND SOIL TYPE IN THE NORTHERN TEXAS PANHANDLE, 1994 CENTRAL HIGH PLAINS IRRIGATION SURVEY

	Irrigation Method									
Soil Type	Furrow	Percent Furrow	Improved Furrow	Percent Improved Furrow	Sprinkler	Percent Sprinkler	LEPA	Percent LEPA	Total	Percent Total
Sand	0	0.0	0	0.0	6	5.5	0	0.0	6	2.5
Sandy Loam	8	20.5	9	31.0	65	59.1	26	43.3	108	45.4
Loam	14	35.9	11	37.9	20	18.2	2	3.3	47	19.7
Clay Loam	17	43.6	9	31.0	18	16.4	32	53.3	76	31.9
Clay	0	0.0	0	0.0	1	0.9	0	0.0	1	0.4
Total	39	100	29	100	110	100	60	100	238	100

and clay loam soils, while sprinkler systems are generally used on sand and sandy loam soils. LEPA systems are used on both sandy loam and clay loam soils within both subregions.

Three soil type dummy variables were created using the information collected from Question C8. These dummy variables are described as follows:

SAND = 1 if soil type = "sand" or "sandy loam"; = 0 otherwise.

LOAM = 1 if soil type = "loam"; = 0 otherwise.

CLAY = 1 if soil type = "clay" or "clay loam"; = 0 otherwise.

SAND and **CLAY** will appear in the logit equations and will measure the log of the technology choice odds relative to **LOAM**.

Slope also affects the adoption of water-conserving irrigation technologies. The higher the slope, the greater the potential for water loss due to runoff. Consequently, furrow systems are often limited to fairly level fields. Sprinkler systems have no such limitation and can be placed on either flat or hilly land.

Question C9 of the Central High Plains Irrigation Survey asked irrigators to identify the predominant slope of acres irrigated by each system used on their farming operations. They were asked to choose between low slope (less than 1 percent), medium slope (between 1 and 3 percent), and high slope (greater than 3 percent). Furrow irrigation can occur on slopes between 0 and 3 percent, while sprinkler irrigation can take place on slopes ranging from 0 to 15 percent (Burt, 1989).

The numbers of systems by irrigation method and field slope for Southwest

Kansas and the Northern Texas Panhandle are shown in Table 19 and Table 20, respectively. In both subregions, most irrigation systems are used on low and medium sloped fields. The Northern Texas Panhandle has a higher percentage of irrigation systems placed on low sloped fields (48.5 percent versus 35.5 percent for Southwest Kansas), while Southwest Kansas has a higher percentage of irrigation systems placed on medium sloped fields (55.2 percent versus 40.6 percent for the Texas Panhandle). High sloped fields are predominately irrigated by sprinkler and LEPA systems.

Three field slope dummy variables were created from the information obtained from Question C9. These dummy variables are described as follows:

LSLOPE = 1 if field slope = "low" (less than 1 percent); = 0 otherwise.

MSLOPE = 1 if field slope = "medium" (between 1 and 3 percent); = 0 otherwise.

HSLOPE = 1 if field slope = "high" (greater than 3 percent); = 0 otherwise.

The **LSLOPE** and **HSLOPE** dummy variables will appear in the logit equations and will measure the log of the technology choice odds relative to **MSLOPE**.

Pump Lifts and Variable Pumping Costs: Researchers generally assume that the likelihood of choosing sprinkler over furrow irrigation is positively related to pump lift and therefore positively related to the energy cost of pumping water (Negri and Brooks, 1989). Because of differences in application efficiency, sprinkler

TABLE 19

NUMBER OF IRRIGATION SYSTEMS BY IRRIGATION METHOD AND SLOPE IN SOUTHWEST KANSAS, 1994
CENTRAL HIGH PLAINS IRRIGATION SURVEY

	Irrigation Method									
Slope	Furrow	Percent Furrow	Improved Furrow	Percent Improved Furrow	Sprinkler	Percent Sprinkler	LEPA	Percent LEPA	Total	Percent Total
Low Slope	34	40.0	71	52.2	74	23.5	43	49.4	222	35.6
Medium Slope	48	56.5	61	44.9	198	62.9	37	42.5	344	55.2
High Slope	3	3.5	4	2.9	43	13.7	7	8.0	57	9.1
Total	85	100	136	100	315	100	87	100	623	100

TABLE 20

NUMBER OF IRRIGATION SYSTEMS BY IRRIGATION METHOD AND SLOPE IN THE NORTHERN TEXAS PANHANDLE, 1994 CENTRAL HIGH PLAINS IRRIGATION SURVEY

	Irrigation Method									
Slope	Furrow	Percent Furrow	Improved Furrow	Percent Improved Furrow	Sprinkler	Percent Sprinkler	LEPA	Percent LEPA	Total	Percent Total
Low Slope	21	53.8	15	51.7	53	48.2	27	44.3	116	48.5
Medium Slope	16	41.0	12	41.4	48	43.6	21	34.4	97	40.6
High Slope	2	5.1	2	6.9	9	8.2	13	21.3	26	10.9
Total	39	100	29	100	110	100	61	100	239	100

systems require less water than furrow systems for a given effective application. Thus, sprinkler irrigation results in less water applied during the growing season. Less water applied results in less water pumped and, other things equal, lower variable pumping costs. However the ability to apply less water during the growing season comes at a cost. Sprinkler systems require pressurization energy to distribute water uniformly throughout the field. The additional cost of sprinkler pressurization may offset any energy cost savings from pumping less water (Caswell and Zilberman, 1986). Thus, the likelihood of choosing sprinkler over furrow irrigation can be negatively related to variable pumping costs and pump lifts.

Variable pumping costs by system were calculated using engineering formulae from the Oklahoma State University Irrigation Cost Generator (Kletke et al., 1978) and information from Questions C4 and C6 of the Central High Plains Irrigation Survey. Question C4 asked irrigators to provide both the type and price of fuel used by every system operated on their farm, while Question C6 asked irrigators to provide the average pump lift of wells serving each system. Variable pumping costs were calculated both with and without the costs of sprinkler pressurization using the following formulas:

$$VPCNP = FM * 2.35632 * [\,(\,2.31 * 14.3\,) + LIFT\,] * PF \tag{4.1}$$

$$VPCP = FM * 2.35632 * [\,(\,2.31 * OP\,) + LIFT\,] * PF \tag{4.2}$$

where

VPCNP = Variable pumping cost per system excluding sprinkler pressurization cost (dollars per acre-foot);

VPCP = Variable pumping cost per system including sprinkler pressurization cost (dollars per acre-foot);

FM = the fuel multiplier (0.011 for natural gas; 0.122 for LPG, 0.848 for electric; and 0.0728 for diesel and gasoline);

OP = Operating pressure in pounds per square inch (psi) required at the wellhead (14.3 psi for furrow and ditch systems; 32.5 psi for low pressure center pivot and linear move systems; 65.0 psi for high pressure center pivot systems, hand move systems, and side roll systems; and 17.5 psi for LEPA systems);

LIFT = Average pump lift (feet) of wells serving the system; and

PF = The price of the fuel used by the system (dollars per unit).

VPCNP is equivalent to the water price variable reported in Negri and Brooks (1990) and represents the energy cost of pumping one acre foot of groundwater to the surface. **VPCP** represents the cost of pumping water to the surface plus the additional energy cost of applying one acre-foot of water to the plant. This additional cost is zero for furrow irrigation, since furrow irrigation uses gravity to transport water to the field. Thus, the difference between **VPCP** and **VPCNP** represents the cost of sprinkler pressurization.

Most respondents answered Question C6 (e.g., give an average pump lift for each irrigation system operated). However, some irrigators were unable to provide complete information for Question C4 (e.g., fuel type and fuel cost). Some respondents provided only the fuel type without providing a fuel cost, while others left Question C4 blank. County average fuel costs were used for irrigators who provided only fuel type information, while the county average natural gas price was assumed for irrigators who left Question C4 blank. Average fuel prices were calculated based upon the county in which the irrigator's farm is located (Question A3 of the Central High Plains Irrigation Survey) and all available fuel price information from respondents in the same county.

Average pump lifts and variable pumping costs (with and without sprinkler pressurization) by irrigation method are reported for Southwest Kansas and the Northern Texas Panhandle in Table 21. The data in Table 21 reveals that pump lifts are deeper on average in the Northern Texas Panhandle. As a result, the cost of pumping water is greater on average for this subregion. Furrow and LEPA systems are placed in areas where pump lifts are deep, while sprinkler systems are placed in areas were pump lifts are shallow. This result may be partially due to the additional cost of pressurization associated with sprinkler irrigation ($3.98 and $3.08 per acre-foot for Southwest Kansas and the Northern Texas Panhandle, respectively).

LIFT and **VPCNP** were each used in separate logit model estimations to determine which variable best explains the effects of well depth on irrigation technology choice. Estimated coefficients for **VPCNP** were generally not significantly different from zero across equations. However, the estimated coefficients for **LIFT** were found to be significantly different from zero in many

TABLE 21

AVERAGE PUMP LIFT AND PUMP COST (WITH AND WITHOUT THE COST OF SPRINKLER PRESSURIZATION) BY IRRIGATION METHOD FOR SOUTHWEST KANSAS AND THE NORTHERN TEXAS PANHANDLE, 1994 CENTRAL HIGH PLAINS IRRIGATION SURVEY

Southwest Kansas					
Irrigation Method	Number of Observations	Average Pump Lift (feet)	Average Pump Cost Without Pressurization ($/ac ft)	Average Pump Cost With Pressurization ($/ac ft)	Sprinkler Pressurization Cost ($/ac ft)
Furrow	82	222	17.80	17.80	0.00
Improved Furrow	127	261	19.32	19.32	0.00
Sprinkler	306	208	16.85	20.83	3.98
LEPA	80	260	17.48	17.93	0.45
Subregion	595	228	17.59	19.70	2.11
Northern Texas Panhandle					
Irrigation Method	Number of Observations	Average Pump Lift (feet)	Average Pump Cost Without Pressurization ($/ac ft)	Average Pump Cost With Pressurization ($/ac ft)	Sprinkler Pressurization Cost ($/ac ft)
Furrow	39	363	23.24	23.24	0.00
Improved Furrow	29	367	23.00	23.00	0.00
Sprinkler	111	310	21.54	24.62	3.08
LEPA	61	374	24.55	25.01	0.46
Subregion	240	341	22.76	24.30	1.54

cases. Thus **LIFT** was used in place of **VPCNP** to explain the effects of well depth on irrigation technology choice.

Well Yields: Sprinkler and LEPA adoption are hypothesized to be inversely related to well yields (**WELLYLD**). Well yields (measured in gallons per minute) are a measure of water availability. With lower well yields, less water is available for pumping. Thus, irrigators are hypothesized to use water-conserving technologies in areas where water is scarce.

Information from Questions C5 and C7 of the Central High Plains Irrigation Survey was used to calculate well yields by system. Question C5 asked the irrigator to provide the number of wells serving each system, while Question C7 asked the irrigator to provide the total gallons per minute (GPM) from the wells serving the system. Well yields were calculated by dividing the total GPM per system by the average number of wells serving the system.

The average number of wells per system, the average GPM per system, and the average GPM per well by irrigation method are presented for Southwest Kansas and the Northern Texas Panhandle in Table 22. Average GPMs per system are similar in magnitude across irrigation methods in both subregions. However, the number of wells per system is larger by irrigation method in the Northern Texas Panhandle. Well yields are also smaller in the Northern Texas Panhandle. As a result of low well yields, many Northern Texas Panhandle irrigators link two or more wells to provide the GPM necessary for field irrigation.

TABLE 22

AVERAGE NUMBER OF WELLS PER SYSTEM, AVERAGE GALLONS PER MINUTE PER SYSTEM, AND AVERAGE GALLONS PER MINUTE PER WELL BY IRRIGATION METHOD IN SOUTHWEST KANSAS AND THE NORTHERN TEXAS PANHANDLE, 1994 CENTRAL HIGH PLAINS IRRIGATION SURVEY

Southwest Kansas				
Irrigation Method	Number of Observations	Average Wells Per System	Average GPM Per System	Average GPM Per Well
Furrow	85	1.2	912	845
Improved Furrow	136	1.2	1077	950
Sprinkler	319	1.1	759	738
LEPA	87	1.1	882	849
Subregion	627	1.1	866	814
Northern Texas Panhandle				
Irrigation Method	Number of Observations	Average Wells Per System	Average GPM Per System	Average GPM Per Well
Furrow	39	1.5	908	646
Improved Furrow	29	1.5	829	608
Sprinkler	111	1.3	845	673
LEPA	61	1.2	841	709
Subregion	240	1.3	852	670

<u>Acres Per Well:</u> Sprinkler and LEPA adoption are hypothesized to be positively related to the number of acres per well (**ACREWELL**). Sprinkler and LEPA technologies are more water saving than furrow technologies and allow the irrigator to irrigate more acres per well. Thus, irrigators with a large number of acres per well and declining water supplies may be more inclined to adopt sprinkler or LEPA technologies rather than reduce irrigated acres or drill additional wells.

Information from Questions C5 and C10 was used to calculate the number of acres per well by system. As mentioned above, Question C5 asked the irrigator to provide the number of wells serving each system, while Question C10 asked the irrigator to provide the number of acres per crop per system. The number of acres per crop per system was added across crops and divided by the total number of crops irrigated by each system to obtain the average number of acres irrigated by each system. The average number of acres per system was then divided by the number of wells serving the system to obtain the average number of acres per well.

The average number of wells per system, the average number of acres per system, and the average number of acres per well by irrigation method are reported for Southwest Kansas and the Northern Texas Panhandle in Table 23. More acres are irrigated per system on average in the Northern Texas Panhandle (133.3 versus 117.1 for Southwest Kansas). The average numbers of acres per well for sprinkler and LEPA systems are larger than the average numbers of acres per well for furrow and improved furrow systems in both subregions.

TABLE 23

AVERAGE NUMBER OF WELLS PER SYSTEM, AVERAGE NUMBER OF ACRES PER SYSTEM, AND AVERAGE NUMBER OF ACRES PER WELL BY IRRIGATION METHOD IN SOUTHWEST KANSAS AND THE NORTHERN TEXAS PANHANDLE, CENTRAL HIGH PLAINS IRRIGATION SURVEY

Irrigation Method	Number of Observations	Average Wells Per System	Average Acres Per System	Average Acres Per Well
Southwest Kansas				
Furrow	84	1.2	103.1	97.0
Improved Furrow	136	1.2	117.7	105.7
Sprinkler	318	1.1	117.2[a]	119.1
LEPA	86	1.1	129.4	128.2
Subregion	624	1.1	117.1	114.4
Northern Texas Panhandle				
Furrow	39	1.5	134.0	99.6
Improved Furrow	29	1.5	120.1	88.7
Sprinkler	109	1.3	134.4[a]	134.8
LEPA	61	1.2	137.1	120.7
Subregion	238	1.3	133.3	119.8

[a] Average acres per system are slightly smaller than average acres per well because of situations where two or more systems are served by only one well.

Irrigator and Farm Characteristics

This section identifies the explanatory variables associated with the irrigator and the farm. Variables in this category vary by irrigator rather than by field. Irrigator characteristics include age, education, and vocational/technical training dummy variables, while farm characteristics include the percent of rented to total irrigated cropland on each farm and a dummy variable indicating whether or not the farm has land in the Conservation Reserve Program (CRP).

Irrigator Age: Age is hypothesized to be negatively related to the adoption of water-conserving irrigation technologies. Many older irrigators have paid off most of their debt and may not be interested in taking on a 10 to 15 year loan to retire the debt on a new sprinkler or LEPA system. Older irrigators may also be oriented towards traditional modes of irrigation and may be reluctant to try new irrigation methods.

Question A4 of the Central High Plains Irrigation Survey asked the irrigator for his or her general age. The irrigator was given ten age ranges to choose from (less than 25 years, between 25 and 29 years, etc.). The total numbers of respondents in each age range are reported for Southwest Kansas and the Northern Texas Panhandle in Table 24. Most respondents in both subregions are at least 40 years old. Nearly half of the respondents in Southwest Kansas and over half of the respondents in the Northern Texas Panhandle are 55 years of age or older.

Three age dummy variables were created using the information from Question A4. These dummy variables are as follows:

AGELE40 = 1 if the irrigator is less than 40 years old; = 0 otherwise;

AGE4055 = 1 if the irrigator is between 40 and 55 years of age; = 0 otherwise;

AGEGE55 = 1 if the irrigator is 55 years or older; = 0 otherwise.

AGE4055 and **AGEGE55** will appear in the logit equations and will measure the log of the technology choice odds relative to **AGELE40**.

Irrigator Education and Vocational/Technical Training: Education and vocational/technical training are measures of human capital. Education is a measure of the number of years of formal schooling completed by the irrigator, while vocational/technical training represents any additional vocational training the irrigator may have received. Human capital variables like education and vocational/technical training enhance the irrigator's ability to obtain information and apply inductive reasoning in making farm decisions. The effects of such variables on irrigation technology adoption are unknown. Rahm and Huffman (1984) point out that adopting new technologies is not always economically feasible for farm operators, and that human capital variables such as education and vocational/technical training may not always enhance the adoption of new technologies. Thus, the effects of education and vocational/technical training on irrigation technology adoption can be positive or negative.

Question A6 of the Central High Plains Irrigation Survey asked for the irrigator's level of formal schooling. The irrigator was given a choice of five

TABLE 24

AGE RANGES FOR IRRIGATORS IN SOUTHWEST KANSAS AND THE NORTHERN TEXAS PANHANDLE, 1994 CENTRAL HIGH PLAINS IRRIGATION SURVEY

	Southwest Kansas		Northern Texas Panhandle	
Age Ranges	Number of Responses[a]	Percent of Sample	Number of Responses[b]	Percent of Sample
less than 25 years	0	0.0	0	0.0
between 25 and 29	4	2.1	1	1.5
between 30 and 34	9	4.7	0	0.0
between 35 and 39	12	6.3	4	6.1
between 40 and 44	31	16.2	5	7.6
between 45 and 49	22	11.5	10	15.2
between 50 and 54	22	11.5	11	16.7
between 55 and 59	21	11.0	7	10.6
between 60 and 64	21	11.0	16	24.2
65 or older	49	25.7	12	18.2

[a] Sample size in Southwest Kansas totaled 191 respondents.

[b] Sample size in the Northern Texas Panhandle totaled 66 respondents.

education ranges (e.g., less than 12 years of education, at least 12 but less than 14 years of education, etc.). Question A7 asked if the irrigator's education included any vocational/technical training. The number of irrigators in each education range and the number of irrigators with vocational/technical training are reported for Southwest Kansas and the Northern Texas Panhandle in Table 25. An education level of less than 14 years is assumed to be equivalent to a high school education. About 51 percent of the respondents in Southwest Kansas and 39 percent of the respondents in the Northern Texas Panhandle have less than 14 years of education. Approximately a third of the respondents in both subregions have had some sort of vocational/technical training.

Two education dummy variables and one vocational/technical training dummy variable were created using the information obtained from Questions A6 and A7. These dummy variables are as follows:

EDUCL14 = 1 if the irrigator has completed less than 14 years of formal schooling; = 0 otherwise;

EDUCG14 = 1 if the irrigator has completed 14 years or more of formal schooling; = 0 otherwise; and

VOCT = 1 if the irrigator's education included any vocational/technical training; = 0 otherwise.

EDUCG14 and **VOCT** will appear in the logit equations. **EDUCG14** will measure the log of the technology choice odds relative to **EDUCL14**.

TABLE 25

YEARS OF EDUCATION RANGES AND TOTAL NUMBER OF RESPONDENTS WITH VOCATIONAL TRAINING FOR IRRIGATORS IN SOUTHWEST KANSAS AND THE NORTHERN TEXAS PANHANDLE, 1994 CENTRAL HIGH PLAINS IRRIGATION SURVEY

	Southwest Kansas		Northern Texas Panhandle	
Education Ranges	Number of Responses[a]	Percent of Sample	Number of Responses[b]	Percent of Sample
less than 12 years	26	13.7	8	12.1
12 but less than 14	71	37.4	18	27.3
14 but less than 16	29	15.3	13	19.7
16 but less than 18	55	29.0	17	25.8
18 or more	9	4.7	10	15.2
Vocational/technical training	62	32.5	23	34.9

[a] Sample size in Southwest Kansas totaled 190 respondents for the education ranges and 191 respondents for the vocational/technical training variable.

[b] Sample size in the Northern Texas Panhandle totaled 66 respondents for both the education ranges and the vocational/technical variable.

<u>Farm Characteristics:</u> Two farm characteristic variables are used as explanatory variables in the logit models. These variables are defined as follows:

RENTIRR: The ratio of rented irrigated cropland to total cropland. This ratio is assumed to be negatively related to the adoption of water-conserving irrigation technologies. In many instances, the landlord may provide only the well and possibly the pump on rented land, while the tenant may be responsible for furnishing the irrigation system. The tenant may be more likely to use furrow systems on rented land in such situations, because furrow systems are cheaper to furnish than center pivot sprinkler systems or LEPA systems.

CRP: A zero/one dummy variable equal to one if the farm has land in the Conservation Reserve Program. The effect of **CRP** on irrigation technology adoption is unknown. Participating farmers place their lowest quality cropland (e.g., cropland highly susceptible to erosion) in the CRP and often grow crops on their remaining cropland. Cultivated cropland on participating farms may be lower in quality (e.g., sandy or hilly) than cultivated cropland on nonparticipating farms. Farms with land in the CRP may also have lower water availability (e.g., lower well yields) than farms without land in the CRP. Thus **CRP** may be positively related to the adoption of water-conserving irrigation methods like sprinkler and LEPA.

RENTIRR was calculated using data from Question B2 of the Central High Plains Irrigation Survey, while **CRP** was created using responses to Question B3

Farm characteristic statistics for Southwest Kansas irrigators and Northern Texas Panhandle irrigators are reported in Table 26. Regional differences are evident between the two subregions. The percent of irrigated cropland rented is greater on average for respondents in Southwest Kansas. However, Northern Texas Panhandle respondents on average operate more irrigated cropland and have more CRP acres per farm than Southwest Kansas respondents.

Information Sources

This section describes how information sources were incorporated into the logit analysis. Central High Plains irrigators have many sources of information available to them when choosing new irrigation technologies, including irrigation equipment dealers, private agricultural consulting firms, and friends and neighbors. Little is known about the information sources used most often or the effect of information sources on the adoption of water-conserving irrigation technologies.

Kromm and White (1991) used the results from their High Plains survey to identify the most widely used and accepted information sources among irrigators when choosing water-conserving management practices. The authors found that friends and neighbors were perceived to be the least reliable source of information to irrigators, while university extension services, private agricultural consulting firms, trade magazines, and local groundwater districts were perceived to be the most reliable information sources.

Question B4 of the Central High Plains Irrigation Survey asked irrigators to identify the information sources they use when choosing irrigation systems or water

TABLE 26

FARM CHARACTERISTIC STATISTICS FOR IRRIGATORS IN SOUTHWEST KANSAS AND THE NORTHERN TEXAS PANHANDLE, 1994 CENTRAL HIGH PLAINS IRRIGATION SURVEY

Subregion	Average Irrigated Cropland Owned (acres)[a]	Average Irrigated Cropland Rented (acres)[a]	Average Irrigated Cropland Farmed (acres)	Average Irrigated Cropland Rented (percent)	Total Farms with Land in CRP[b]	Average Land in the CRP (acres)[b]
Southwest Kansas	523.0	456.0	978.9	46.6	64	157.82
Northern Texas Panhandle	1087.6	552.3	1639.9	33.7	21	246.97

[a] Sample response sizes for owned and rented irrigated cropland in Southwest Kansas and the northern Texas Panhandle were 190 and 66, respectively.

[b] Sample response sizes for CRP farms, and CRP acres in Southwest Kansas and the Northern Texas Panhandle were 191 and 66, respectively.

management practices. The entire list of information sources and the number of irrigators who use each source are reported for Southwest Kansas and the Northern Texas Panhandle in Table 27. Irrigation equipment dealers and friends and neighbors are used by the majority of respondents in both subregions. Over 35 percent of the respondents in both subregions use the Soil Conservation Service as a source of information, followed by private consulting firms in Southwest Kansas (31.1 percent) and extension in the Northern Texas Panhandle (34.9 percent). Groundwater districts were fifth in terms of the number of respondents using this source of information. This result is surprising, because most survey respondents from both subregions have close ties with local groundwater districts.

Question B4 also asked irrigators for the information sources they use most often when choosing irrigation systems or water management practices. The results are summarized in Table 28. Friends and neighbors were the information source used most often by individual respondents in both subregions, followed by irrigation equipment dealers. Private agricultural consulting firms were the third most often used source of information in Southwest Kansas, while the Soil Conservation Service was the third most often used source of information in the Northern Texas Panhandle.

Data from Question B4 were used to construct a zero/one dummy variable for every information source listed in Tables 27 and 28. A dummy variable was created for each information source since irrigators often use more than one source of information. The information source dummy variables are defined as follows:

IRRDEALER	Irrigation equipment dealers;
PCF	Private agricultural consulting firms;
SCS	Soil Conservation Service;
EXTENSION	University Extension Service;
NEIGHBOR	Friends and neighbors;
PRINT	Trade magazines or other printed material;
CHD	Chemical dealers;
GDIST	Groundwater district;
OWNEXP	Irrigator's own experience; and
OTHINFO	Other information sources (e.g., tenants, university research stations, etc).

This concludes the discussion on the explanatory variables used in the multinomial logit analysis. The next chapter will present the results of a multinomial logit model of irrigation method adoption for the Central High Plains.

TABLE 27

INFORMATION SOURCES USED BY IRRIGATORS WHEN CHOOSING WATER CONSERVING IRRIGATION TECHNOLOGIES OR WATER MANAGEMENT PRACTICES IN SOUTHWEST KANSAS AND THE NORTHERN TEXAS PANHANDLE, 1994 CENTRAL HIGH PLAINS IRRIGATION SURVEY

	Southwest Kansas		Northern Texas Panhandle	
Type of Information	Number of Responses[a]	Percent of Sample	Number of Responses[b]	Percent of Sample
Extension	55	29.0	23	34.9
Irrigation dealers	142	74.7	47	71.2
Groundwater district	57	30.0	21	31.8
Private consultants	59	31.1	11	16.7
Chemical dealers	17	9.0	7	10.6
Soil Conservation Service	67	35.3	25	37.9
Friends and neighbors	139	73.2	53	80.3
Print	6	3.2	3	4.6
Own experience	17	9.0	5	7.6
Other	8	4.2	4	6.1

[a] Sample size in Southwest Kansas totaled 190 respondents.

[b] Sample size in the Northern Texas Panhandle totaled 66 respondents.

TABLE 28

MOST USED INFORMATION SOURCES BY IRRIGATORS WHEN ADOPTING WATER CONSERVING IRRIGATION TECHNOLOGIES OR WATER MANAGEMENT PRACTICES IN SOUTHWEST KANSAS AND THE NORTHERN TEXAS PANHANDLE, 1994 CENTRAL HIGH PLAINS IRRIGATION SURVEY

	Southwest Kansas		Northern Texas Panhandle	
Type of Information	Number of Responses[a]	Percent of Sample	Number of Responses[b]	Percent of Sample
Extension	4	2.3[c]	5	8.2[c]
Irrigation dealers	44	25.1	11	18.0
Groundwater district	4	2.3	1	1.6
Private consultants	34	19.4	3	4.9
Chemical dealers	3	1.7	0	0.0
Soil Conservation Service	13	7.4	9	14.8
Friends and neighbors	56	32.0	28	45.9
Print	4	2.3	1	1.6
Own experience	14	8.0	5	8.2
Other	5	2.9	2	3.3

[a] Sample size in Southwest Kansas totaled 175 respondents.

[b] Sample size in the Northern Texas Panhandle totaled 61 respondents.

[c] Sum of percentages is slightly greater than one for both subregions. A few irrigators identified more than one source of information as being used most often.

CHAPTER V

ESTIMATED MODEL AND MODEL RESULTS FOR THE CENTRAL HIGH PLAINS

Data for both Southwest Kansas and the Northern Texas Panhandle were merged to estimate a multinomial logit model for the entire Central High Plains region. A subregional dummy variable (KANSAS) was included as an explanatory variable to capture subregional differences in system preferences. The maximum likelihood estimates of the natural log of the odds of adopting water-conserving irrigation technologies in the Central High Plains are presented in Table 29. The first three columns of Table 29 are the parameter estimates for the J - 1 equations in (3.11) of Chapter III, while the last three columns are the parameter estimates for the set of equations in (3.14) of Chapter III. Unrestricted and restricted log likelihood estimates, a chi-square statistic, and the McFadden R^2 statistic for the model are also reported at the bottom of Table 29.

The chi-square test is a likelihood ratio test of the null hypothesis that all slope parameters are equal to zero. The chi-square test statistic is calculated as follows:

$$(4.3) \qquad LR = -2[L(\theta_r) - L(\theta_u)]$$

where

LR = The likelihood ratio which is distributed as a chi-square with T degrees of freedom;

$L(\theta_r)$ = The restricted log likelihood estimate of the model (slope parameters = 0); and

$L(\theta_u)$ = The unrestricted log likelihood estimate of the model.

The null hypothesis that all slope parameters equal zero is rejected if the calculated chi-square statistic is greater than a critical chi-square statistic with T degrees of freedom and some specified level of significance α. The total degrees of freedom (T) is equal to the number of restrictions imposed upon the model. The critical chi-square statistic for $T = 72$ and $\alpha = 0.005$ is approximately 104.215 and the calculated chi-square statistic is 535.30. Thus the null hypothesis of zero slope parameters is rejected at the 0.005 level of significance.

The McFadden R^2 statistic is closely related to the likelihood ratio test and is a measure for the "goodness of fit". This statistic is calculated as follows:

$$\text{(4.4)} \qquad \textit{McFadden } R^2 = 1 - \left(\frac{L(\theta_u)}{L(\theta_r)} \right)$$

where

$L(\theta_r)$ = The restricted log likelihood estimate of the model (slope parameters = 0); and

TABLE 29

MAXIMUM LIKELIHOOD ESTIMATES OF THE LOG OF THE ODDS OF ADOPTING WATER-CONSERVING IRRIGATION TECHNOLOGIES IN THE CENTRAL HIGH PLAINS

Variable	Improved Furrow Versus Furrow	Sprinkler Versus Furrow	LEPA Versus Furrow	Sprinkler Versus Improved Furrow	LEPA Versus Improved Furrow	LEPA Versus Sprinkler
WELLYLD	0.0003	-0.0020 ***	-0.0008 *	-0.0023 ***	-0.0011 ***	0.0012 ***
	(0.749)	(-4.809)	(-1.745)	(-6.030)	(-2.677)	(2.860)
LIFT	0.0047 ***	-0.0030 *	0.0033 *	-0.0077 ***	-0.0013	0.0064 ***
	(2.734)	(-1.957)	(1.777)	(-5.409)	(-0.771)	(4.435)
SAND	-0.0092	1.5300 ***	1.3783 ***	1.5392 ***	1.3875 ***	-0.1517
	(-0.027)	(5.054)	(3.436)	(5.636)	(3.728)	(-0.459)
CLAY	0.0485	-0.4232	0.9977 **	-0.4717	0.9492 **	1.4209 ***
	(0.143)	(-1.255)	(2.347)	(-1.506)	(2.395)	(3.734)
LSLOPE	0.2517	-0.5876 **	0.2643	-0.8393 ***	0.0125	0.8519 ***
	(0.866)	(-2.134)	(0.794)	(-3.401)	(0.041)	(3.140)
HSLOPE	0.5532	1.4854 ***	1.8320 ***	0.9322 *	1.2788 **	0.3466
	(0.816)	(2.585)	(2.859)	(1.852)	(2.253)	(0.924)
ACREWELL	0.0022	0.0165 ***	0.0158 ***	0.0143 ***	0.0136 ***	-0.0007
	(0.661)	(5.279)	(4.517)	(5.280)	(4.402)	(-0.310)

$L(\theta_u)$ = The unrestricted log likelihood estimate of the model.

The McFadden R^2 statistic for this model is 0.2613, which is similar to values reported by Negri and Brooks (1990) for sprinkler versus furrow irrigation (McFadden R^2 = .22) and Caswell and Zilberman (1985) for sprinkler and drip versus furrow irrigation (McFadden R^2 = .265).

Parameter Estimates for the Central High Plains Model

The estimated multinomial logit model in Table 29 contains 150 parameters including intercept terms. Of the 150 coefficients estimated, 47 are significant at the 0.01 level of significance, 15 are significant at the 0.05 level of significance, and 12 are significant at the 0.10 level of significance. Thus, a total of 74 parameters (49.3 percent) are significant at acceptable levels of significance.

The estimated coefficients generally conform to the hypotheses specified earlier. Coefficients for **WELLYLD** are negative and significantly different from zero for sprinkler and LEPA irrigation versus furrow and improved furrow irrigation, implying that sprinkler and LEPA technologies are more likely than furrow technologies to be used in areas where water is sparse. The LEPA versus sprinkler well yield coefficient is positive and significantly different from zero, implying that LEPA systems are more likely than sprinkler systems to be used in areas where water is abundant. One might expect the opposite to be true, since LEPA is more water-conserving than sprinkler irrigation. However, field trials indicate that LEPA crop yields are consistently higher than conventional center pivot sprinkler crop yields

TABLE 29 CONTINUED

Variable	Improved Furrow Versus Furrow	Sprinkler Versus Furrow	LEPA Versus Furrow	Sprinkler Versus Improved Furrow	LEPA Versus Improved Furrow	LEPA Versus Sprinkler
CRP	0.0096	0.9445 ***	0.7648 **	0.9348 ***	0.7551 **	-0.1797
	(0.031)	(3.348)	(2.276)	(3.571)	(2.406)	(-0.687)
RENTIRR	0.5507	0.5718	0.0736	0.0211	-0.4771	-0.4982
	(1.387)	(1.582)	(0.164)	(0.063)	(-1.134)	(-1.438)
AGE4054	-0.1414	0.3498	-0.8724 *	0.4912	-0.7310 *	-1.2222 ***
	(-0.306)	(0.797)	(-1.780)	(1.359)	(-1.770)	(-3.464)
AGEGE55	-0.4834	-0.3735	-1.6100 ***	0.1098	-1.1266 **	-1.2364 ***
	(-0.970)	(-0.802)	(-3.068)	(0.278)	(-2.466)	(-3.329)
EDUCG14	-0.5471 *	-0.6278 **	0.4319	-0.0807	0.9790 ***	1.0597 ***
	(-1.877)	(-2.293)	(1.279)	(-0.326)	(3.141)	(3.926)
VOCT	-0.5146 *	0.2158	0.1622	0.7304 **	0.6768 **	-0.0536
	(-1.664)	(0.782)	(0.482)	(2.570)	(2.007)	(-0.196)
IRRDEALER	1.1539 ***	1.5710 ***	3.4461 ***	0.4171	2.2922 ***	1.8751 ***
	(3.812)	(5.558)	(6.710)	(1.456)	(4.443)	(3.889)
PCF	1.0416 ***	0.8959 ***	0.7779 *	-0.1457	-0.2638	-0.1181
	(3.064)	(2.798)	(1.948)	(-0.538)	(-0.756)	(-0.377)

TABLE 29 CONTINUED

Variable	Improved Furrow Versus Furrow	Sprinkler Versus Furrow	LEPA Versus Furrow	Sprinkler Versus Improved Furrow	LEPA Versus Improved Furrow	LEPA Versus Sprinkler
SCS	0.1838	0.1784	-0.6496 *	-0.0054	-0.8334 **	-0.8280 ***
	(0.577)	(0.599)	(-1.704)	(-0.020)	(-2.324)	(-2.610)
EXTENSION	0.4079	0.2852	0.1534	-0.1227	-0.2545	-0.1318
	(1.252)	(0.929)	(0.402)	(-0.448)	(-0.723)	(-0.422)
NEIGHBOR	0.4201	-0.1750	-0.8909 **	-0.5952 *	-1.3110 ***	-0.7159 **
	(1.051)	(-0.518)	(-2.289)	(-1.801)	(-3.479)	(-2.525)
PRINT	-0.5013	-1.2693	-1.3677	-0.7680	-0.8663	-0.0983
	(-0.808)	(-1.635)	(-1.523)	(-1.085)	(-0.997)	(-0.102)
OWNEXP	0.4707	0.1225	1.2423 **	-0.3482	0.7717 *	1.1199 ***
	(1.006)	(0.282)	(2.505)	(-0.899)	(1.759)	(2.969)
GDIST	-0.2744	-0.5132	-0.3461	-0.2389	-0.0718	0.1671
	(-0.828)	(-1.638)	(-0.927)	(-0.882)	(-0.215)	(0.574)
CHD	-0.7730	-1.3581 ***	-0.5977	-0.5851	0.1753	0.7604
	(-1.601)	(-2.768)	(-1.053)	(-1.284)	(0.321)	(1.567)
OTHINFO	0.3603	-1.8091 ***	0.2553	-2.1694 ***	-0.1050	2.0644 ***
	(0.604)	(-3.084)	(0.438)	(-3.703)	(-0.185)	(4.204)

TABLE 29 CONTINUED

Variable	Improved Furrow Versus Furrow	Sprinkler Versus Furrow	LEPA Versus Furrow	Sprinkler Versus Improved Furrow	LEPA Versus Improved Furrow	LEPA Versus Sprinkler
KANSAS	1.0114 **	-0.4254	-0.2082	-1.4369 ***	-1.2196 ***	0.2173
	(2.532)	(-1.194)	(-0.487)	(-4.187)	(-2.997)	(0.658)
CONSTANT	-3.3629 ***	0.4286	-4.5111 ***	3.7915 ***	-1.1482	-4.9397 ***
	(-3.352)	(0.480)	(-4.010)	(4.407)	(-1.084)	(-5.481)
Number of Observations		827				
Log Likelihood		-756.49				
Log Likelihood (slope = 0)		-1024.13				
Chi-Sq (72 d.f.)		535.30				
McFadden R^2		0.2613				

[a] Numbers in parentheses are asymptotic t-statistics.

[b] *** = 0.01 significance level, ** = 0.05 significance level, and * = 0.10 significance level.

(Fipps and New, 1990). Thus LEPA irrigation may be more profitable than sprinkler irrigation where water is plentiful.

The pump lift coefficients (LIFT) indicate that LEPA and improved furrow technologies are more likely to be used in locations where pump lifts are large. Thus LEPA and improved furrow technologies appear to be energy-saving. The signs of the sprinkler pump lift coefficients indicate that the likelihood of adopting sprinkler irrigation decreases with increasing pump lifts. There are two possible reasons for this result. One is that sprinkler systems have higher operating pressures than improved furrow or LEPA systems and thus have higher water application costs at large pump lifts. However, a more likely possibility is that sprinkler systems are placed in areas with both low saturated thickness and shallow pump lifts. Saturated thickness is another measure of water availability and is positively related to well yields (Weeks, 1986). Areas with low saturated thickness would have low well yields but may not necessarily have deep pump lifts. The well yield coefficients indicate that sprinkler adoption is highly likely in areas with low well yields. Such areas may have shallow pump lifts.

The soil coefficients conform to previous expectations. They are not significant for improved furrow versus furrow irrigation because the two technologies are generally placed on fields with similar soil types. The sand coefficients indicate both sprinkler and LEPA irrigation are more likely than either furrow technology to be placed on sandy fields. Thus sprinkler and LEPA are water-conserving relative to furrow or improved furrow irrigation. LEPA also appears to be well suited for use on clay soils (the clay coefficients for LEPA versus furrow, improved furrow, and sprinkler irrigation are all positive and significantly different from zero). These results are probably due to the land management practices used in conjunction with LEPA irrigation (e.g., furrow diking and planting in a circle) which are aimed at reducing runoff (Fipps and New, 1990). Such practices make LEPA irrigation ideal for use on clay soils with a high potential for runoff.

The field slope coefficients also conform to previous expectations. They indicate that furrow and improved furrow technologies are more likely on low sloped fields, while sprinkler and LEPA technologies are more likely on high sloped fields. The slope coefficients are not significant for improved furrow versus furrow irrigation, implying both irrigation methods are typically placed on fields with similar slopes. However the **LSLOPE** coefficient for LEPA versus sprinkler is positive and significantly different from zero, indicating that LEPA systems are more likely than sprinkler systems on low sloped fields.

Coefficients for the number of acres per well (**ACREWELL**) are positive and significantly different from zero for sprinkler and LEPA irrigation versus furrow and improved furrow irrigation. These results indicate that irrigators with large numbers os acres per well are more likely to adopt sprinkler and LEPA technologies than furrow or improved furrow technologies.

The coefficients for **CRP** indicate that sprinkler and LEPA irrigation are more likely than either furrow method to be used on farms with land in the CRP. These results may occur because of lower land quality or lower water availability on farms with land in the CRP. None of the **RENTIRR** coefficients are significantly different from zero, implying that the amount of rented irrigated cropland on a farm has little impact on the likelihood of adopting water-conserving irrigation technologies in the Central High Plains.

The age coefficients are negative and significantly different from zero for LEPA versus furrow, improved furrow and sprinkler irrigation, implying that the likelihood of LEPA adoption decreases with age. This result may occur because of financial reasons, as mentioned earlier. Older farmers generally have most of their debt paid off and may not be willing to start new debt to purchase LEPA systems. Older farmers may also be oriented towards traditional methods of irrigation and may be reluctant to adopt LEPA technology.

Education also affects the likelihood of adopting LEPA technology. Higher education tends to increase the likelihood of adopting LEPA irrigation over improved furrow or sprinkler irrigation. Higher education has a negative impact on the likelihood of adopting sprinkler or improved furrow irrigation over furrow irrigation, while Vocational/technical training has a positive impact on the likelihood of adopting sprinkler and LEPA irrigation over improved furrow irrigation.

Irrigation equipment dealers appear to be the most influential information source affecting the adoption of water-conserving irrigation technologies in the Central High Plains. The **IRRDEALER** coefficients are positive and significantly different from zero for every relationship except sprinkler versus furrow irrigation. Private agricultural consulting firms (**PCF**) tend to increase the likelihood of adopting improved furrow, sprinkler, and LEPA irrigation over furrow irrigation, although the **PFC** coefficient for the latter information source is significantly different from zero at only the .10 level.

Irrigators who depend on their own farming experience (**OWNEXP**) appear to have a greater likelihood of adopting LEPA technology, conforming to findings by Kromm and White (1991). However, friends and neighbors (**NEIGHBOR**) appear to have a negative impact on the likelihood of adopting water conserving irrigation technologies such as sprinkler and LEPA irrigation. This result is expected, since irrigators who rely heavily on friends and neighbors tend to be oriented towards traditional technologies and are thought to lag behind others in adopting new technologies (Rogers, 1962). Use of the Soil Conservation Service (**SCS**) as an information source appears to have a negative effect on the likelihood of adopting LEPA irrigation, while use of chemical dealers (**CHD**) and "other information sources (**OTHINFO**) appears to have a negative effect on the likelihood of adopting sprinkler irrigation. Groundwater districts (**GDIST**), printed materials (**PRINT**), and extension appear to have little impact on the likelihood of adopting water-conserving irrigation technologies in the Central High Plains.

Differences in location appear to influence irrigation technology adoption in the Central High Plains. The coefficients for **KANSAS** are significant for every relationship involving improved furrow irrigation, and the signs for **KANSAS** indicate that the likelihood of adopting improved furrow irrigation is greatest in Southwest Kansas. These findings imply a greater preference for improved furrow irrigation in Southwest Kansas and conform to findings presented in Chapter IV. Differences in soil types, aquifer characteristics (water availability and depths to water), or information flows (e.g., knowledge of the LEPA concept in the Texas Panhandle) between the two subregions may explain why improved furrow irrigation is more prevalent in Southwest Kansas than in the Northern Texas Panhandle.

Predicted Irrigation Method Adoption Probabilities by Soil Type and Field Slope in the Central High Plains

Predicted irrigation method adoption probabilities by soil type and slope are presented for the Central High Plains region in Table 30. The probabilities were calculated using equations (3.12) and (3.13) in Chapter III. The probabilities were estimated by setting the binary variables of interest equal to zero or one and holding all other explanatory variables constant at their mean levels. For example, irrigation method adoption probabilities for sandy soils were calculated by setting **SAND** equal to one and **CLAY** equal to zero. The mean levels of the explanatory variables are presented in Table 56 of Appendix B.

Soil type greatly impacts irrigation method adoption probabilities. Sprinkler adoption probabilities decline as soils become heavier in texture. The probability of adopting sprinkler irrigation is greatest on sandy fields and smallest on clay fields. Furrow and improved furrow adoption probabilities are similar because both irrigation methods are used on the same soil types. Adoption probabilities for both furrow technologies are greatest on loam and clay fields and smallest on sandy fields. The probability of LEPA adoption is greatest on clay fields. This result is probably due to the field practices used in conjunction with LEPA irrigation (e.g., furrow diking and planting in a circle) which are aimed at reducing field runoff.

Slope also greatly affects the probabilities of irrigation method adoption.

TABLE 30

PREDICTED PROBABILITIES OF IRRIGATION METHOD ADOPTION BY SOIL TYPE AND SLOPE, CENTRAL HIGH PLAINS REGION

	Irrigation Method			
Soil and Slope	Furrow	Improved Furrow	Sprinkler	LEPA
Sand	0.071	0.086	0.747	0.096
Loam	0.206	0.253	0.470	0.070
Clay	0.212	0.274	0.317	0.197
High slope	0.035	0.065	0.760	0.140
Medium slope	0.132	0.140	0.645	0.084
Low slope	0.169	0.231	0.460	0.140
Sand, high slope	0.017	0.030	0.846	0.107
Sand, medium slope	0.069	0.072	0.789	0.070
Sand, low slope	0.099	0.134	0.634	0.132
Loam, high slope	0.065	0.119	0.712	0.104
Loam, medium slope	0.208	0.220	0.518	0.054
Loam, low slope	0.245	0.333	0.339	0.082
Clay, high slope	0.069	0.133	0.497	0.301
Clay, medium slope	0.225	0.250	0.367	0.158
Clay, low slope	0.236	0.336	0.213	0.215
Region	0.132	0.163	0.593	0.112

Sprinkler adoption probabilities fall as field slopes decline. The two furrow methods once again have similar adoption probabilities under different field slopes. However, improved furrow adoption probabilities are slightly larger than those of furrow irrigation, indicating that improved furrow is better at reducing water runoff. LEPA adoption probabilities are equal on both high and low sloped fields and are smallest on medium sloped fields.

The effects of soil/slope combinations on irrigation method adoption probabilities are also shown in Table 30. Sprinkler adoption probabilities are smallest on loam and clay fields with low slopes, where furrow and improved furrow adoption probabilities are greatest. LEPA adoption probabilities are smallest on sandy and loam soils with medium slopes and largest on clay fields with high slopes. LEPA adoption probabilities are also relatively large on clay fields with low slopes. Thus, LEPA irrigation appears to compete with furrow irrigation on clay fields.

Predicted Irrigation Method Adoption Probabilities by Pump Lift in the Central High Plains

The effects of increasing pump lift on irrigation method adoption in the Central High Plains are shown in Figure 1. The adoption probabilities in Figure 1 were calculated by parameterizing pump lifts upward in 20 foot increments from approximately one standard deviation below the mean pump lift to one standard deviation above the mean pump lift. These adoption probabilities are presented in Table 58 of Appendix B.

Increasing pump lifts have the greatest positive effect on the probability of

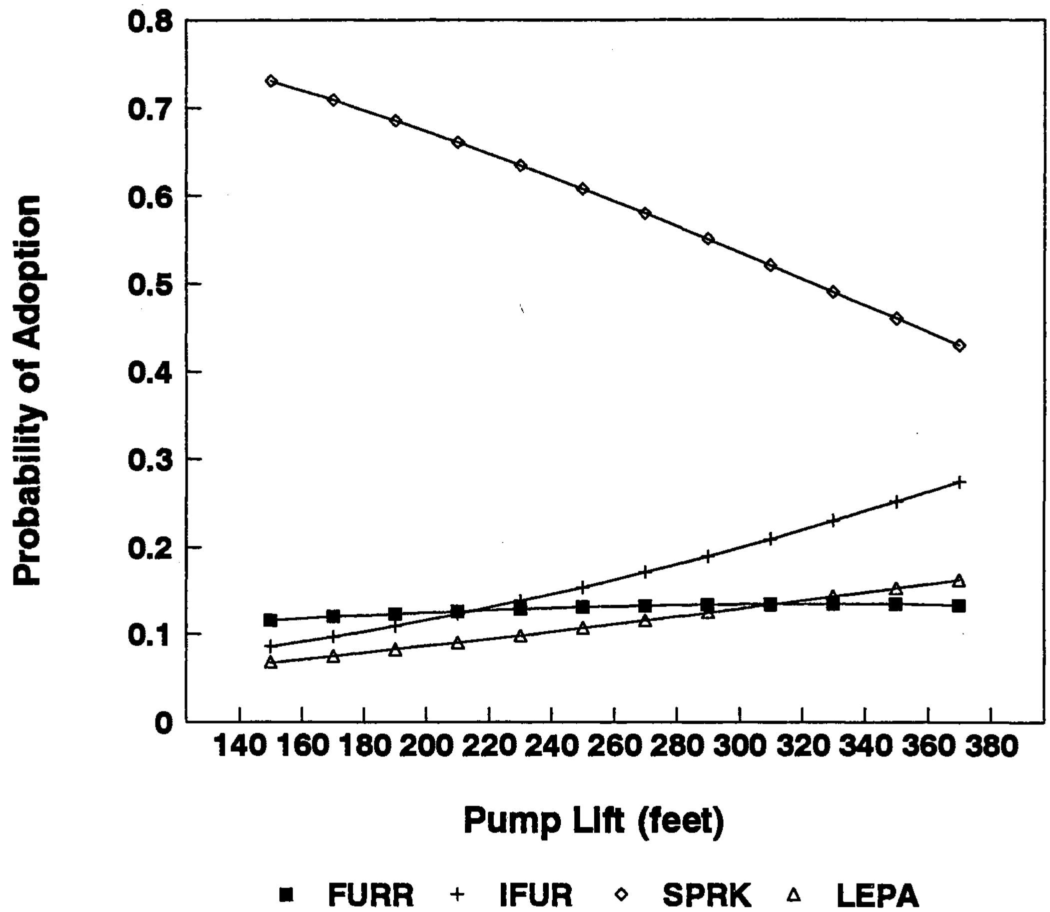

Figure 1. Predicted Probabilities of Irrigation Method Adoption by Pump Lift, Central High Plains Region

adopting improved furrow irrigation and the greatest negative effect on the probability of adopting sprinkler irrigation. Again, one might conclude that improved furrow irrigation is less energy intensive than sprinkler irrigation. However, sprinkler adoption may be more probable in areas with both low well yields and shallow pump lifts, as was mentioned earlier. The probability of adopting LEPA irrigation increases with higher pump lifts, implying that LEPA irrigation is energy-saving. Increasing pump lifts have little impact on furrow adoption probabilities.

Pump Lift Effects on Irrigation Method Adoption by Soil Type and Field Slope in the Central High Plains

The previous section presented irrigation method adoption probabilities by pump lift holding all other variables constant. However, the pump lift effect on irrigation method adoption can vary by location in the Central High Plains because of different soil types and field slopes across the region. The effects of increasing pump lifts on irrigation method adoption by soil type and field slope in the Central High Plains are shown in Table 31. Adoption probabilities are predicted for the maximum and minimum pump lifts presented in Table 58 of Appendix B. The differences reported in Table 31 represent the effect of increasing pump lifts on irrigation method adoption for different soil types and field slopes.

Increasing pump lifts have the greatest positive impact on the probability of adopting improved furrow irrigation and the greatest negative impact on the probability of adopting sprinkler irrigation in the Central High Plains as was shown in the previous section (see bottom line of Table 31). However, the pump lift effect for

TABLE 31

PUMP LIFT EFFECTS ON IRRIGATION METHOD ADOPTION BY SOIL TYPE AND FIELD SLOPE IN THE CENTRAL HIGH PLAINS

Soil and Slope	Pump Lift (feet)	Irrigation Method			
		Furrow	Improved Furrow	Sprinkler	LEPA
Sand, Low Slope	150	0.086	0.069	0.767	0.079
	370	0.103	0.230	0.470	0.197
	Difference	0.017	0.161	-0.296	0.118
Sand, Medium Slope	150	0.054	0.034	0.873	0.038
	370	0.080	0.140	0.662	0.118
	Difference	0.026	0.106	-0.212	0.080
Sand, High Slope	150	0.013	0.014	0.916	0.057
	370	0.020	0.061	0.733	0.185
	Difference	0.007	0.047	-0.183	0.129
Clay, Low Slope	150	0.267	0.227	0.338	0.168
	370	0.187	0.445	0.122	0.246
	Difference	-0.079	0.218	-0.217	0.078
Clay, Medium Slope	150	0.226	0.149	0.516	0.109
	370	0.199	0.367	0.233	0.201
	Difference	-0.027	0.218	-0.283	0.091
Clay, High Slope	150	0.066	0.075	0.661	0.198
	370	0.064	0.205	0.330	0.402
	Difference	-0.002	0.129	-0.331	0.204
Loam, Low Slope	150	0.251	0.204	0.487	0.058
	370	0.211	0.477	0.209	0.102
	Difference	-0.040	0.274	-0.277	0.044
Loam, Medium Slope	150	0.189	0.119	0.658	0.034
	370	0.204	0.358	0.363	0.076
	Difference	0.015	0.239	-0.295	0.042
Loam, High Slope	150	0.054	0.059	0.828	0.060
	370	0.070	0.214	0.553	0.163
	Difference	0.016	0.155	-0.275	0.103
Region	150	0.116	0.086	0.730	0.068
	370	0.133	0.275	0.430	0.162
	Difference	0.017	0.189	-0.301	0.094

these irrigation methods varies by soil type and field slope. The positive pump lift effect on improved furrow adoption is largest on loam and clay fields with low to medium slopes. These are the areas where improved furrow irrigation has the highest adoption probabilities. The negative pump lift effect on sprinkler adoption is greatest on clay fields with high slopes, sandy fields with low slopes, and loam fields with medium slopes. The pump lift effect on LEPA adoption is always positive and is greatest on clay fields with high slopes. The pump lift effect on furrow adoption is small on sandy fields and loam fields with medium to high slopes. However, the pump lift effect on furrow adoption is negative on clay fields and loam fields with low slopes.

Predicted Irrigation Method Adoption Probabilities by Well Yield in the Central High Plains

The effect of increasing well yields on irrigation method adoption in the Central High Plains are shown in Figure 2. The adoption probabilities in Figure 2 were calculated by parameterizing well yields upward in 50 GPM increments from approximately one standard deviation below the mean well yield to one standard deviation above the mean well yield. These adoption probabilities are shown in Table 61 of Appendix B.

As with pump lift, well yields appear to have the greatest impact on improved furrow and sprinkler adoption. Sprinkler adoption probabilities decrease with increasing well yields, while improved furrow adoption probabilities increase with increasing well yields. Higher well yields also increase the probability of adopting

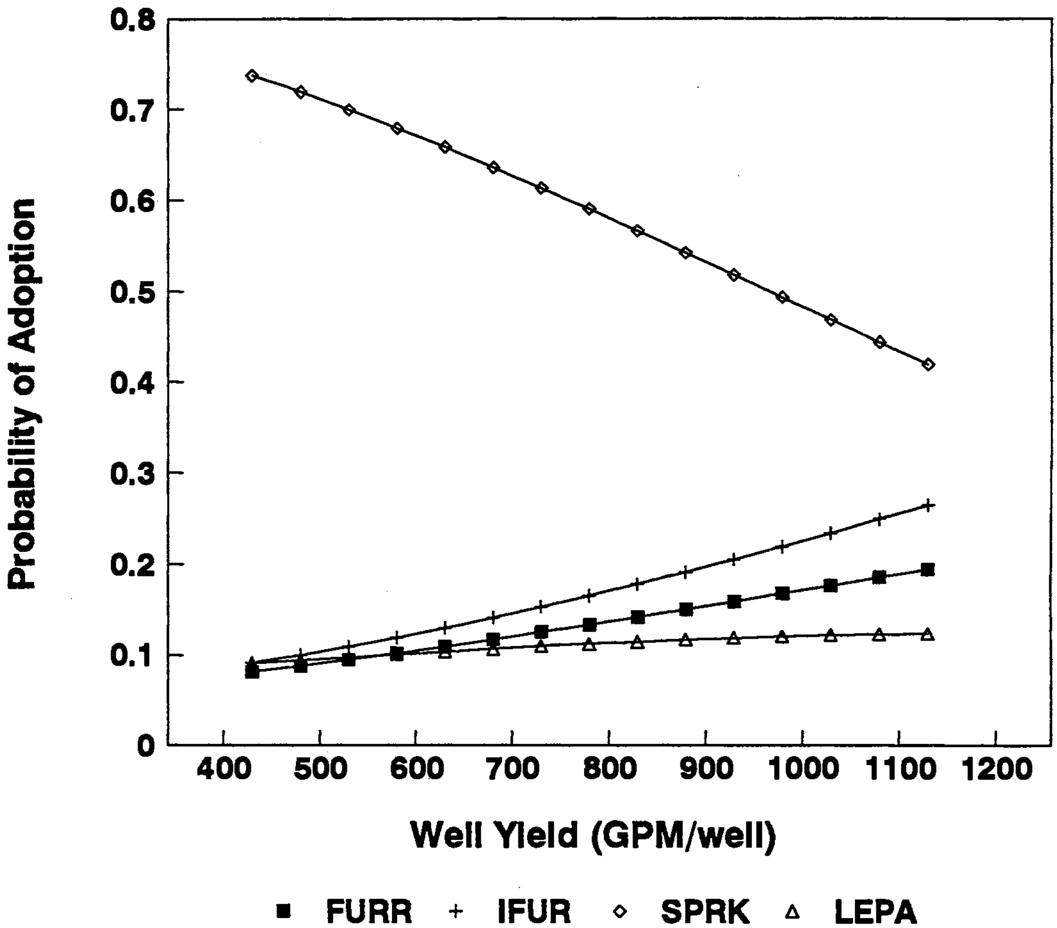

Figure 2. Predicted Probabilities of Irrigation Method Adoption by Well Yield, Central High Plains Region

furrow irrigation. These results imply that furrow and improved furrow adoption are more probable in areas where water is abundant, while sprinkler adoption is more probable in areas where water is sparse. Increasing pump lifts have little effect on LEPA adoption probabilities.

Well Yield Effects on Irrigation Method Adoption by Soil Type and Field Slope in the Central High Plains

The effects of increasing well yields on irrigation method adoption by soil type and field slope in the Central High Plains are presented in Table 32. Adoption probabilities are predicted for the maximum and minimum well yields in Table 59 of Appendix B. The differences reported in Table 32 represent the effect of increasing well yields on irrigation method adoption for different soil types and field slopes.

Increasing well yields have the greatest positive impact on improved furrow irrigation and the greatest negative impact on sprinkler irrigation, as was pointed out in the previous section. The positive well yield effect on improved furrow adoption is greatest on loam fields with low to medium slopes and clay fields with low to medium slopes. The negative effect of well yields on sprinkler adoption is greatest on loam fields with low to medium slopes, clay fields with medium slopes, and sandy fields with low slopes. The well yield effect on furrow adoption is always positive and is greatest on loam and clay fields with medium slopes and loam fields with low slopes. Increasing well yields have both a positive and a negative impact on LEPA adoption. The greatest positive impact occurs on clay fields with high slopes and the greatest negative impact occurs on clay fields with low slopes.

TABLE 32

WELL YIELD EFFECTS ON IRRIGATION METHOD ADOPTION BY SOIL TYPE AND FIELD SLOPE IN THE CENTRAL HIGH PLAINS

Soil and Slope	Well Yield (GPM)	Irrigation Method			
		Furrow	Improved Furrow	Sprinkler	LEPA
Sand, Low Slope	430	0.059	0.072	0.764	0.104
	1130	0.152	0.226	0.469	0.152
	Difference	0.093	0.154	-0.296	0.048
Sand, Medium Slope	430	0.038	0.036	0.876	0.051
	1130	0.118	0.137	0.655	0.091
	Difference	0.080	0.101	-0.221	0.040
Sand, High Slope	430	0.009	0.015	0.903	0.074
	1130	0.031	0.062	0.758	0.149
	Difference	0.022	0.048	-0.145	0.075
Clay, Low Slope	430	0.188	0.243	0.344	0.225
	1130	0.270	0.426	0.118	0.185
	Difference	0.083	0.183	-0.226	-0.040
Clay, Medium Slope	430	0.161	0.162	0.530	0.148
	1130	0.283	0.346	0.222	0.149
	Difference	0.122	0.185	-0.307	0.000
Clay, High Slope	430	0.043	0.076	0.631	0.250
	1130	0.101	0.215	0.351	0.332
	Difference	0.058	0.140	-0.280	0.082
Loam, Low Slope	430	0.183	0.225	0.511	0.081
	1130	0.292	0.439	0.195	0.074
	Difference	0.110	0.214	-0.316	-0.007
Loam, Medium Slope	430	0.136	0.131	0.687	0.046
	1130	0.281	0.328	0.337	0.054
	Difference	0.144	0.197	-0.349	0.008
Loam, High Slope	430	0.037	0.062	0.823	0.079
	1130	0.105	0.213	0.556	0.127
	Difference	0.068	0.151	-0.267	0.048
Region	430	0.081	0.091	0.737	0.090
	1130	0.193	0.264	0.419	0.123
	Difference	0.112	0.173	-0.318	0.032

Predicted Irrigation Method Adoption Probabilities by the Number of Acres Per Well in the Central High Plains

Predicted irrigation method adoption probabilities by the number of acres per well in the Central High Plains are shown graphically in Figure 3. The adoption probabilities in Figure 3 were calculated by parameterizing the number of acres per well upward in 10 acre increments from approximately one standard deviation below the mean number of acres per well to one standard deviation above the mean number of acres per well. These adoption probabilities are shown in Table 60 of Appendix B. The probabilities of adopting sprinkler and LEPA irrigation increase as the number of acres per well increases. The opposite is true for furrow and improved furrow adoption probabilities. These results imply that irrigators with large numbers of acres per well and declining water supplies are more likely to adopt sprinkler or LEPA technologies rather than reduce irrigated area or drill additional wells.

Predicted Irrigation Method Adoption Probabilities by Age, Education, and Vocational/Technical Training in the Central High Plains

Predicted irrigation method adoption probabilities by irrigator age in the Central High Plains are presented in Table 33. Irrigators between 40 and 55 years of age have the highest probability of adopting sprinkler irrigation. Irrigators less than 40 years of age have the highest probability of adopting LEPA irrigation, while irrigators greater than 55 years of age have the highest probability of adopting furrow irrigation. Age appears to have little effect on the adoption of improved furrow

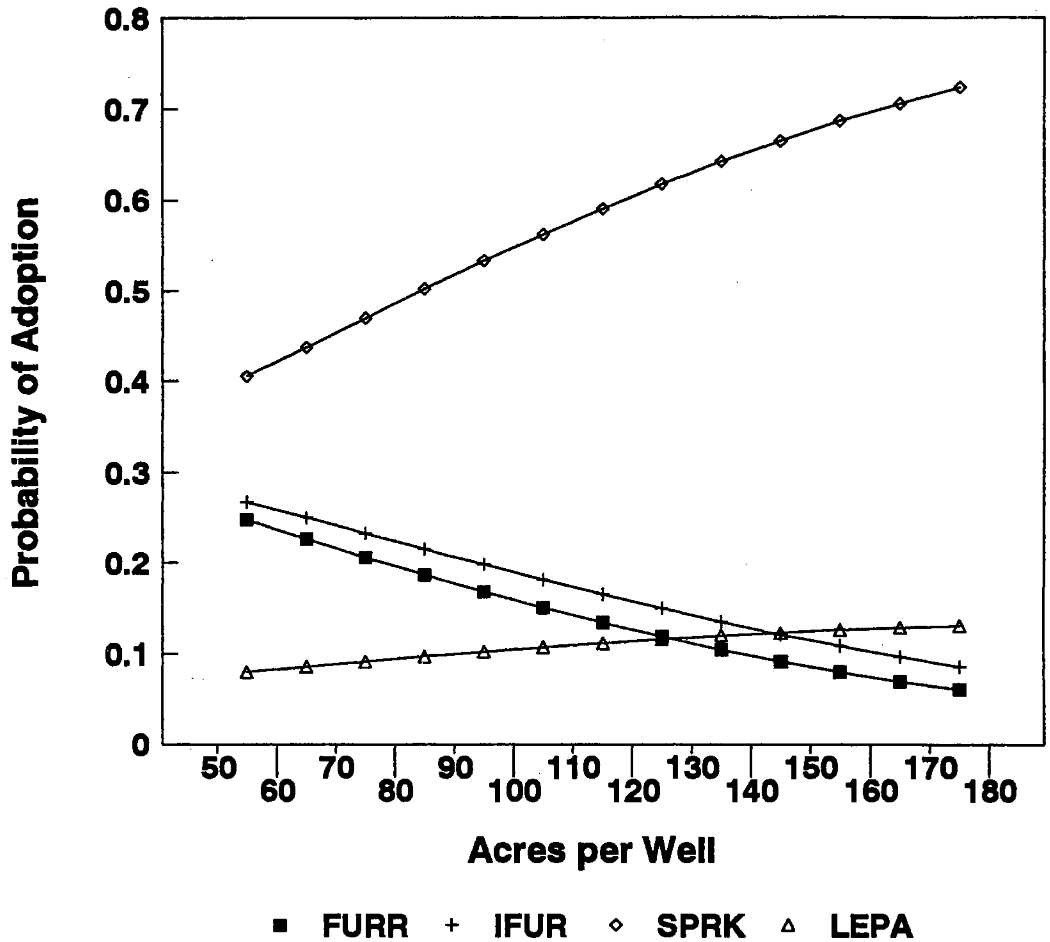

Figure 3. Predicted Probabilities of Irrigation Method Adoption by Number of Acres Per Well, Central High Plains Region

TABLE 33

PREDICTED PROBABILITIES OF IRRIGATION METHOD ADOPTION BY IRRIGATOR AGE, CENTRAL HIGH PLAINS REGION

	Irrigation Method			
Irrigator Age	Furrow	Improved Furrow	Sprinkler	LEPA
Less than 40 years	0.100	0.166	0.471	0.263
Between 40 and 55 years	0.098	0.141	0.654	0.107
Greater than 55 years	0.173	0.177	0.560	0.091
Region	0.132	0.163	0.593	0.112

irrigation.

Predicted irrigation method adoption probabilities by irrigator education in the Central High Plains are shown in Table 34. Irrigators with more than 14 years of formal schooling have a highest probabilities of adopting LEPA and furrow irrigation, while irrigators with less than 14 years of formal schooling have the highest probability of adopting sprinkler irrigation. Education has little effect on the probability of adopting improved furrow irrigation. These results imply that more education increases the probability of adopting LEPA irrigation but does not necessarily increase the probability of adopting other water-conserving irrigation technologies (e.g., sprinkler and improved furrow irrigation).

Predicted irrigation method adoption probabilities for irrigators with and without vocational/technical training are presented in Table 35. Vocational/technical training has little effect on the probabilities of adopting furrow or LEPA irrigation but does affect improved furrow and sprinkler adoption probabilities. The presence of vocational/technical training increases the probability of adopting sprinkler irrigation and decreases the probability of adopting improved furrow irrigation.

Predicted Irrigation Method Adoption Probabilities by Farm Characteristic in the Central High Plains

Irrigation method adoption probabilities by the percent of irrigated cropland rented in the Central High Plains are presented graphically in Figure 4. These adoption probabilities are also show in Table 59 of Appendix B. The amount of rented irrigated cropland in a farming operation has a slight positive effect on

TABLE 34

PREDICTED PROBABILITIES OF IRRIGATION METHOD ADOPTION BY IRRIGATOR EDUCATION, CENTRAL HIGH PLAINS REGION

	Irrigation Method			
Irrigator Education:	Furrow	Improved Furrow	Sprinkler	LEPA
Greater than 14 years	0.158	0.151	0.526	0.165
Less than 14 years	0.105	0.172	0.652	0.071
Difference	0.054	-0.022	-0.126	0.094
Region	0.132	0.163	0.593	0.112

TABLE 35

PREDICTED PROBABILITIES OF IRRIGATION METHOD ADOPTION WITH AND WITHOUT VOCATIONAL/TECHNICAL TRAINING, CENTRAL HIGH PLAINS REGION

Vocational/Technical Training:	Irrigation Method			
	Furrow	Improved Furrow	Sprinkler	LEPA
Yes	0.125	0.109	0.648	0.118
No	0.134	0.197	0.561	0.108
Difference	-0.009	-0.087	0.087	0.010
Region	0.132	0.163	0.593	0.112

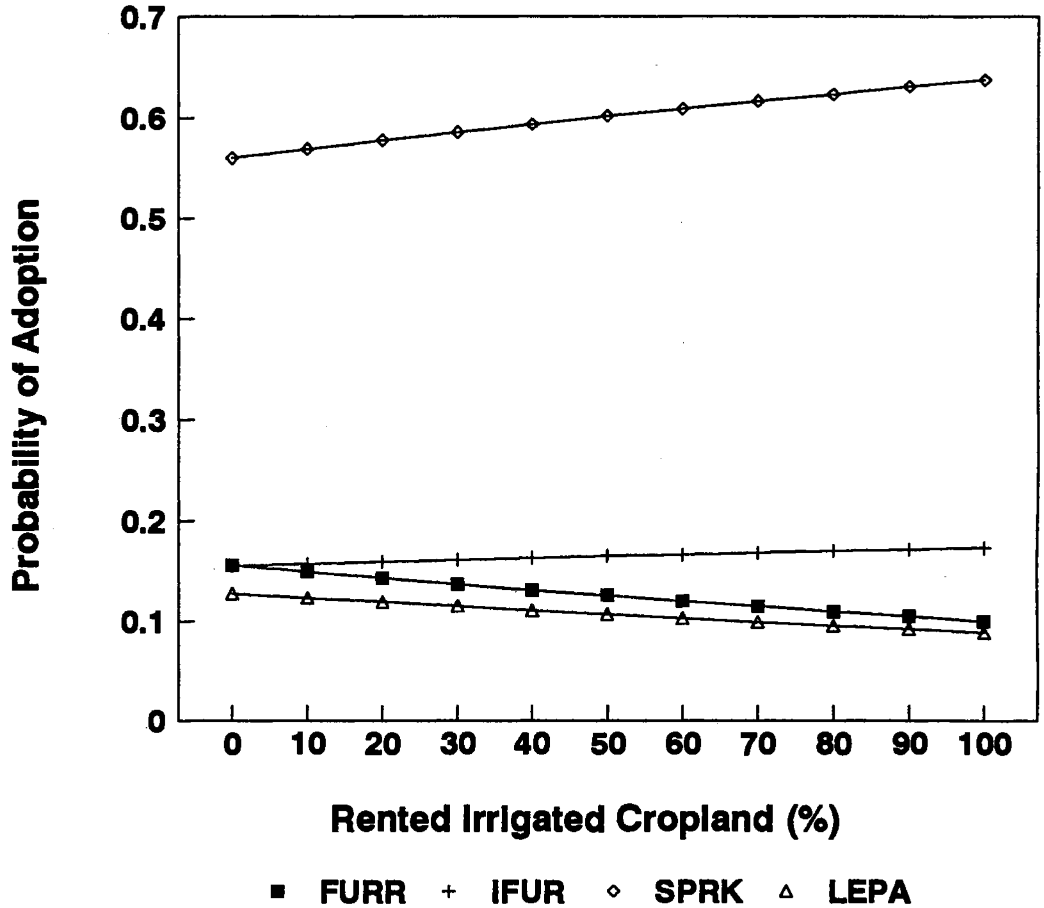

Figure 4. Predicted Probabilities of Irrigation Method Adoption by Percent of Irrigated Cropland Rented, Central High Plains Region

sprinkler adoption probabilities and a slight negative effect on LEPA and furrow adoption probabilities. However, the amount of rented irrigated cropland on a farm appears to have little effect on irrigation method adoption in general in the Central High Plains.

Irrigation method adoption probabilities for Central High Plains farms with and without land in the CRP are presented in Table 36. Farms with land in the CRP have the highest probability of adopting sprinkler irrigation, while farms without land in the CRP have the highest probability of adopting either furrow or improved furrow irrigation.

Predicted Irrigation Method Adoption Probabilities by Information Source in the Central High Plains

Predicted irrigation method adoption probabilities for Central High Plains irrigators who use only one source of information are shown in Table 37. Adoption probabilities in Table 37 provide a measure of the relative importance of each information source to irrigation method adoption. Sprinkler adoption probabilities are greatest for irrigators using private agricultural consulting firms, irrigation equipment dealers, the Soil Conservation Service, or extension as their information source. Furrow adoption probabilities also tend to be smallest for these information sources. Thus irrigation equipment dealers, private agricultural consulting firms, the Soil Conservation Service, and extension appear to promote the use of sprinkler irrigation over furrow irrigation in the Central High Plains. LEPA adoption probabilities are greatest for irrigators using irrigation equipment dealers or their own personal

TABLE 36

PREDICTED PROBABILITIES OF IRRIGATION METHOD ADOPTION WITH AND WITHOUT ACRES IN THE CONSERVATION RESERVE PROGRAM, CENTRAL HIGH PLAINS REGION

	Irrigation Method			
Acres in the CRP:	Furrow	Improved Furrow	Sprinkler	LEPA
Yes	0.083	0.103	0.698	0.116
No	0.162	0.200	0.532	0.106
Difference	-0.079	-0.097	0.166	0.010
Region	0.132	0.163	0.593	0.112

TABLE 37

PREDICTED PROBABILITIES OF IRRIGATION METHOD ADOPTION ASSUMING THE IRRIGATOR USES ONLY ONE INFORMATION SOURCE, CENTRAL HIGH PLAINS REGION

	Irrigation Method			
Information Source	Furrow	Improved Furrow	Sprinkler	LEPA
Irrigation Dealers	0.071	0.061	0.556	0.312
Private Consulting Firms	0.165	0.126	0.658	0.050
Friends and Neighbors	0.353	0.145	0.482	0.020
Soil Conservation Service	0.299	0.097	0.582	0.022
Extension	0.268	0.109	0.579	0.044
Groundwater District	0.439	0.090	0.427	0.043
Print	0.604	0.099	0.276	0.022
Own Experience	0.266	0.115	0.489	0.129
Chemical Dealers	0.617	0.077	0.258	0.048
Other Information Sources	0.545	0.211	0.145	0.099
Region	0.132	0.163	0.593	0.112

experience and smallest for irrigators using friends and neighbors, printed materials, or the Soil Conservation Service. Improved furrow adoption probabilities are greatest for irrigators who use friends and neighbors or private agricultural consulting firms as information sources, while furrow adoption probabilities are greatest for irrigators using chemical dealers or printed materials as information sources.

The adoption probabilities in Table 37 are based on the assumption that irrigators uses only one source of information when making irrigation technology adoption decisions. However, most respondents to the Central High Plains Irrigation Survey use an average of approximately three information sources. The majority of respondents use irrigation equipment dealers and/or friends and neighbors (see Table 27 in Chapter IV). Thus, most Central High Plains irrigators probably use irrigation equipment dealers, friends and neighbors, and one additional source of information when making irrigation method adoption decisions.

Irrigation method adoption probabilities for irrigators who use irrigation equipment dealers, friends and neighbors, and one additional source of information are presented in Table 38. The probability of adopting sprinkler irrigation is greatest when the additional information source is the Soil Conservation Service, private agricultural consulting firms, no other information source, or extension. These information sources also tend to result in the lowest furrow adoption probabilities. Thus, private agricultural consulting firms, the Soil Conservation Service, and extension appear to promote the use of sprinkler irrigation over furrow irrigation when combined with both irrigation equipment dealers and friends and neighbors. The probability of adopting LEPA irrigation is greatest for irrigators who use either

TABLE 38

PREDICTED PROBABILITIES OF IRRIGATION METHOD ADOPTION ASSUMING THE IRRIGATOR USES IRRIGATION DEALERS, FRIENDS AND NEIGHBORS, AND A THIRD INFORMATION SOURCE, CENTRAL HIGH PLAINS REGION

	Irrigation Method			
Use Irrigation Dealers, Friends and Neighbors, and:	Furrow	Improved Furrow	Sprinkler	LEPA
No Other Information Source	0.094	0.122	0.615	0.169
Private Consulting Firms	0.040	0.150	0.651	0.159
Soil Conservation Service	0.088	0.138	0.691	0.083
Extension	0.072	0.142	0.633	0.152
Groundwater District	0.139	0.138	0.546	0.177
Print	0.244	0.193	0.451	0.112
Own Experience	0.060	0.125	0.443	0.373
Chemical Dealers	0.234	0.141	0.394	0.232
Other Information Sources	0.159	0.298	0.172	0.371
Region	0.132	0.163	0.593	0.112

their own personal experience, "other information sources", or chemical dealers as their third information source. The probability of adopting improved furrow irrigation is greatest when the third information source is either "other information sources" or printed materials, while the probability of adopting furrow irrigation is greatest when the third information sources is printed materials or chemical dealers.

Predicted Irrigation Method Adoption Probabilities by Location in the Central High Plains

Irrigation method adoption probabilities by subregional location in the Central High Plains are reported in Table 39. The adoption probabilities are calculated at the means of the explanatory variables within each subregion. Data in Table 39 reveals distinct differences in predicted adoption probabilities between the two subregions. Furrow and sprinkler adoption probabilities are similar across subregions, while improved furrow and LEPA adoption probabilities vary in opposite directions. Thus the model predicts that Southwest Kansas irrigators place higher emphasis on improved furrow irrigation, while irrigators in the Northern Texas Panhandle place higher emphasis on LEPA irrigation.

Important Irrigation Technology Adoption Factors Identified by Irrigators in the Central High Plains

The previous sections have shown how field characteristics, irrigator and farm characteristics, and information sources affect the probability of adopting water-

TABLE 39

PREDICTED PROBABILITIES OF IRRIGATION METHOD ADOPTION BY LOCATION, CENTRAL HIGH PLAINS

Location	Furrow	Improved Furrow	Sprinkler	LEPA
Southwest Kansas	0.124	0.194	0.592	0.090
Northern Texas Panhandle	0.140	0.099	0.584	0.177
Region	0.132	0.163	0.593	0.112

conserving irrigation technologies in the Central High Plains. However, respondents to the Central High Plains Irrigation Survey also provided information on irrigation technology adoption factors that they feel to be most important when choosing water-conserving irrigation technologies. Question B5 of the Central High Plains Irrigation Survey asked irrigators to rank eight adoption factors from 1 (not important) to 5 (very important). Question B5 also asked irrigators to give the most important factor affecting their decision to adopt water-conserving irrigation technologies.

Mean rankings of importance for irrigation technology factors and the most important adoption factors to Central High Plains irrigators are reported in Table 40. Greater water savings has the greatest mean ranking of importance (4.77), followed by energy cost (4.57), better timing of water application (4.55), the possibility of higher yields (4.50), and irrigation system cost (4.28). Over half of the respondents identified greater water savings as being the most important factor affecting their decision to adopt water-conserving irrigation technologies. Other factors identified as being most important were the possibility of higher yields (19.3 percent), better timing of water application (12.6 percent), energy cost (12.6 percent), and irrigation system cost (12.2 percent). Factors such as credit availability, labor availability, and reductions in nitrogen and pesticide losses appear to be the least important irrigation technology adoption factors to Central High Plains Irrigators.

TABLE 40

MEAN RANKINGS OF IMPORTANCE FOR IRRIGATION TECHNOLOGY ADOPTION FACTORS AND MOST IMPORTANT ADOPTION FACTORS TO IRRIGATORS, 1994 CENTRAL HIGH PLAINS IRRIGATION SURVEY

	Ranking of Importance		Most Important Factors	
Adoption Factor	Number of Responses	Mean Ranking [a]	Number of Responses	Percent of Sample
Possibility of higher yields	254	4.50	49	19.3[b]
Better timing of water application	254	4.55	32	12.6
Greater water savings	254	4.77	135	53.1
Credit availability	254	2.86	5	2.0
Labor availability	254	3.60	8	3.1
Irrigation system cost	254	4.28	31	12.2
Energy cost	254	4.57	32	12.6
Reductions in nitrogen and pesticide losses	254	3.89	2	0.8
Other	15	4.00	8	3.1

[a] Rankings range from 1 (not important) to 5 (very important).

[b] Sum of percentages is greater than one. Many irrigators identified more than one adoption factor as being most important.

CHAPTER VI

ESTIMATED MODELS AND MODEL RESULTS FOR SOUTHWEST KANSAS AND THE NORTHERN TEXAS PANHANDLE

Chapter V reported results from a multinomial logit model of irrigation method adoption in the Central High Plains. However, it was shown in Chapter V that subregional location has a significant impact on irrigation technology adoption in this region. Specifically, it was shown that Southwest Kansas irrigators place more emphasis on improved furrow technologies, while Northern Texas Panhandle irrigators place more emphasis on LEPA technology. These differences in system preference were assumed to be associated with differences in soil types, aquifer characteristics, and information flows between the two subregions.

This chapter presents results from two separate multinomial logit models; one for Southwest Kansas and the other for the Northern Texas Panhandle. Results from both models are used to explain irrigation technology adoption in the two subregions and are compared to identify the effects of subregional location on irrigation method adoption in the Central High Plains.

Model Results for Southwest Kansas

The maximum likelihood estimates of the natural log of the odds of adopting water-conserving irrigation technologies in Southwest Kansas are reported in Table

41. Unrestricted and restricted log likelihood estimates, chi-square statistics, and the McFadden R^2 statistic of the model are reported at the bottom of Table 41. The chi-square statistic for the Southwest Kansas model compares the estimated model to a restricted model where all slope parameters are equal to zero. The restricted model is rejected at the 0.005 level of significance (critical chi-square statistic for T = 69 degrees of freedom and $\alpha = 0.005$ is approximately 105.215). The McFadden R^2 statistic for this model equals 0.3218, which is slightly larger than the McFadden R^2 of the Central High Plains model (McFadden $R^2 = .2613$).

The estimated multinomial logit model in Table 41 contains 144 parameters including the intercept terms. Of the 144 coefficients estimated, 45 are significantly different from zero at the 0.01 level of significance, 14 are significantly different from zero at the 0.05 level of significance, and 12 are significantly different from zero at the 0.10 level of significance. Thus a total of 71 parameters (49.3 percent) are significantly different from zero at acceptable levels of significance.

The well yield coefficients indicate that sprinkler and LEPA irrigation are more likely than furrow or improved furrow irrigation to be used in areas with small well yields. The LEPA versus sprinkler well yield coefficient is positive and significantly different from zero, indicating that LEPA irrigation is more likely than sprinkler irrigation to be used in areas with large well yields. These results conform to the well yield results from the Central High Plains model. The pump lift coefficients imply that improved furrow and LEPA irrigation are more likely to be used in locations where pump lifts are large. Again, these results conform to pump lift results from the Central High Plains model.

TABLE 41

MAXIMUM LIKELIHOOD ESTIMATES OF THE LOG OF THE ODDS OF ADOPTION OF WATER-CONSERVING IRRIGATION TECHNOLOGIES IN SOUTHWEST KANSAS

Variable	Improved Furrow Versus Furrow	Sprinkler Versus Furrow	LEPA Versus Furrow	Sprinkler Versus Improved Furrow	LEPA Versus Improved Furrow	LEPA Versus Sprinkler
WELLYLD	1.3E-5	-0.0025 ***	-0.0011 **	-0.0025 ***	-0.0011 **	0.0014 ***
	(0.030)	(-4.862)	(-1.968)	(-5.587)	(-2.418)	(2.769)
LIFT	0.0041 *	-0.0050 **	0.0028	-0.0091 ***	-0.0013	0.0078 ***
	(1.899)	(-2.387)	(1.111)	(-5.246)	(-0.596)	(4.062)
SAND	-0.2093	1.3353 ***	0.8261	1.5446 ***	1.0354 **	-0.5092
	(-0.523)	(3.626)	(1.627)	(4.815)	(2.263)	(-1.198)
CLAY	0.3064	-1.0015 **	0.5973	-1.3079 ***	0.2909	1.5988 ***
	(0.708)	(-2.146)	(1.042)	(-3.215)	(0.583)	(3.102)
LSLOPE	-0.0356	-1.1956 ***	-0.4133	-1.1600 ***	-0.3777	0.7823 **
	(-0.095)	(-3.162)	(-0.901)	(-3.829)	(-0.975)	(2.142)
HSLOPE	0.8199	2.1945 ***	2.1729 **	1.3746 **	1.3530 *	-0.0216
	(0.903)	(2.728)	(2.352)	(2.161)	(1.788)	(-0.040)
ACREWELL	0.0078 *	0.0240 ***	0.0230 ***	0.0162 ***	0.0151 ***	-0.0010
	(1.843)	(5.713)	(4.759)	(4.922)	(3.889)	(-0.310)

TABLE 41 CONTINUED

Variable	Improved Furrow Versus Furrow	Sprinkler Versus Furrow	LEPA Versus Furrow	Sprinkler Versus Improved Furrow	LEPA Versus Improved Furrow	LEPA Versus Sprinkler
CRP	0.4086	1.6267 ***	0.8699 *	1.2182 ***	0.4613	-0.7569 **
	(0.970)	(4.155)	(1.766)	(3.804)	(1.100)	(-2.021)
RENTIRR	0.2796	0.7421	-0.2322	0.4625	-0.5117	-0.9743 **
	(0.566)	(1.588)	(-0.388)	(1.148)	(-0.953)	(-2.135)
AGE4054	-0.2102	0.2996	-1.5553 **	0.5098	-1.3451 ***	-1.8549 ***
	(-0.382)	(0.562)	(-2.474)	(1.245)	(-2.625)	(-4.082)
AGEGE55	-1.0810 *	-0.8145	-2.5174 ***	0.2665	-1.4364 **	-1.7029 ***
	(-1.773)	(-1.407)	(-3.532)	(0.571)	(-2.344)	(-3.282)
EDUCG14	-0.4877	-0.6581 *	1.2829 ***	-0.1704	1.7707 ***	1.9410 ***
	(-1.344)	(-1.862)	(2.752)	(-0.563)	(4.256)	(5.024)
VOCT	-0.3777	0.7273 *	0.2012	1.1050 ***	0.5788	-0.5262
	(-0.916)	(1.907)	(0.411)	(3.037)	(1.262)	(-1.343)
IRRDEALER	1.5594 ***	1.8955 ***	4.1926 ***	0.3362	2.6332 ***	2.2971 ***
	(4.030)	(5.221)	(6.025)	(0.939)	(3.843)	(3.562)
PCF	1.5775 ***	1.5013 ***	1.5747 ***	-0.0761	-0.0028	0.0734
	(3.711)	(3.569)	(2.994)	(-0.241)	(-0.006)	(0.181)

TABLE 41 CONTINUED

Variable	Improved Furrow Versus Furrow	Sprinkler Versus Furrow	LEPA Versus Furrow	Sprinkler Versus Improved Furrow	LEPA Versus Improved Furrow	LEPA Versus Sprinkler
SCS	0.7584 *	0.7390 *	0.1413	-0.0193	-0.6171	-0.5978
	(1.797)	(1.769)	(0.263)	(-0.058)	(-1.335)	(-1.424)
EXTENSION	0.6308	0.0618	0.6162	-0.5691	-0.0147	0.5544
	(1.463)	(0.148)	(1.098)	(-1.628)	(-0.030)	(1.222)
NEIGHBOR	0.6217	0.1447	-1.4395 ***	-0.4770	-2.0612 ***	-1.5843 ***
	(1.335)	(0.350)	(-2.823)	(-1.248)	(-4.352)	(-4.067)
PRINT	-1.1217	-2.1603 **	-1.6971	-1.0386	-0.5754	0.4632
	(-1.390)	(-2.085)	(-1.332)	(-1.183)	(-0.496)	(0.363)
OWNEXP	1.1549 **	0.4180	2.7010 ***	-0.7369	1.5461 ***	2.2830 ***
	(2.000)	(0.719)	(4.083)	(-1.597)	(2.940)	(4.559)
GDIST	0.1203	-0.0651	-0.1141	-0.1853	-0.2344	-0.0490
	(0.276)	(-0.151)	(-0.222)	(-0.570)	(-0.557)	(-0.129)
CHD	-0.1560	-1.1189	0.9991	-0.9628 *	1.1551 *	2.1179 ***
	(-0.230)	(-1.527)	(1.193)	(-1.738)	(1.692)	(3.408)
OTHINFO	0.9757	0.1145	-0.9482	-0.8612	-1.9239	-1.0627
	(1.043)	(0.122)	(-0.675)	(-1.116)	(-1.524)	(-0.872)

TABLE 41 CONTINUED

Variable	Improved Furrow Versus Furrow	Sprinkler Versus Furrow	LEPA Versus Furrow	Sprinkler Versus Improved Furrow	LEPA Versus Improved Furrow	LEPA Versus Sprinkler
CONSTANT	-3.2234 ***	-0.6927	-5.3193 ***	2.5307 ***	-2.0960 *	-4.6267 ***
	(-3.134)	(-0.728)	(-4.205)	(2.945)	(-1.815)	(-4.470)
Number of Observations		585				
Log Likelihood		-481.10				
Log Likelihood (slope = 0)		-709.33				
Chi-Sq (69 d.f.)		456.46				
McFadden R^2		0.3218				

[a] Numbers in parentheses are asymptotic t-statistics.

[b] *** = 0.01 significance level, ** = 0.05 significance level, and * = 0.10 significance level.

The **SAND** coefficients indicate that sprinkler and LEPA irrigation are more likely than furrow or improved furrow irrigation to be used on sandy fields, while the **CLAY** coefficients indicate that furrow, improved furrow, and LEPA irrigation are more likely than sprinkler irrigation to be used on clay fields. The slope coefficients indicate that sprinkler and LEPA irrigation are more likely than either furrow method on high sloped fields while furrow, improved furrow, and LEPA irrigation are more likely than sprinkler irrigation to be used on low sloped fields. Thus, LEPA irrigation appears to be well suited for use on clay fields with high or low slopes in Southwest Kansas.

The acres per wells coefficients (**ACREWELL**) are positive and significantly different from zero for sprinkler and LEPA irrigation versus furrow or improved furrow irrigation. Thus, Southwest Kansas irrigators with large numbers of acres per well are more likely to adopt sprinkler or LEPA technologies. The improved furrow versus furrow **ACREWELL** coefficient is also positive and significantly different from zero at the 0.10 level of significance. Thus, improved furrow irrigation may have a higher likelihood than furrow irrigation of being adopted in areas with large numbers of acres per well in Southwest Kansas.

The coefficients for **CRP** indicate that sprinkler irrigation is more likely than furrow, improved furrow, or LEPA irrigation to be used on farms with land in the CRP. LEPA irrigation appear to be more likely than furrow irrigation on farms with land in the CRP. Again, these results may be due to low land quality or low water availability on farms participating in the CRP. The **RENTIRR** coefficients are negative for LEPA versus all other irrigation methods, implying that LEPA irrigation is less likely to be used on rented cropland. However, only the **RENTIRR** coefficient for LEPA versus sprinkler irrigation is significantly different from zero. Thus, rented irrigated cropland has little effect on irrigation method adoption in Southwest Kansas.

Irrigator age and education have large impacts on the likelihood of adopting LEPA irrigation in Southwest Kansas. Higher age decreases the likelihood of adopting LEPA irrigation, while higher education has the opposite effect. Age appears to have a slight negative effect on the likelihood of adopting improved furrow over furrow irrigation, while education appears to have a slight negative effect on the likelihood of adopting sprinkler over furrow irrigation. Vocational/technical training increases the likelihood of adopting sprinkler over improved furrow or furrow irrigation in Southwest Kansas.

Irrigation equipment dealers have the greatest positive impact on the likelihood of adopting water-conserving irrigation technologies in Southwest Kansas. The **IRRDEALER** coefficients are positive and significantly different from zero for every relationship except sprinkler versus improved furrow irrigation. Use of private agricultural consulting firms **(PCF)** has a positive impact on the likelihood of adopting improved furrow, sprinkler, and LEPA irrigation over furrow irrigation. The Soil Conservation Service **SCS** also has a positive impact on the likelihood of adopting improved furrow, sprinkler, and LEPA irrigation over furrow irrigation. However, the **SCS** coefficients are only significant for improved furrow and sprinkler versus furrow irrigation.

Friends and neighbors **(NEIGHBOR)** have a strong negative impact on the likelihood of adopting LEPA versus furrow irrigation, while the irrigator's own experience (**OWNEXP**) has a strong positive impact on the likelihood of adopting LEPA versus all other irrigation methods. The irrigator's own experience also increases the likelihood of adopting improved furrow over furrow irrigation. Chemical dealers (**CHD**) appear to have a positive effect on the likelihood of adopting LEPA over sprinkler and improved furrow irrigation, while printed materials (**PRINT**) appear to have a negative impact on the adoption of sprinkler versus furrow irrigation in Southwest Kansas. Groundwater districts (**GDIST**), extension, and "other information sources" (**OTHINFO**) have little impact on the adoption of water-conserving irrigation technologies in Southwest Kansas.

Model Results for the Northern Texas Panhandle

The maximum likelihood estimates of the natural log of the odds of adopting water-conserving irrigation technologies in the Northern Texas Panhandle are reported in Table 42. Unrestricted and restricted log likelihood estimates, chi-square statistics, and the Fadden R^2 statistic for the model are reported at the bottom of Table 42. The restricted model with all zero parameters is rejected at the 0.005 level of significance (critical chi-square statistic for T = 69 degrees of freedom and α = 0.005 is approximately 105.215). The Fadden R^2 statistic for this model equals 0.3387, which is slightly larger than the Fadden R^2 statistic for the Central High Plains model (Fadden R^2 = .2613).

The estimated multinomial logit model in Table 42 contains 144 parameters including the intercept terms. Of the 144 coefficients estimated, 8 are significantly different from zero at the 0.01 level of significance, 10 are significantly different from zero at the 0.05 level of significance, and 12 are significantly different from zero at the 0.10 level of significance. Thus only 30 parameters (20.8 percent) are significantly different from zero at acceptable levels of significance. The small number of significant parameters may be due to the smaller number of observations used in estimating the Northern Texas Panhandle model (237 observations versus 585 observations in the Southwest Kansas model).

The well yield coefficients indicate that sprinkler irrigation is more likely than and other irrigation method to be used in areas with small well yields. However, none of the well yield coefficients are significantly different from zero. These results may be due to small variability in saturated thickness across the Northern Texas Panhandle. Saturated thickness is another measure of water availability and is positively related to well yields (Weeks, 1986). The entire area of the Northern Texas Panhandle had at least some saturated thickness in 1980, while 80 percent had a saturated thickness greater than 100 feet (see Chapter I, Table 10). Saturated thickness is more variable in Southwest Kansas. Only 55 percent of Southwest Kansas had saturated thickness greater than 100 feet in 1980, while 17 percent had little to no saturated thickness (see Chapter I, Table 9). Thus, well yields appear to have a greater effect on irrigation technology adoption in Southwest Kansas than in the Northern Texas Panhandle.

Pump lift has a negative effect on the likelihood of adopting sprinkler irrigation in the Northern Texas Panhandle. This result implies that pump lifts are similar for furrow, improved furrow, and LEPA irrigation across the northern Texas

TABLE 42

MAXIMUM LIKELIHOOD ESTIMATES OF THE LOG OF THE ODDS OF ADOPTING WATER-CONSERVING IRRIGATION TECHNOLOGIES IN THE NORTHERN TEXAS PANHANDLE

Variable	Improved Furrow Versus Furrow	Sprinkler Versus Furrow	LEPA Versus Furrow	Sprinkler Versus Improved Furrow	LEPA Versus Improved Furrow	LEPA Versus Sprinkler
WELLYLD	-0.0008	-0.0014	0.0002	-0.0006	0.0010	0.0016
	(-0.494)	(-1.080)	(0.122)	(-0.415)	(0.548)	(1.069)
LIFT	-0.0004	-0.0078 *	0.0030	-0.0073 *	0.0034	0.0108 **
	(-0.087)	(-1.863)	(0.563)	(-1.695)	(0.631)	(2.562)
SAND	-0.0771	2.1002 ***	2.4960 *	2.1773 **	2.5731 *	0.3958
	(-0.074)	(2.599)	(1.928)	(2.372)	(1.902)	(0.339)
CLAY	-1.3038	-0.1593	1.8227	1.1445	3.1265 **	1.9820
	(-1.404)	(-0.212)	(1.470)	(1.252)	(2.330)	(1.611)
LSLOPE	0.3382	0.5565	0.8439	0.2184	0.5058	0.2874
	(0.467)	(0.919)	(1.179)	(0.356)	(0.687)	(0.491)
HSLOPE	-0.0841	0.7330	2.8596 **	0.8171	2.9437 **	2.1267 **
	(-0.064)	(0.638)	(2.309)	(0.722)	(2.388)	(2.410)
ACREWELL	-0.0029	0.0032	0.0078	0.0061	0.0107	0.0046
	(-0.310)	(0.582)	(1.074)	(0.722)	(1.116)	(0.829)

TABLE 42 CONTINUED

Variable	Improved Furrow Versus Furrow	Sprinkler Versus Furrow	LEPA Versus Furrow	Sprinkler Versus Improved Furrow	LEPA Versus Improved Furrow	LEPA Versus Sprinkler
CRP	-0.4537	-0.0017	0.6850	0.4520	1.1387	0.6867
	(-0.564)	(-0.003)	(0.942)	(0.624)	(1.375)	(1.172)
RENTIRR	1.4700	-0.2850	-0.3434	-1.7550 **	-1.8134 *	-0.0584
	(1.397)	(-0.332)	(-0.335)	(-1.991)	(-1.656)	(-0.068)
AGE4054	-1.5645	1.0363	0.1600	2.6009 *	1.7246	-0.8763
	(-1.157)	(0.806)	(0.123)	(1.858)	(1.214)	(-0.761)
AGEGE55	-0.9290	0.7715	-0.4088	1.7004	0.5202	-1.1802
	(-0.717)	(0.621)	(-0.329)	(1.277)	(0.392)	(-1.057)
EDUCG14	-1.0813	-1.1196 *	-1.3177 *	-0.0383	-0.2364	-0.1982
	(-1.422)	(-1.761)	(-1.696)	(-0.055)	(-0.285)	(-0.310)
VOCT	-1.2647	-1.1111 *	-0.2740	0.1536	0.9908	0.8371
	(-1.600)	(-1.813)	(-0.381)	(0.212)	(1.229)	(1.430)
IRRDEALER	1.0604	1.9579 ***	3.5191 ***	0.8975	2.4587 **	1.5613
	(1.331)	(2.776)	(3.445)	(1.283)	(2.289)	(1.604)
PCF	-0.7161	0.9038	1.1881	1.6199	1.9042	0.2843
	(-0.642)	(1.189)	(1.132)	(1.561)	(1.514)	(0.314)

TABLE 42 CONTINUED

Variable	Improved Furrow Versus Furrow	Sprinkler Versus Furrow	LEPA Versus Furrow	Sprinkler Versus Improved Furrow	LEPA Versus Improved Furrow	LEPA Versus Sprinkler
SCS	0.2527	0.1492	-0.7327	-0.1035	-0.9854	-0.8819
	(0.299)	(0.214)	(-0.766)	(-0.140)	(-1.003)	(-1.050)
EXTENSION	0.6533	0.3100	0.0874	-0.3433	-0.5659	-0.2226
	(0.820)	(0.474)	(0.103)	(-0.501)	(-0.646)	(-0.322)
NEIGHBOR	-0.4320	0.1348	0.0760	0.5667	0.5080	-0.0587
	(-0.393)	(0.151)	(0.070)	(0.639)	(0.473)	(-0.069)
PRINT	0.0273	-0.3449	1.2189	-0.3721	1.1916	1.5637
	(0.018)	(-0.239)	(0.826)	(-0.226)	(0.723)	(0.949)
OWNEXP	0.9935	2.0135 *	0.1703	1.0199	-0.8233	-1.8432
	(0.614)	(1.871)	(0.107)	(0.683)	(-0.431)	(-1.448)
GDIST	-2.2777 ***	-1.4950 **	-1.6808 *	0.7828	0.5970	-0.1858
	(-2.629)	(-2.081)	(-1.828)	(1.070)	(0.633)	(-0.245)
CHD	-1.5576	-1.5455	-3.7092 **	0.0121	-2.1516	-2.1637
	(-1.043)	(-1.562)	(-2.211)	(0.008)	(-1.085)	(-1.345)
OTHINFO	2.2133	-1.6168	1.7641	-3.8301 ***	-0.4493	3.3809 ***
	(1.455)	(-1.407)	(1.462)	(-2.664)	(-0.298)	(3.122)

TABLE 42 CONTINUED

Variable	Improved Furrow Versus Furrow	Sprinkler Versus Furrow	LEPA Versus Furrow	Sprinkler Versus Improved Furrow	LEPA Versus Improved Furrow	LEPA Versus Sprinkler
CONSTANT	2.9785	2.5969	-5.5381 *	-0.3816	-8.5166 ***	-8.1350 ***
	(1.103)	(1.081)	(-1.782)	(-0.152)	(-2.637)	(-2.982)
Number of Observations		237				
Log Likelihood		-197.31				
Log Likelihood (slope = 0)		-298.38				
Chi-Sq (69 d.f.)		202.15				
McFadden R^2		0.3387				

[a] Numbers in parentheses are asymptotic t-statistics.

[b] *** = 0.01 significance level, ** = 0.05 significance level, and * = 0.10 significance level.

Panhandle but are much smaller for sprinkler irrigation. Again, this result may be partially due to sprinkler systems being used in areas with both low saturated thickness and shallow pump lifts. This result may also be partially due to the cost of applying water associated with sprinkler systems. Sprinkler systems have a higher operating pressure relative to LEPA systems. Thus, LEPA systems are less costly to operate in areas with deep pump lifts. It will be shown later in this chapter that increasing pump lifts have a strong positive impact on LEPA adoption probabilities in the Northern Texas Panhandle

The **SAND** coefficients indicate that sprinkler and LEPA irrigation are more likely than either furrow method on sandy fields, while the **CLAY** coefficients indicate that LEPA irrigation is more likely than improved furrow irrigation on clay fields. None of the **LSLOPE** coefficients are significant from zero. However, the **HSLOPE** coefficients are positive and significant from zero for LEPA versus all other irrigation methods. Thus LEPA appears to be more likely than any other irrigation method to be used on high sloped fields in the Northern Texas Panhandle.

The **ACREWELL** coefficients are positive for sprinkler and LEPA irrigation versus furrow and improved furrow irrigation, implying that Northern Texas Panhandle irrigators with many acres per well have a high likelihood of adopting sprinkler or LEPA irrigation. However, none of the **ACREWELL** coefficients are significantly different from zero.

The **CRP** coefficients are not significantly different from zero, implying that having land in the CRP has little effect on irrigation technology adoption in the Northern Texas Panhandle. The coefficients for **RENTIRR** are negative and significantly different from zero for sprinkler and LEPA versus improved furrow irrigation, implying that improved furrow irrigation is more likely than sprinkler or LEPA irrigation on rented irrigated cropland. Thus, rented irrigated cropland appears to have a greater effect on irrigation technology adoption in the Northern Texas Panhandle than in Southwest Kansas. The **AGE4054** coefficient is positive and significantly different from zero for sprinkler versus improved furrow irrigation, implying that irrigators between 40 and 55 years of age are more likely to adopt sprinkler over improved furrow irrigation in the Northern Texas Panhandle. Higher education and vocational/technical training appear to have a slight negative impact on the likelihood of adopting sprinkler and LEPA over furrow irrigation in the Northern Texas Panhandle.

Of the information sources analyzed, irrigation equipment dealers appear to have the greatest positive effect on the adoption of water-conserving irrigation technologies in the Northern Texas Panhandle. The **IRRDEALER** coefficients are all positive and are significantly different from zero for sprinkler versus furrow irrigation, LEPA versus furrow irrigation, and LEPA versus improved furrow irrigation. Groundwater districts **(GDIST)** appear to have a negative impact on the likelihood of adopting improved furrow, sprinkler, and LEPA over furrow irrigation. This is surprising, since groundwater districts promote water conservation. "Other information sources" **(OTHINFO)** appear to have a negative impact on the likelihood of adopting sprinkler irrigation, while the irrigator's own experience appears to have a slight positive impact on the likelihood of adopting sprinkler over furrow irrigation. The remaining information sources (the Soil Conservation Service, extension, friends and neighbors, printed materials, and chemical dealers) appear to have little effect on irrigation method adoption in the Northern Texas Panhandle.

Predicted Irrigation Method Adoption Probabilities by Soil Type and Field Slope in Southwest Kansas and the Northern Texas Panhandle

Irrigation method adoption probabilities by soil type and field slope are reported for Southwest Kansas in Table 43. Soil type and field slope greatly impact the probabilities of adopting furrow, improved furrow, and sprinkler irrigation in Southwest Kansas. Sprinkler adoption probabilities are greatest on sandy fields and fields with high slopes, while furrow and improved furrow adoption probabilities are greatest on clay fields and fields with low slopes. LEPA adoption probabilities are greatest on clay fields. However, field slopes and other soil types appear to have little impact on LEPA adoption probabilities in Southwest Kansas.

Irrigation method adoption probabilities by soil type and field slope are reported for the Northern Texas Panhandle in Table 44. Sprinkler adoption probabilities are greatest on sandy soils and smallest on clay soils. However, sprinkler adoption probabilities increase as field slope declines in the Northern Texas Panhandle. Thus, sprinkler adoption probabilities are greatest on low sloped fields in the Northern Texas Panhandle. Furrow and improved furrow adoption probabilities are greatest on loam fields and fields with medium slopes, while LEPA adoption probabilities are greatest on clay fields and fields with high slopes.

TABLE 43

PREDICTED PROBABILITIES OF IRRIGATION METHOD ADOPTION BY SOIL TYPE AND SLOPE, SOUTHWEST KANSAS

	Irrigation Method			
Soil and Slope	Furrow	Improved Furrow	Sprinkler	LEPA
Sand	0.057	0.092	0.793	0.058
Loam	0.141	0.280	0.516	0.063
Clay	0.170	0.461	0.230	0.139
High slope	0.012	0.050	0.858	0.079
Medium slope	0.090	0.159	0.687	0.065
Low slope	0.182	0.311	0.421	0.087
Sand, high slope	0.006	0.020	0.923	0.050
Sand, medium slope	0.048	0.072	0.834	0.046
Sand, low slope	0.119	0.174	0.630	0.077
Loam, high slope	0.020	0.084	0.821	0.075
Loam, medium slope	0.127	0.237	0.583	0.054
Loam, low slope	0.223	0.403	0.311	0.063
Clay, high slope	0.035	0.201	0.528	0.237
Clay, medium slope	0.166	0.423	0.281	0.129
Clay, low slope	0.223	0.548	0.114	0.115
Subregion	0.102	0.193	0.626	0.078

TABLE 44

PREDICTED PROBABILITIES OF IRRIGATION METHOD ADOPTION BY SOIL TYPE AND SLOPE, NORTHERN TEXAS PANHANDLE

	Irrigation Method			
Soil and Slope	Furrow	Improved Furrow	Sprinkler	LEPA
Sand	0.053	0.059	0.794	0.095
Loam	0.238	0.287	0.440	0.035
Clay	0.261	0.086	0.412	0.241
High slope	0.062	0.037	0.434	0.467
Medium slope	0.183	0.119	0.618	0.079
Low slope	0.113	0.104	0.669	0.114
Sand, high slope	0.025	0.022	0.562	0.390
Sand, medium slope	0.074	0.071	0.789	0.065
Sand, low slope	0.044	0.058	0.809	0.089
Loam, high slope	0.169	0.160	0.457	0.214
Loam, medium slope	0.294	0.303	0.382	0.021
Loam, low slope	0.205	0.296	0.465	0.035
Clay, high slope	0.088	0.023	0.203	0.687
Clay, medium slope	0.352	0.099	0.391	0.158
Clay, low slope	0.229	0.090	0.443	0.239
Subregion	0.134	0.102	0.644	0.120

Predicted Irrigation Method Adoption Probabilities by Pump Lift in Southwest Kansas and the Northern Texas Panhandle

Irrigation method adoption probabilities by pump lift are presented for Southwest Kansas in Figure 5 and in Table 62 of Appendix B. Increased pump lifts have the greatest positive effect on the probability of adopting improved furrow irrigation and the greatest negative effect on the probability of adopting sprinkler irrigation. Increasing pump lifts also increase the probability of adopting LEPA irrigation, but have little effect on the probability of adopting furrow irrigation in Southwest Kansas. These results are similar to those of the Central High Plains Model (see Chapter V).

Irrigation method adoption probabilities by pump lift are presented for the Northern Texas Panhandle in Figure 6 and Table 63 of Appendix B. Increasing pump lifts appear to have the greatest positive impact on LEPA adoption in the Northern Texas Panhandle. Thus, LEPA irrigation appears to be more energy saving than other irrigation methods in the Northern Texas Panhandle. Furrow and improved furrow adoption probabilities increase with increasing pump lifts, while sprinkler adoption probabilities decrease with increasing pump lifts in the Northern Texas Panhandle.

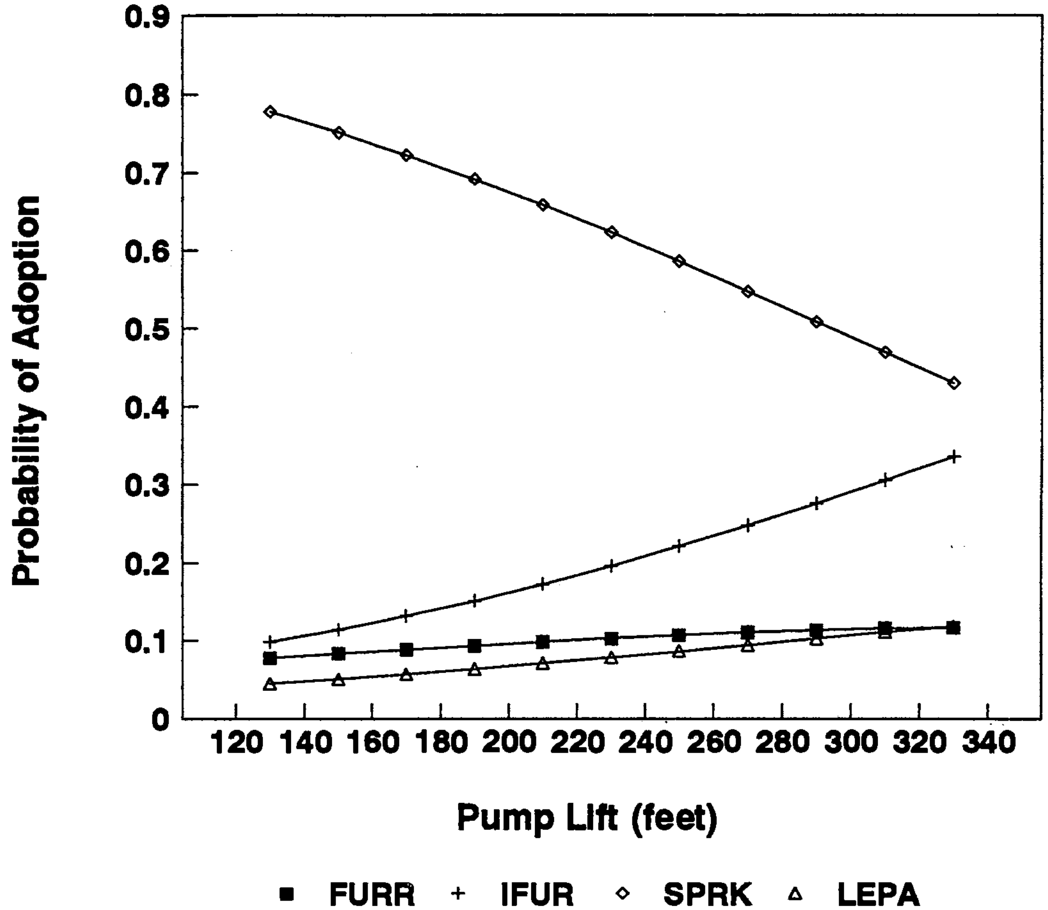

Figure 5. Predicted Probabilities of Irrigation Method Adoption by Pump Lift, Southwest Kansas

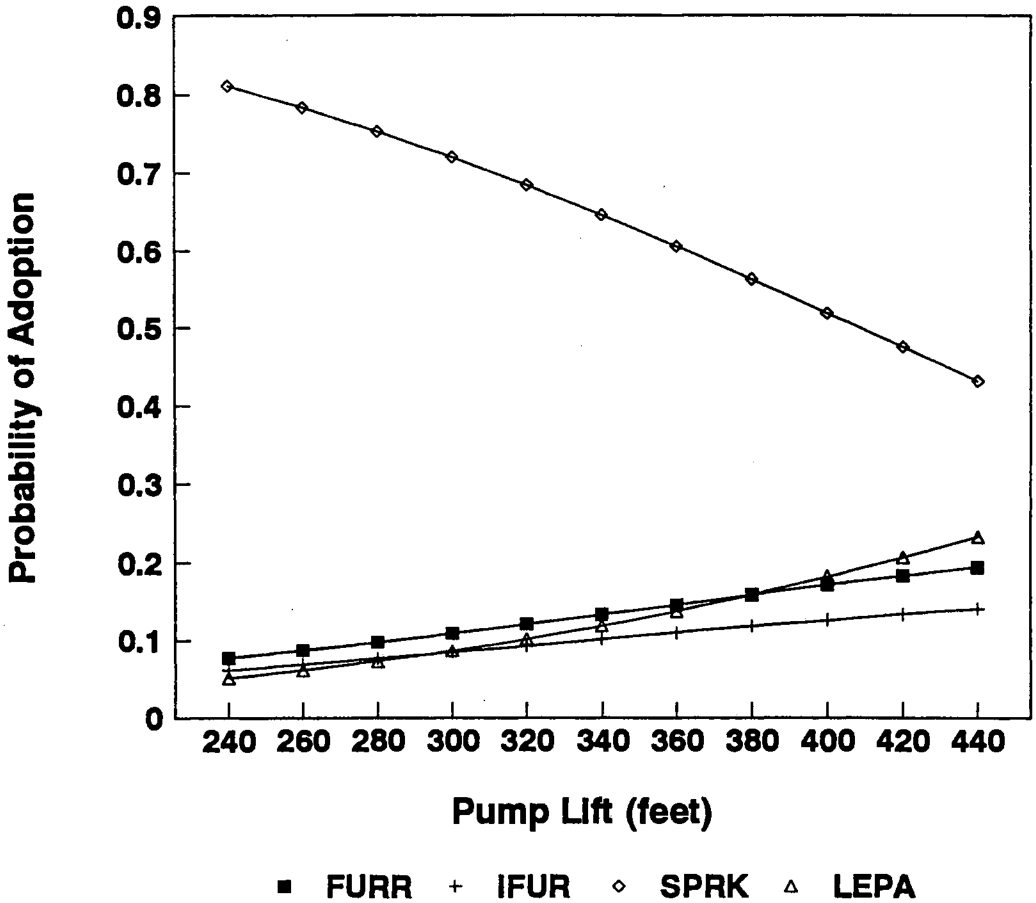

Figure 6. Predicted Probabilities of Irrigation Method Adoption by Pump Lift, Northern Texas Panhandle

Pump Lift Effects on Irrigation Method Adoption by Soil Type and Field Slope in Southwest Kansas and the Northern Texas Panhandle

The effects of increasing pump lifts on irrigation method adoption by soil type and field slope in Southwest Kansas are shown in Table 45. The pump lift effects in Southwest Kansas are similar to those presented for the Central High Plains (see Chapter V). Pump lift effects are always positive for improved furrow and LEPA adoption probabilities and are always negative for sprinkler adoption probabilities. The positive pump lift effect on improved furrow adoption is greatest on clay and loam fields with low to medium slopes. The positive pump lift effect on LEPA adoption is typically much smaller and is greatest on clay fields with high slopes.

The effects of increasing pump lifts on irrigation method adoption by soil type and field slope in the Northern Texas Panhandle are shown in Table 46. Two differences can be seen between pump lift effects in the Northern Texas Panhandle and pump lift effects in Southwest Kansas. First of all, the negative pump lift effect on sprinkler adoption is generally greater in the Northern Texas Panhandle. Second, the positive pump lift effect on LEPA adoption is typically greater than that on improved furrow adoption in the Northern Texas Panhandle. Both results occur because of differences in depths to water between the two subregions. Depths to water are generally larger in the Northern Texas Panhandle than in Southwest Kansas (see Chapter I, Tables 5 and 6). Thus pumping costs on average are probably much higher in the Northern Texas Panhandle. This was demonstrated in Table 21 of Chapter IV. LEPA is more water efficient than either improved furrow or sprinkler

TABLE 45

PUMP LIFT EFFECTS ON IRRIGATION METHOD ADOPTION BY SOIL TYPE AND FIELD SLOPE IN SOUTHWEST KANSAS

Soil and Slope	Pump Lift (feet)	Irrigation Method			
		Furrow	Improved Furrow	Sprinkler	LEPA
Sand, Low Slope	130	0.090	0.088	0.778	0.044
	330	0.137	0.307	0.438	0.118
	Difference	0.047	0.219	-0.340	0.074
Sand, Medium Slope	130	0.032	0.032	0.912	0.024
	330	0.066	0.153	0.695	0.086
	Difference	0.034	0.120	-0.217	0.062
Sand, High Slope	130	0.004	0.009	0.963	0.024
	330	0.009	0.047	0.842	0.102
	Difference	0.005	0.038	-0.121	0.078
Clay, Low Slope	130	0.259	0.424	0.216	0.101
	330	0.174	0.652	0.054	0.120
	Difference	-0.085	0.228	-0.162	0.019
Clay, Medium Slope	130	0.166	0.281	0.456	0.097
	330	0.144	0.559	0.147	0.150
	Difference	-0.021	0.278	-0.310	0.052
Clay, High Slope	130	0.029	0.111	0.712	0.149
	330	0.036	0.314	0.326	0.325
	Difference	0.007	0.203	-0.386	0.176
Loam, Low Slope	130	0.213	0.257	0.484	0.046
	330	0.201	0.554	0.169	0.076
	Difference	-0.012	0.297	-0.316	0.030
Loam, Medium Slope	130	0.099	0.124	0.745	0.032
	330	0.139	0.396	0.385	0.079
	Difference	0.040	0.273	-0.360	0.047
Loam, High Slope	130	0.014	0.038	0.910	0.038
	330	0.027	0.173	0.666	0.134
	Difference	0.013	0.135	-0.244	0.096
Subregion	130	0.078	0.098	0.779	0.045
	330	0.117	0.335	0.429	0.119
	Difference	0.039	0.237	-0.349	0.074

TABLE 46

PUMP LIFT EFFECTS ON IRRIGATION METHOD ADOPTION BY SOIL TYPE AND FIELD SLOPE IN THE NORTHERN TEXAS PANHANDLE

Soil and Slope	Pump Lift (feet)	Irrigation Method			
		Furrow	Improved Furrow	Sprinkler	LEPA
Sand, Low Slope	240	0.022	0.031	0.912	0.034
	440	0.073	0.094	0.631	0.202
	Difference	0.051	0.063	-0.282	0.168
Sand, Medium Slope	240	0.039	0.038	0.898	0.025
	440	0.125	0.114	0.614	0.147
	Difference	0.086	0.076	-0.284	0.122
Sand, High Slope	240	0.016	0.015	0.785	0.184
	440	0.031	0.026	0.313	0.630
	Difference	0.014	0.011	-0.472	0.446
Clay, Low Slope	240	0.156	0.064	0.660	0.120
	440	0.272	0.102	0.244	0.381
	Difference	0.117	0.039	-0.416	0.261
Clay, Medium Slope	240	0.246	0.072	0.600	0.082
	440	0.419	0.113	0.216	0.253
	Difference	0.173	0.040	-0.384	0.171
Clay, High Slope	240	0.082	0.022	0.417	0.478
	440	0.078	0.019	0.083	0.819
	Difference	-0.005	-0.003	-0.334	0.342
Loam, Low Slope	240	0.131	0.199	0.654	0.016
	440	0.273	0.378	0.287	0.062
	Difference	0.142	0.180	-0.367	0.045
Loam, Medium Slope	240	0.201	0.216	0.572	0.011
	440	0.372	0.368	0.224	0.036
	Difference	0.171	0.151	-0.348	0.025
Loam, High Slope	240	0.113	0.112	0.670	0.106
	440	0.206	0.187	0.258	0.349
	Difference	0.093	0.075	-0.412	0.244
Region	240	0.077	0.061	0.811	0.051
	440	0.194	0.141	0.432	0.233
	Difference	0.117	0.080	-0.379	0.182

irrigation. Thus LEPA may be more energy efficient and more profitable in areas with large pump lifts. These differences help explain why LEPA is used more extensively in the Northern Texas Panhandle.

The pump lift effect on LEPA adoption is greatest on sand and clay fields with low or high slopes in the Northern Texas Panhandle. The pump lift effect on furrow adoption is greatest on loam fields and clay fields with medium slopes, while the pump lift effect on improved furrow adoption is greatest on loam fields with low to medium slopes. The pump lift effect is always negative for sprinkler adoption and is greatest on sandy fields with high slopes and loam fields with high slopes.

Predicted Irrigation Method Adoption Probabilities by Well Yield in Southwest Kansas and the Northern Texas Panhandle

Irrigation method adoption probabilities for different well yields in Southwest Kansas are shown in Figure 7 and Table 64 of Appendix B. The effects of increasing well yields on irrigation method adoption in Southwest Kansas are similar to those presented for the Central High Plains (see Chapter V). Increasing well yields have the greatest positive impact on improved furrow adoption probabilities and the greatest negative impact on sprinkler adoption probabilities, implying that sprinkler systems are used in areas where water is scarce and improved furrow systems are used in areas where water is plentiful. Increasing well yields also have a positive impact on furrow adoption probabilities. Increasing well yields appear to have little impact on LEPA adoption probabilities in Southwest Kansas.

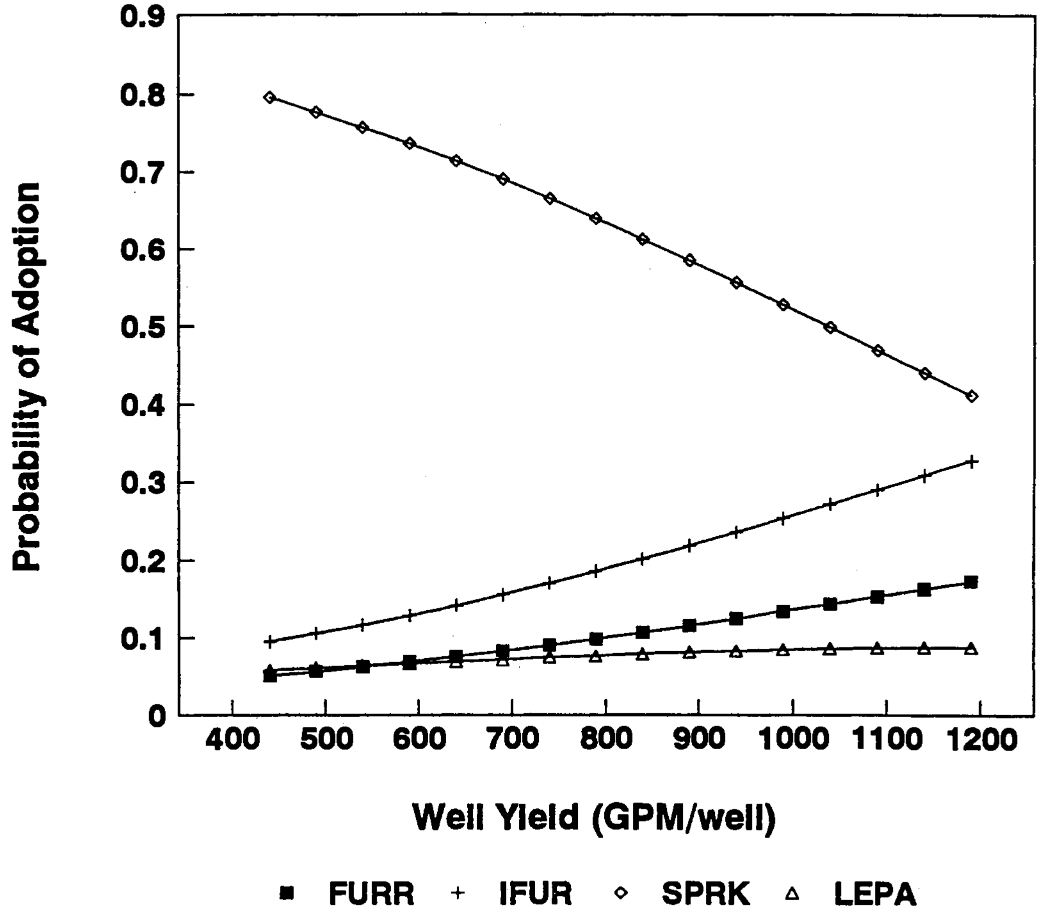

Figure 7. Predicted Probabilities of Irrigation Method Adoption by Well Yield, Southwest Kansas

Irrigation method adoption probabilities for different well yields in the Northern Texas Panhandle are presented in Figure 8 and in Table 65 of Appendix B. Well yields have a smaller impact on irrigation technology adoption in the Northern Texas Panhandle. This result occurs because well yields are less variable across the Northern Texas Panhandle. Increasing well yields have the greatest positive impact on furrow and LEPA adoption probabilities and the greatest negative impact on sprinkler adoption probabilities, implying that LEPA and furrow irrigation are used in areas where water is plentiful while sprinkler irrigation is used in areas where water is scarce in the Northern Texas Panhandle. Increasing well yields have little effect on improved furrow adoption probabilities in the Northern Texas Panhandle.

Well Yield Effects on Irrigation Method Adoption by Soil Type and Field Slope in Southwest Kansas and the Northern Texas Panhandle

The effects of increasing well yields on irrigation method adoption by soil type and field slope in Southwest Kansas are shown in Table 47. Increasing well yields have the greatest positive impact on improved furrow adoption probabilities. The impact is greatest on clay and loam fields with medium slopes. Increasing well yields also have a positive impact on furrow adoption probabilities. The positive well yield effect on furrow adoption is greatest on sandy fields with low slopes and loam fields with low to medium slopes. Well yield effects are always negative for sprinkler adoption probabilities, with the largest negative effects on sandy fields with low slopes, and loam fields with low to medium slopes. Increasing well yields have both

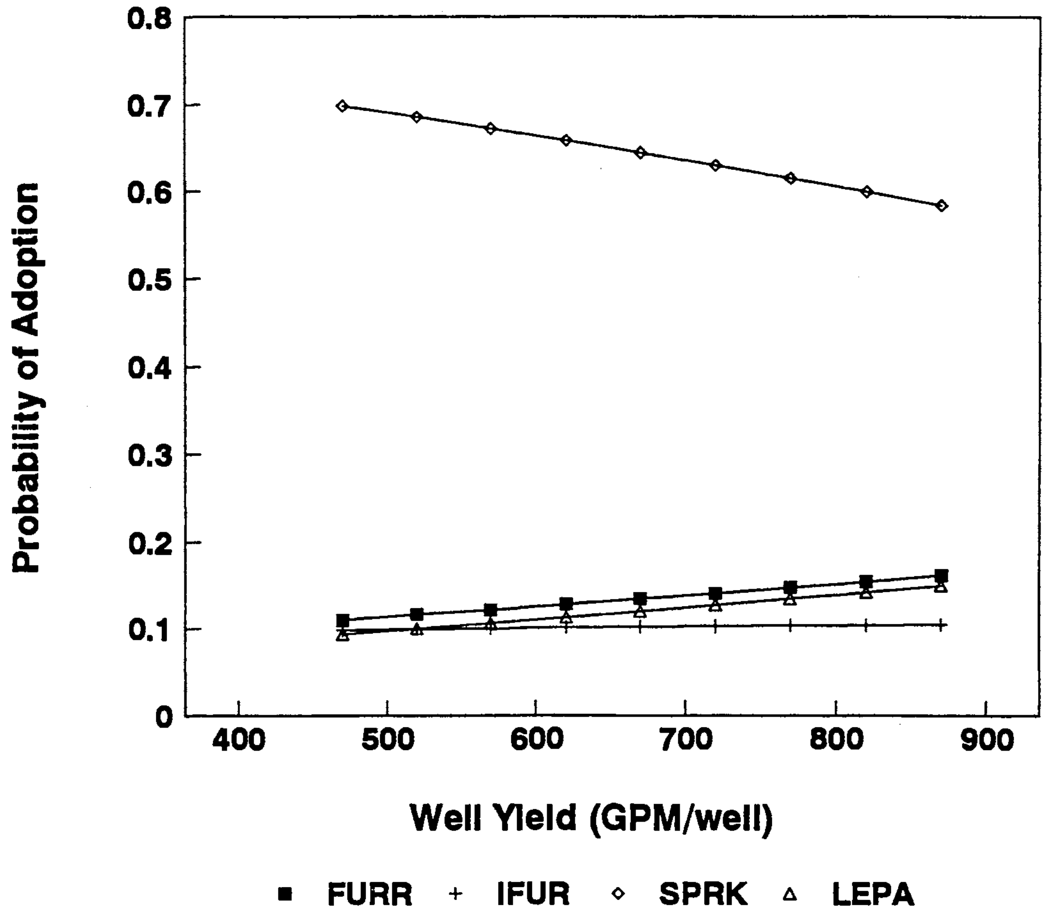

Figure 8. Predicted Probabilities of Irrigation Method Adoption by Well Yield, Northern Texas Panhandle

TABLE 47

WELL YIELD EFFECTS ON IRRIGATION METHOD ADOPTION BY SOIL TYPE AND FIELD SLOPE IN SOUTHWEST KANSAS

Soil and Slope	Well Yield (GPM)	Irrigation Method			
		Furrow	Improved Furrow	Sprinkler	LEPA
Sand, Low Slope	440	0.059	0.086	0.798	0.057
	1190	0.201	0.296	0.415	0.087
	Difference	0.142	0.211	-0.383	0.030
Sand, Medium Slope	440	0.021	0.031	0.919	0.030
	1190	0.100	0.153	0.682	0.065
	Difference	0.080	0.122	-0.237	0.036
Sand, High Slope	440	0.002	0.008	0.959	0.031
	1190	0.014	0.049	0.857	0.080
	Difference	0.012	0.040	-0.102	0.050
Clay, Low Slope	440	0.181	0.442	0.237	0.139
	1190	0.250	0.615	0.050	0.086
	Difference	0.068	0.173	-0.188	-0.053
Clay, Medium Slope	440	0.111	0.281	0.480	0.129
	1190	0.211	0.540	0.139	0.110
	Difference	0.100	0.259	-0.341	-0.019
Clay, High Slope	440	0.018	0.103	0.697	0.183
	1190	0.058	0.336	0.342	0.264
	Difference	0.040	0.233	-0.355	0.082
Loam, Low Slope	440	0.147	0.265	0.525	0.062
	1190	0.282	0.512	0.153	0.053
	Difference	0.135	0.247	-0.373	-0.009
Loam, Medium Slope	440	0.065	0.122	0.771	0.042
	1190	0.202	0.379	0.361	0.058
	Difference	0.136	0.257	-0.410	0.016
Loam, High Slope	440	0.009	0.036	0.907	0.048
	1190	0.042	0.179	0.674	0.105
	Difference	0.033	0.143	-0.233	0.057
Subregion	440	0.051	0.095	0.796	0.058
	1190	0.173	0.328	0.411	0.088
	Difference	0.122	0.232	-0.384	0.030

a positive and a negative effect on LEPA adoption probabilities in Southwest Kansas. The greatest positive impact occurs on clay fields with high slopes, while the greatest negative impact occurs on clay fields with low slopes.

The effects of increasing well yields on irrigation method adoption by soil type and field slope in the Northern Texas Panhandle are shown in Table 48. Increasing well yields have a negative impact on sprinkler adoption probabilities in every case in the Northern Texas Panhandle. However, negative well yield effects on sprinkler adoption are generally smaller than those on sprinkler adoption in Southwest Kansas. Also, increasing well yields have less effect on furrow and improved furrow adoption probabilities in the Northern Texas Panhandle. These differences occur because well yields are less variable across the Northern Texas Panhandle. Increasing well yields have the greatest positive impact on LEPA adoption probabilities in the Northern Texas Panhandle. The positive impact is greatest on sandy fields with high slopes and clay fields with high slopes. Increasing well yields also have a positive effect on furrow adoption in the Northern Texas Panhandle. The positive well yield effect on furrow adoption is greatest on clay and loam fields with medium slopes.

Predicted Irrigation Method Adoption Probabilities by the Number of Acres Per Well in Southwest Kansas and the Northern Texas Panhandle

Predicted irrigation method adoption probabilities by the number of acres per well in Southwest Kansas are shown in Figure 9 and Table 66 in Appendix B. The results in Figure 9 are similar to those presented in Figure 3 in Chapter V.

Increasing acres per well has a strong positive impact on the probability of adopting sprinkler irrigation and a small positive impact on the probability of adopting LEPA irrigation in Southwest Kansas. Increasing acres per well has a negative impact on the probabilities of adopting furrow and improved furrow irrigation.

Predicted irrigation method adoption probabilities by the number of acres per well in the Northern Texas Panhandle are shown in Figure 10 and Table 67 in Appendix B. Increasing acres per well has a strong positive impact on LEPA adoption probabilities and a small positive impact on sprinkler adoption probabilities in the Northern Texas Panhandle. Increasing acres per well have a negative impact on furrow and improved furrow adoption probabilities.

Predicted Irrigation Method Adoption Probabilities by Age, Education, and Vocational/Technical Training in Southwest Kansas and the Northern Texas Panhandle

Irrigation method adoption probabilities by irrigator age are presented for Southwest Kansas and the Northern Texas Panhandle in Table 49. Irrigators between 40 and 55 years of age have the highest probability of adopting sprinkler irrigation in Southwest Kansas. Irrigators less than 40 years of age have the highest probability of adopting LEPA irrigation, while irrigators greater than 55 years of age have the highest probability of adopting furrow irrigation. Thus, LEPA adoption decreases with age while furrow adoption increases with age in Southwest Kansas. Irrigator age has little effect on the probability of adopting improved furrow irrigation in Southwest

TABLE 48

WELL YIELD EFFECTS ON IRRIGATION METHOD ADOPTION BY SOIL TYPE AND FIELD SLOPE IN THE NORTHERN TEXAS PANHANDLE

Soil and Slope	Well Yield (GPM)	Irrigation Method			
		Furrow	Improved Furrow	Sprinkler	LEPA
Sand, Low Slope	470	0.034	0.054	0.844	0.067
	870	0.055	0.062	0.766	0.117
	Difference	0.020	0.008	-0.078	0.049
Sand, Medium Slope	470	0.059	0.066	0.826	0.049
	870	0.093	0.076	0.746	0.085
	Difference	0.034	0.010	-0.080	0.036
Sand, High Slope	470	0.022	0.022	0.636	0.320
	870	0.029	0.022	0.484	0.465
	Difference	0.007	-0.001	-0.152	0.145
Clay, Low Slope	470	0.199	0.092	0.510	0.199
	870	0.257	0.086	0.376	0.280
	Difference	0.058	-0.006	-0.134	0.081
Clay, Medium Slope	470	0.310	0.102	0.455	0.133
	870	0.393	0.094	0.329	0.184
	Difference	0.083	-0.008	-0.126	0.051
Clay, High Slope	470	0.084	0.025	0.258	0.633
	870	0.090	0.020	0.157	0.734
	Difference	0.006	-0.006	-0.101	0.101
Loam, Low Slope	470	0.170	0.289	0.513	0.028
	870	0.242	0.299	0.416	0.043
	Difference	0.072	0.010	-0.097	0.015
Loam, Medium Slope	470	0.250	0.302	0.431	0.017
	870	0.340	0.299	0.334	0.026
	Difference	0.091	-0.003	-0.096	0.008
Loam, High Slope	470	0.145	0.161	0.519	0.175
	870	0.193	0.156	0.395	0.255
	Difference	0.049	-0.005	-0.124	0.080
Region	470	0.110	0.098	0.698	0.094
	870	0.161	0.105	0.584	0.150
	Difference	0.051	0.007	-0.114	0.056

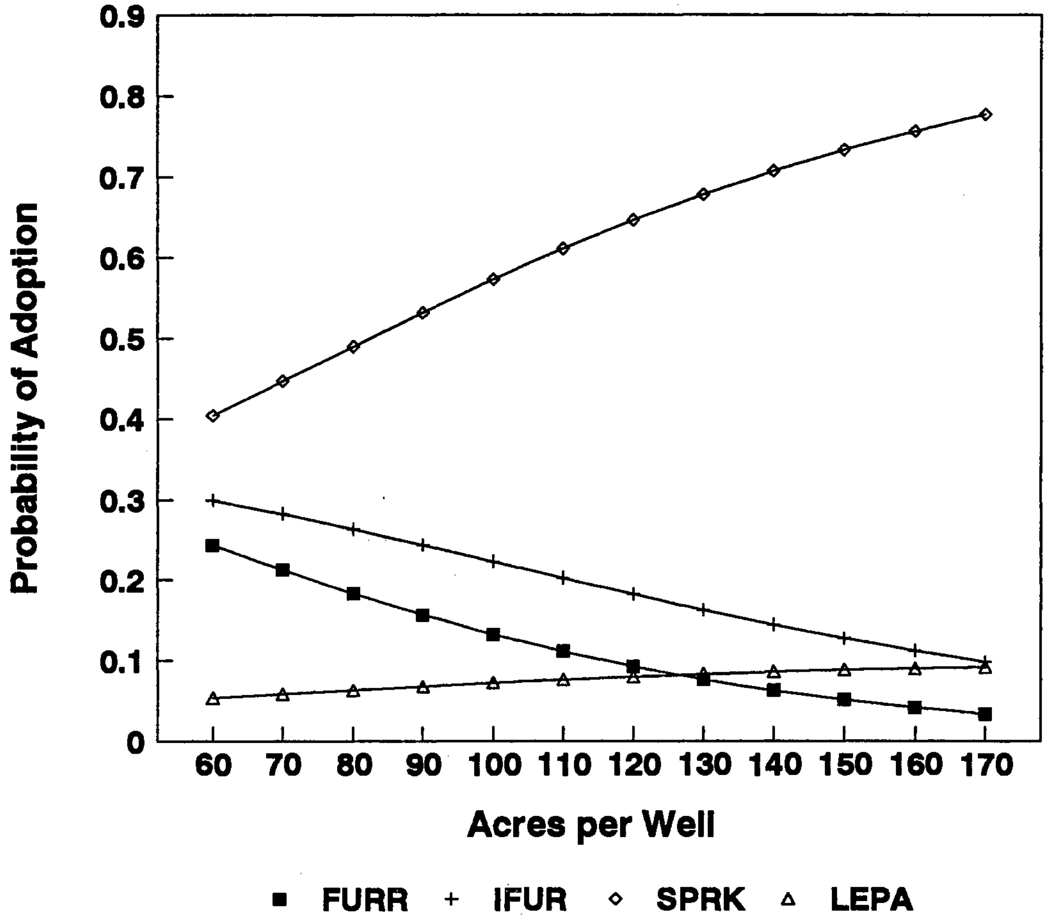

Figure 9. Predicted Probabilities of Irrigation Method Adoption by Number of Acres Per Well, Southwest Kansas

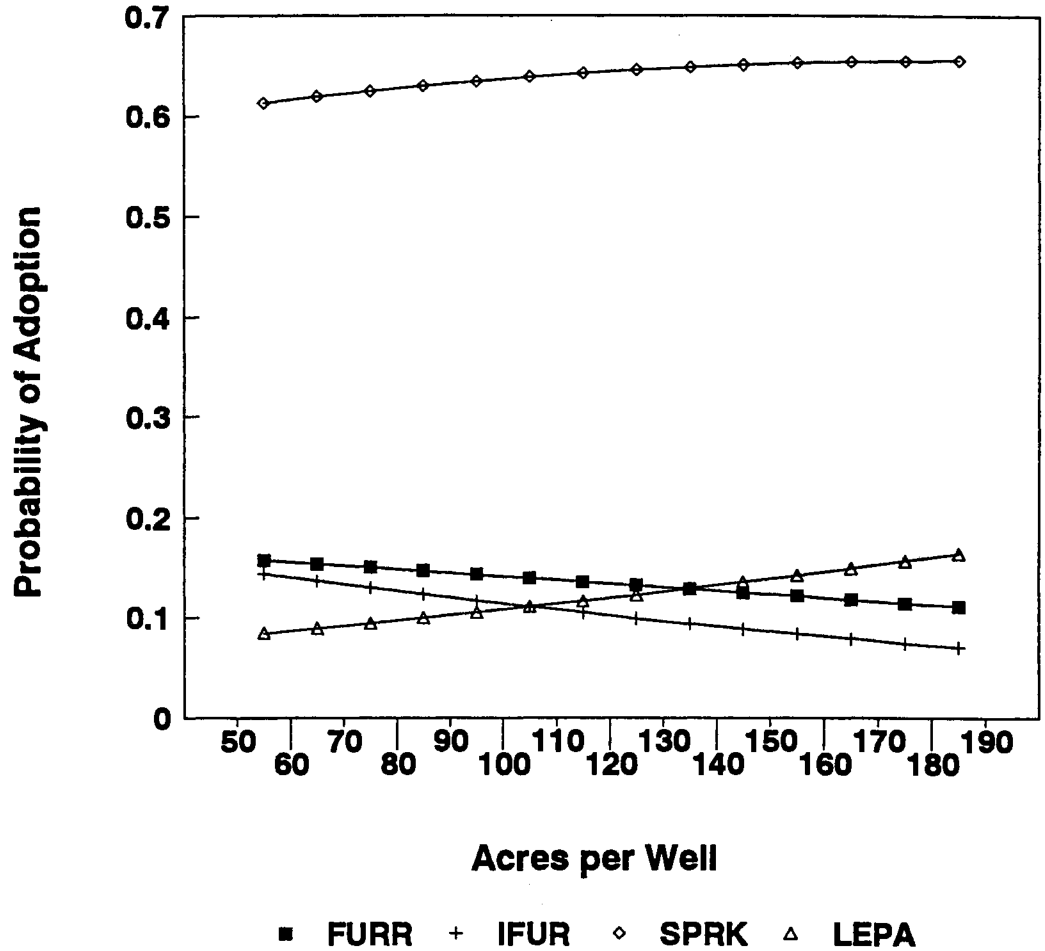

Figure 10. Predicted Probabilities of Irrigation Method Adoption by Number of Acres Per Well, Northern Texas Panhandle

TABLE 49

PREDICTED PROBABILITIES OF IRRIGATION METHOD ADOPTION BY IRRIGATOR AGE, SOUTHWEST KANSAS AND THE NORTHERN TEXAS PANHANDLE

Southwest Kansas				
	Irrigation Method			
Irrigator Age	Furrow	Improved Furrow	Sprinkler	LEPA
Less than 40 years	0.059	0.201	0.469	0.272
Between 40 and 55 years	0.064	0.178	0.694	0.063
Greater than 55 years	0.164	0.191	0.583	0.062
Subregion	0.102	0.193	0.626	0.078
Northern Texas Panhandle				
	Irrigation Method			
Irrigator Age	Furrow	Improved Furrow	Sprinkler	LEPA
Less than 40 years	0.155	0.357	0.328	0.161
Between 40 and 55 years	0.115	0.056	0.688	0.141
Greater than 55 years	0.139	0.127	0.638	0.096
Subregion	0.134	0.102	0.644	0.120

Kansas.

Age has slightly different effects on irrigation method adoption probabilities in the Northern Texas Panhandle. Irrigators between 40 and 55 years of age have the highest probability of adopting sprinkler irrigation. Young irrigators (e.g., irrigators less than 40 years of age) have the highest probability of adopting improved furrow irrigation, while irrigators less than 40 years of age and irrigators between 40 and 55 years of age have the highest probabilities of adopting LEPA irrigation. Age has little effect on the probability of adopting furrow irrigation in the Northern Texas Panhandle.

Irrigation method adoption probabilities by irrigator education in Southwest Kansas and the Northern Texas Panhandle are shown in Table 50. Southwest Kansas irrigators with more than 14 years of formal schooling have a higher probability of adopting LEPA and furrow irrigation, while Southwest Kansas irrigators with less than 14 years of formal schooling have a higher probability of adopting sprinkler irrigation. Higher education has little impact on the probability of adopting improved furrow irrigation. Education has different effects on irrigation method adoption in the Northern Texas Panhandle. Irrigators with 14 or more years of formal schooling have a higher probability of adopting furrow irrigation, while irrigators with less than 14 years of formal schooling have a higher probability of adopting sprinkler and LEPA irrigation. Higher education has little effect on the probability of adopting improved furrow irrigation in the Northern Texas Panhandle.

TABLE 50

PREDICTED PROBABILITIES OF IRRIGATION METHOD ADOPTION BY IRRIGATOR EDUCATION, SOUTHWEST KANSAS AND THE NORTHERN TEXAS PANHANDLE

Southwest Kansas				
	Irrigation Method			
Irrigator Education:	Furrow	Improved Furrow	Sprinkler	LEPA
Greater than 14 years	0.120	0.177	0.526	0.176
Less than 14 years	0.082	0.196	0.689	0.033
Difference	0.039	-0.019	-0.163	0.143
Subregion	0.102	0.193	0.626	0.078

Northern Texas Panhandle				
	Irrigation Method			
Irrigator Education:	Furrow	Improved Furrow	Sprinkler	LEPA
Greater than 14 years	0.196	0.097	0.603	0.104
Less than 14 years	0.072	0.105	0.680	0.143
Difference	0.124	-0.008	-0.077	-0.039
Subregion	0.134	0.102	0.644	0.120

Irrigation method adoption probabilities for irrigators with and without vocational/technical training in Southwest Kansas and the Northern Texas Panhandle are shown in Table 51. Vocational/technical training increases the probability of adopting sprinkler irrigation and decreases the probabilities of adopting furrow and improved furrow irrigation in Southwest Kansas. Vocational/technical training has little effect on the probability of adopting LEPA irrigation in Southwest Kansas. Vocational/technical training increases furrow and LEPA adoption probabilities and reduces sprinkler and improved furrow adoption probabilities in the Northern Texas Panhandle.

Predicted Irrigation Method Adoption Probabilities by Farm Characteristic in Southwest Kansas and the Northern Texas Panhandle

Irrigation method adoption probabilities by percent of irrigated cropland rented are presented for Southwest Kansas in Figure 11 and Table 68 of Appendix B. The percent of rented irrigated cropland on a farm increases the probability of adopting sprinkler irrigation and decreases the probabilities of adopting furrow, improved furrow, and LEPA irrigation in Southwest Kansas. However, the effect of rented irrigation cropland on irrigation method adoption in Southwest Kansas is small.

Irrigation method adoption probabilities by percent of irrigated cropland rented are presented for the Northern Texas Panhandle in Figure 12 and Table 69 of Appendix B. Rented irrigated cropland has a stronger effect on irrigation method adoption in the Northern Texas Panhandle. Improved furrow adoption probabilities

TABLE 51

PREDICTED PROBABILITIES OF IRRIGATION METHOD ADOPTION WITH AND WITHOUT VOCATIONAL/TECHNICAL TRAINING, SOUTHWEST KANSAS AND THE NORTHERN TEXAS PANHANDLE

Southwest Kansas				
	Irrigation Method			
Vocational/Technical Training:	Furrow	Improved Furrow	Sprinkler	LEPA
Yes	0.075	0.110	0.750	0.065
No	0.115	0.246	0.557	0.082
Difference	-0.040	-0.136	0.193	-0.017
Subregion	0.102	0.193	0.626	0.078
Northern Texas Panhandle				
	Irrigation Method			
Vocational/Technical Training:	Furrow	Improved Furrow	Sprinkler	LEPA
Yes	0.227	0.076	0.528	0.169
No	0.098	0.116	0.691	0.096
Difference	0.129	-0.040	-0.163	0.073
Subregion	0.134	0.102	0.644	0.120

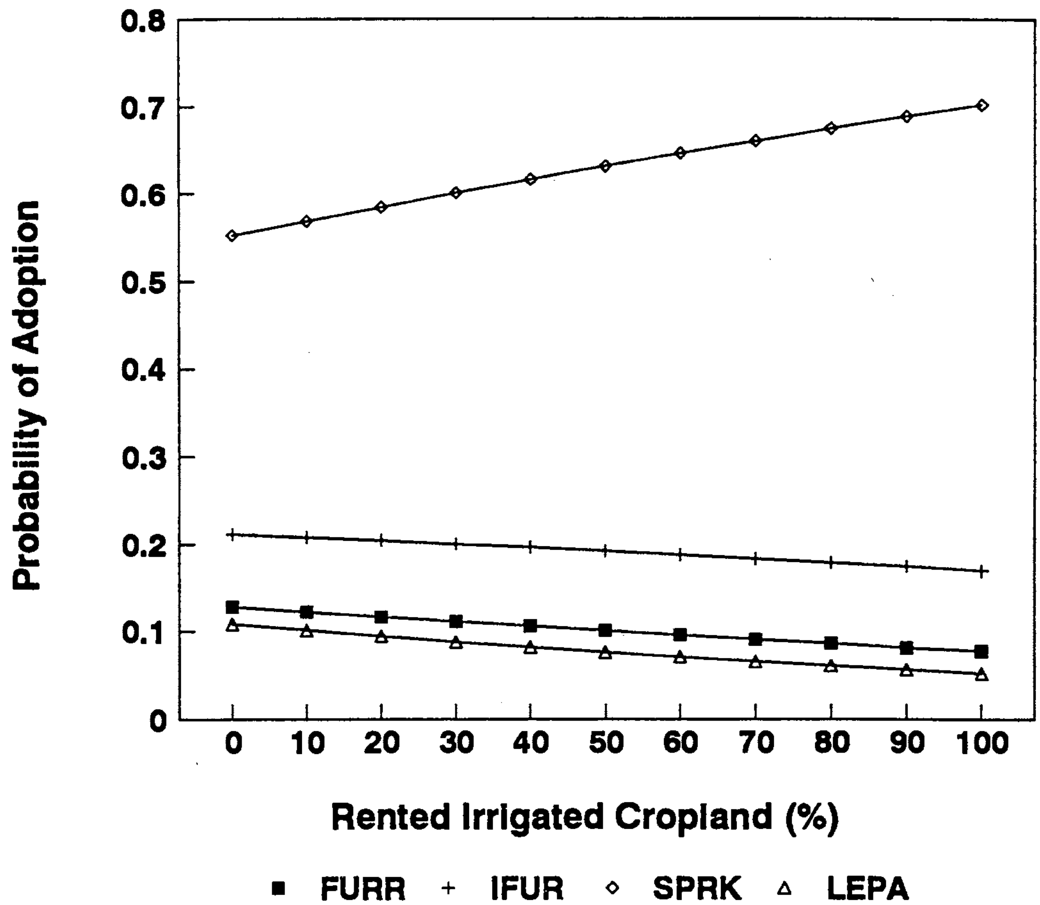

Figure 11. Predicted Probabilities of Irrigation Method Adoption by Percent of Irrigated Cropland Rented, Southwest Kansas

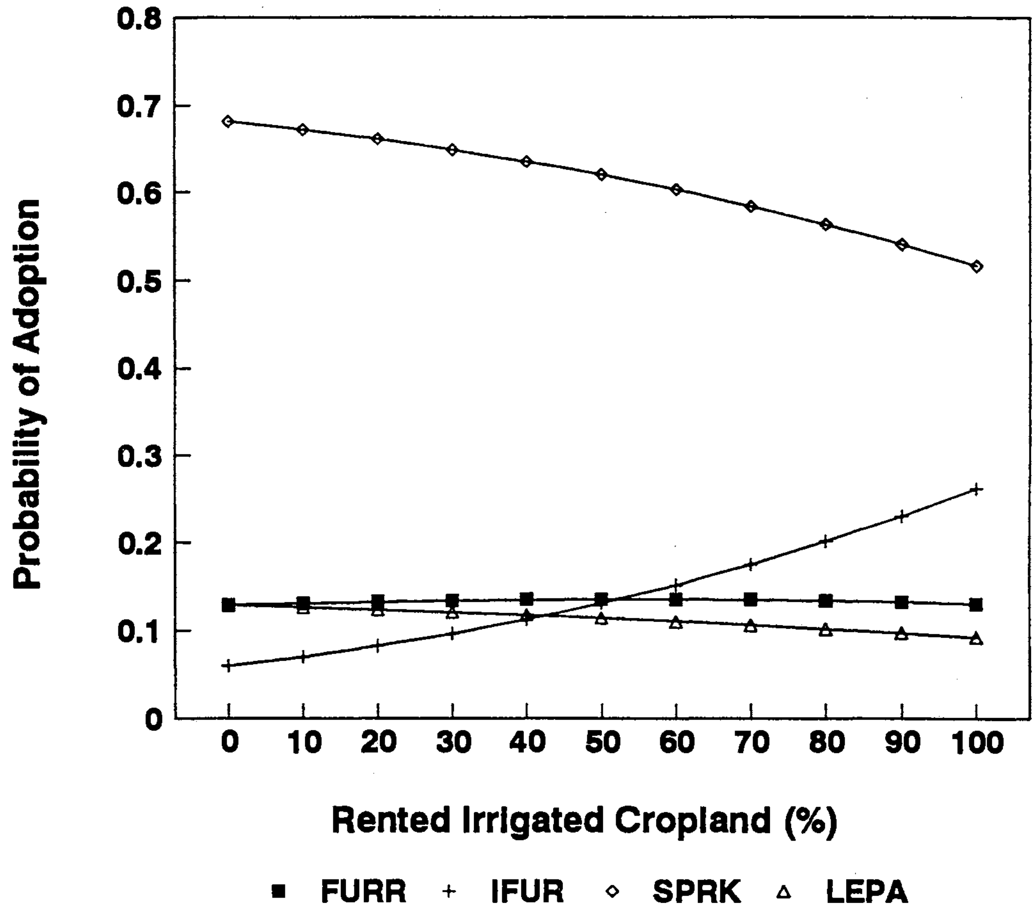

Figure 12. Predicted Probabilities of Irrigation Method Adoption by Percent of Irrigated Cropland Rented, Northern Texas Panhandle

increase considerably as the percent of rented irrigated cropland increases. Rented irrigated cropland has a strong negative effect on sprinkler adoption and a small negative effect on LEPA adoption probabilities in the Northern Texas Panhandle. Rented irrigated cropland has little effect on furrow adoption probabilities.

Irrigation method adoption probabilities for farms with and without land in the CRP are shown for Southwest Kansas and the Northern Texas Panhandle in Table 52. Southwest Kansas farms with land in the CRP have the highest probability of adopting sprinkler irrigation, while Southwest Kansas farms without land in the CRP have the highest probabilities of adopting furrow and improved furrow irrigation. Texas Panhandle farms with land in the CRP have the highest probability of adopting LEPA irrigation, while Northern Texas Panhandle farms without land in the CRP have the highest probabilities of adopting improved furrow and sprinkler irrigation.

Predicted Irrigation Method Adoption Probabilities by Information Source for Southwest Kansas and the Northern Texas Panhandle

Irrigation method adoption probabilities for irrigators who use only one information source are presented for Southwest Kansas and Northern Texas Panhandle in Table 53 and Table 54, respectively. Sprinkler adoption probabilities are greatest for irrigators using private agricultural consulting firms, irrigation equipment dealers, or the Soil Conservation Service in Southwest Kansas (Table 53). Use of these information sources also tends to result in the lowest furrow adoption probabilities. Thus, private agricultural consulting firms, irrigation equipment dealers, and the Soil

TABLE 52

PREDICTED PROBABILITIES OF IRRIGATION METHOD ADOPTION WITH AND WITHOUT ACRES IN THE CONSERVATION RESERVE PROGRAM, SOUTHWEST KANSAS AND THE NORTHERN TEXAS PANHANDLE

Southwest Kansas				
	Irrigation Method			
Acres in the CRP:	Furrow	Improved Furrow	Sprinkler	LEPA
Yes	0.044	0.108	0.789	0.059
No	0.148	0.243	0.525	0.084
Difference	-0.104	-0.135	0.264	-0.025
Subregion	0.102	0.193	0.626	0.078
Northern Texas Panhandle				
	Irrigation Method			
Acres in the CRP:	Furrow	Improved Furrow	Sprinkler	LEPA
Yes	0.129	0.072	0.616	0.183
No	0.135	0.119	0.649	0.097
Difference	-0.007	-0.047	-0.033	0.086
Subregion	0.134	0.102	0.644	0.120

TABLE 53

PREDICTED PROBABILITIES OF IRRIGATION METHOD ADOPTION ASSUMING THE IRRIGATOR USES ONLY ONE INFORMATION SOURCE, SOUTHWEST KANSAS

	Irrigation Method			
Information Source	Furrow	Improved Furrow	Sprinkler	LEPA
Irrigation Dealers	0.111	0.068	0.543	0.278
Private Consulting Firms	0.196	0.121	0.646	0.036
Friends and Neighbors	0.477	0.114	0.405	0.004
Soil Conservation Service	0.351	0.096	0.538	0.015
Extension	0.478	0.115	0.373	0.034
Groundwater District	0.536	0.077	0.368	0.018
Print	0.883	0.037	0.075	0.006
Own Experience	0.324	0.131	0.361	0.183
Chemical Dealers	0.689	0.075	0.165	0.071
Other Information Sources	0.460	0.156	0.378	0.007
Subregion	0.102	0.193	0.626	0.078

TABLE 54

PREDICTED PROBABILITIES OF IRRIGATION METHOD ADOPTION ASSUMING THE IRRIGATOR USES ONLY ONE INFORMATION SOURCE, NORTHERN TEXAS PANHANDLE

	Irrigation Method			
Information Source	Furrow	Improved Furrow	Sprinkler	LEPA
Irrigation Dealers	0.054	0.126	0.542	0.277
Private Consulting Firms	0.185	0.073	0.649	0.093
Friends and Neighbors	0.302	0.159	0.490	0.050
Soil Conservation Service	0.266	0.277	0.438	0.019
Extension	0.215	0.335	0.415	0.036
Groundwater District	0.699	0.058	0.223	0.020
Print	0.298	0.249	0.300	0.154
Own Experience	0.071	0.156	0.759	0.013
Chemical Dealers	0.677	0.116	0.205	0.003
Other Information Sources	0.104	0.774	0.029	0.093
Subregion	0.134	0.102	0.644	0.120

Conservation Service promote the use of sprinkler irrigation over furrow irrigation in Southwest Kansas. LEPA adoption probabilities are greatest for irrigators who use irrigation equipment dealers or irrigators who depend on their own experience, while furrow adoption probabilities are greatest for irrigators who use printed materials, chemical dealers, or groundwater districts. Single information sources appear to have little effect on improved furrow adoption probabilities in Southwest Kansas.

Sprinkler adoption probabilities in the Northern Texas Panhandle are greatest for irrigators who use their own experience, private agricultural consulting firms, or irrigation equipment dealers as sources of information (Table 54). Use of these information sources also tends to result in the lowest furrow adoption probabilities. LEPA adoption probabilities are greatest for irrigators who use irrigation equipment dealers or printed materials as their single source of information, while improved furrow adoption probabilities are greatest for irrigators who use "other information sources". Furrow adoption probabilities are greatest for irrigators who use groundwater districts or chemical dealers as their single source of information. This result is surprising, because groundwater districts promote water conservation. However, only one irrigator in the Northern Texas Panhandle indicated that he or she uses groundwater districts more often than any other information source when choosing irrigation systems or water management practices (see Chapter IV, Table 27). Thus, irrigators who use groundwater districts also rely heavily on other information sources when making irrigation technology adoption decisions.

The adoption probabilities in Tables 53 and 54 are based upon the assumption that irrigators use only one source of information when making irrigation technology adoption decisions. However, as was pointed out in Chapter V, most Central High Plains irrigators use an average of approximately three information sources when making irrigation technology adoption decisions. The majority of respondents in both Central High Plains subregions use irrigation equipment dealers and friends and neighbors (see Table 26 in Chapter IV). Thus, most irrigators in either subregion probably use irrigation equipment dealers, friends and neighbors, and at least one additional source of information.

Tables 55 and 56 present irrigation method adoption probabilities for irrigators who use irrigation equipment dealers, friends and neighbors, and one additional source of information in Southwest Kansas and the Northern Texas Panhandle, respectively. The probability of adopting sprinkler irrigation in Southwest Kansas is greatest when the additional information source is either the Soil Conservation Service, private agricultural consulting firms, no other information source, or groundwater districts (Table 55). The probability of LEPA adoption is greatest for irrigators who use either their own experience or chemical equipment dealers as their third source of information, while the probability of adopting furrow irrigation is greatest for irrigators who use printed materials as their third source of information. Improved furrow adoption probabilities are greatest for irrigators who use "other information sources" or their own experience as their third source of information.

The probability of adopting sprinkler irrigation in the Northern Texas Panhandle is greatest when irrigators use their own experience, the soil conservation service, and chemical equipment dealers as their third source of information (Table 56). LEPA adoption probabilities are greatest when the third information source is either "other information sources" or printed materials. The probability of furrow adoption is greatest for irrigators who use chemical dealers or groundwater districts as their third source of information, while improved furrow adoption probabilities are greatest for irrigators who use "other information sources" as their third source of information.

TABLE 55

PREDICTED PROBABILITIES OF IRRIGATION METHOD ADOPTION ASSUMING THE IRRIGATOR USES IRRIGATION DEALERS, FRIENDS AND NEIGHBORS, AND A THIRD INFORMATION SOURCE, SOUTHWEST KANSAS

Use Irrigation Dealers, Friends and Neighbors, and:	Irrigation Method			
	Furrow	Improved Furrow	Sprinkler	LEPA
No Other Information Source	0.120	0.135	0.674	0.071
Private Consulting Firms	0.029	0.158	0.730	0.083
Soil Conservation Service	0.063	0.152	0.742	0.043
Extension	0.098	0.208	0.587	0.108
Groundwater District	0.124	0.158	0.653	0.065
Print	0.470	0.173	0.306	0.051
Own Experience	0.045	0.163	0.389	0.402
Chemical Dealers	0.184	0.178	0.340	0.297
Other Information Sources	0.095	0.284	0.599	0.022
Subregion	0.102	0.193	0.626	0.078

TABLE 56

PREDICTED PROBABILITIES OF IRRIGATION METHOD ADOPTION ASSUMING THE IRRIGATOR USES IRRIGATION DEALERS, FRIENDS AND NEIGHBORS, AND A THIRD INFORMATION SOURCE, NORTHERN TEXAS PANHANDLE

Use Irrigation Dealers, Friends and Neighbors, and:	Irrigation Method			
	Furrow	Improved Furrow	Sprinkler	LEPA
No Other Information Source	0.051	0.078	0.588	0.283
Private Consulting Firms	0.021	0.015	0.588	0.376
Soil Conservation Service	0.053	0.103	0.704	0.140
Extension	0.039	0.114	0.611	0.236
Groundwater District	0.210	0.033	0.541	0.217
Print	0.034	0.053	0.276	0.637
Own Experience	0.010	0.042	0.881	0.067
Chemical Dealers	0.256	0.082	0.628	0.035
Other Information Sources	0.020	0.281	0.046	0.653
Subregion	0.134	0.102	0.644	0.120

CHAPTER VII

SUMMARY AND CONCLUSIONS

The High Plains region experienced a net water-level decline prior to 1980. Water-level declines within the region were greatest in the Southern and Central High Plains, where irrigation development was most extensive. Declining water-levels brought about increased pump lifts and reduced well yields and led to uncertainty about the sustainability of irrigated agriculture in many parts of the region. Water levels continued to decline throughout the 1980s. However, the rate of decline was slower during this period. The slower rate of decline was partially due to reduced use of conventional furrow irrigation and increased use of water-conserving irrigation technologies such as surge-flow furrow systems, center pivot sprinkler systems, and LEPA systems.

The goals of this study were (1) to identify the most important factors affecting the adoption of water-conserving irrigation technologies in the Central High Plains, and (2) to predict irrigation method adoption probabilities for different field, farm, and irrigator characteristics in the Central High Plains. These goals were accomplished using multinomial logit models of irrigation method adoption. Multinomial logit models relate the log odds of a particular choice being made to attributes or characteristics of the decision maker and are used in situations where the decision maker has three or more discrete alternatives. In this study, the decision maker (e.g., the irrigator) is assumed to choose among furrow, improved furrow, sprinkler, and LEPA irrigation systems. Furrow irrigation refers to irrigation technologies that deliver water either by open ditch or gated pipe. Improved furrow irrigation refers to gated pipe systems modified to control the flow of water running down the furrow (surge-flow and cablegation) or gated pipe systems with tailwater pits to capture field runoff. Sprinkler irrigation refers to irrigation technologies that combine equipment (spray nozzles, drop tubes, etc.) and energy in the form of pressurization to distribute water uniformly throughout the field. Finally, LEPA irrigation refers to Low Energy Precision Application systems that distribute water directly to the furrow at very low pressure through drop tubes and emitters.

The multinomial logit models were estimated using data collected by a mail survey from irrigators in Southwest Kansas and the Northern Texas Panhandle. The survey was conducted from mid-March to late-May, 1994 and was sent to 1513 possible irrigators within the two subregions (940 in Southwest Kansas and 573 in the Northern Texas Panhandle). Overall, the survey achieved a 17 percent response rate. Survey respondents provided information about the types of systems used on their farming operations and the field characteristics (soil type, field slope, etc.) associated with each system. Respondents also provided individual information about themselves, their farming operations, and the information sources they use when making irrigation technology adoption decisions.

Three multinomial logit models were estimated for the study; one for the entire Central High Plains region, one for Southwest Kansas, and one for the Northern Texas Panhandle. Field characteristics (soil type, field slope, pump lift), irrigator and farm characteristics (irrigator age, irrigator education, percent of irrigated cropland rented) and information sources were used as explanatory variables in each model. The estimated parameters of the three models were used to identify factors that significantly effect the likelihood of adopting water-conserving irrigation technologies and to predict the probability of adopting furrow, improved furrow, sprinkler, and LEPA irrigation in the Central High Plains, Southwest Kansas, and the Northern Texas Panhandle.

Goodness of fit measures for the three models were comparable to measures from previous studies (McFadden R^2 statistics equaled 0.2613, 0.3218, and 0.3387 for the Central High Plains model, the Southwest Kansas model, and the Northern Texas Panhandle model, respectively). Chi-square statistics indicated that all slope parameters as a group were significantly different from zero in every model. The percent of parameters significantly different from zero ranged from 49.3 percent for the Central High Plains model, 49.3 percent for the Southwest Kansas model, and 20.8 percent for the Northern Texas Panhandle model. The Northern Texas Panhandle model had fewer significant parameters primarily because it was estimated with fewer observations (237 system observations versus 585 for the Southwest Kansas model and 827 for the Central High Plains model).

Summary Results from the Multinomial Logit Models

Soil types, field slopes, pump lifts, and well yields have a significant impact on irrigation method adoption in the Central High Plains. Sprinkler adoption probabilities are greatest in areas with small pump lifts, in areas with small well yields, and on sandy fields and/or fields with high slopes. LEPA adoption probabilities are greatest in areas with large pump lifts and on sandy or clay fields and/or fields with high slopes. Improved furrow adoption probabilities are greatest in areas with large pump lifts, in areas with large well yields, and on loam or clay fields and/or fields with low to medium slopes. Finally, furrow adoption probabilities are greatest in areas with large well yields and on loam or clay fields and/or fields with low to medium slopes.

Increasing pump lifts have a greater effect on irrigation method adoption in the Northern Texas Panhandle, while increasing well yields have a greater effect on irrigation method adoption in Southwest Kansas. These results occur because of differences in aquifer characteristics between the two subregions. Pump lifts are much larger on average in the Northern Texas Panhandle. Thus increasing pump lifts have a greater impact on irrigation method adoption in this subregion. Alternatively, saturated thickness is more variable throughout Southwest Kansas. Therefore, well yields are more variable and have a greater impact on irrigation method adoption in this subregion.

The number of acres per well is positively related to the probabilities of adopting sprinkler and LEPA irrigation and negatively related to the probability of adopting furrow irrigation in the Central High Plains. Sprinkler and LEPA technologies are more water saving than furrow technologies. Thus, irrigators with large numbers of acres per well and declining water supplies are more likely to adopt sprinkler or LEPA technologies than reduce irrigated area or drill additional wells.

Irrigator age is negatively related to the probability of LEPA adoption while irrigator education is positively related to the probability of LEPA adoption in the Central High Plains. However, irrigator age has a smaller negative effect on LEPA adoption in the Northern Texas Panhandle than in Southwest Kansas. Also, irrigator education has a positive effect on the probability of LEPA adoption in Southwest Kansas but has a slight negative effect on the probability of LEPA adoption in the Northern Texas Panhandle. These results imply that Northern Texas Panhandle irrigators are more familiar with LEPA irrigation than Southwest Kansas irrigators. This is not surprising, since LEPA irrigation was first introduced in the Texas Panhandle in the early 1980s.

The percent of rented irrigated cropland on a farm has little effect on irrigation method adoption in the Central High Plains. However, the percent of rented irrigated cropland on a farm has a negative effect on the probabilities of adopting sprinkler and LEPA irrigation and a positive effect on the probability of adopting improved furrow irrigation in the Northern Texas Panhandle. This result is expected in cropland rental arrangements where the tenant is responsible for furnishing the irrigation system. The percent of rented irrigated cropland on a farm has little effect on irrigation method adoption in Southwest Kansas. Such a result may imply that landlords furnish the irrigation technology in many Southwest Kansas rental arrangements.

Farms with land in the Conservation Reserve Program (CRP) tend to have a higher probability of adopting sprinkler or LEPA irrigation than farms without land in the CRP in the Central High Plains. Farms with land in the CRP in Southwest Kansas have a high probability of adopting sprinkler irrigation, while farms with land in the CRP in the Northern Texas Panhandle have a high probability of adopting LEPA irrigation. These results may be related to land quality or water availability. Cultivated cropland on farms with land in the CRP may be lower in quality (e.g., more sandy or more prone to runoff) or have lower water availability than cultivated cropland on farms without land in the CRP. Sprinkler and LEPA systems are well suited for use on such cropland.

Information sources such as private agricultural consulting firms, irrigation equipment dealers, the Soil Conservation Service, and extension appear to promote the use of sprinkler irrigation over furrow irrigation in the Central High Plains. LEPA adoption probabilities are greatest for irrigators who use irrigation equipment dealers or their own personal experience and smallest for irrigators who use friends and neighbors as information sources. However, friends and neighbors have a smaller negative effect on the probability of LEPA adoption in the Northern Texas Panhandle than in Southwest Kansas. This result provides additional evidence that Northern Texas Panhandle irrigators are more familiar with LEPA irrigation than Southwest Kansas irrigators.

Conclusions of the Study

The results of this study provide some indication of where water-conserving irrigation technologies will most likely be adopted in the Central High Plains given continued declines in water-levels. Continuing water-level declines should have the greatest impact on LEPA usage in the Northern Texas Panhandle. The model results imply that LEPA irrigation is more energy efficient than either sprinkler or improved furrow irrigation in areas where pump lifts are large. The model results also indicate that LEPA irrigation is well suited for use on sandy fields, clay fields, or fields with high slopes. Thus, LEPA usage should expand in these areas as water-levels continue to decline in the Northern Texas Panhandle. Much of the expansion in LEPA usage should occur in the eastern counties of the Northern Texas Panhandle (Hutchinson, Lipscomb, Ochiltree, and Roberts). About 42 percent of the area in these counties has depths to water in excess of 300 feet, and nearly three-quarters of cropland area in these counties is composed of heavy clay loam soils (Mapp et al., 1991).

The model results indicate that sprinkler irrigation is well suited for use in areas with low well yields or in areas with sandy soils. Thus, expanded sprinkler usage should be greatest in the western counties of the Northern Texas Panhandle (Dallam, Hansford, Hartley, Moore, and Sherman). Two of these counties (Dallam and Hartley) have large areas with less than 100 feet of saturated thickness (McGrath and Dugan, 1991, page 21). Also, the western counties have a slightly larger percentage of cropland area with light sandy soils (36.4 percent, versus 27.3 percent in the eastern counties) and a smaller percentage of cropland area with depths to water in excess of 300 feet (25.6 percent versus 41.7 percent in the eastern counties) (Mapp et al., 1991).

Continued water-level declines should have the greatest impact on improved furrow adoption in Southwest Kansas. The model results indicate that pump lift effects on improved furrow adoption are much greater than pump lift effects on LEPA adoption. Thus, improved furrow irrigation may be more energy saving than LEPA irrigation in Southwest Kansas. However, LEPA irrigation does appear to be better suited for use on clay fields with high slopes. Thus, LEPA usage should expand on clay fields with high slopes while improved furrow usage should expand on loam and clay fields with low to medium slopes as water-levels continue to decline in Southwest Kansas. Sprinkler usage should expand, assuming that it is profitable and feasible, in areas where well yields have been reduced by declining water-levels or in any remaining undeveloped areas with sandy or hilly terrain in Southwest Kansas.

Expanded use of both improved furrow and LEPA irrigation should be greatest in the eastern counties of Southwest Kansas (Finney, Ford, Gray, Haskell, Meade, and Seward). Nearly half the cropland area in these counties is composed of heavy soils with low percolation volumes (Mapp et al., 1991). Alternatively, sprinkler expansion should be greatest in the western counties of Southwest Kansas (Grant, Hamilton, Kearny, Morton, Stanton, and Stevens), primarily because nearly 66 percent of cropland area in these counties is composed of light soils with medium to high water percolation volume (Mapp et al., 1991).

The results of this study can also be used to develop more accurate policies aimed at protecting groundwater in the Central High Plains. Water-conserving irrigation technologies have the potential to reduce runoff and percolation of nitrates and pesticides. Policy makers may be interested in the factors that lead to voluntarily adoption of water-conserving irrigation technologies. Policy makers may also be interested in knowing the locations where such technologies have the highest or lowest probabilities of being adopted. Given this information, policy makers can develop incentive policies that promote the use of water-conserving irrigation technologies in areas where such technologies are least likely to be adopted.

Irrigation method adoption probabilities by soil type can be used to illustrate this point. Furrow irrigation is the least efficient water application method of the four analyzed in this study. Predicted irrigation method adoption probabilities by soil type in the Central High Plains reveal that furrow adoption probabilities are smallest and sprinkler adoption probabilities are greatest on sandy fields. These results imply that Central High Plains irrigators are voluntarily using water-conserving irrigation technologies on soils that have a high potential for water percolation. Thus, sprinkler adoption incentives may be unnecessary for light sandy soils in the Central High Plains.

Predicted furrow adoption probabilities are fairly large on fields with loam and clay soils. Improved furrow adoption probabilities are also large on loam soils. Loam and clay soils are not as susceptible to water percolation as sandy soils. However, many loam type soils have medium percolation volumes while many clay type soils have high runoff volumes in the Central High Plains. Many of the medium percolation loam soils are located in Southwest Kansas (e.g., Richfield silty loam soils) while many of the high runoff clay soils are located in the Northern Texas Panhandle (e.g., Sherm silty clay loam and Sherm clay loam soils). Sprinkler technologies may be more appropriate than either furrow or improved furrow technologies on loam soils with medium percolation volume, while improved furrow or LEPA technologies may be more appropriate than furrow technologies on clay soils with high runoff volume. LEPA irrigation appears to be extremely well suited for use on clay type soils due to the land management practices used in conjunction with LEPA irrigation (e.g., furrow diking and planting in a circle). These land management practices reduce water runoff and allow for better utilization of rainwater.

Limitations and Need for Further Research

This research has several limitations which need to be addressed. One limitation of the study was the low survey response rate. The overall response rate for the survey was 17 percent, which was disappointing. The low overall response rate can be attributed to several factors. First, the mailing lists used for the survey contained several addresses of non-irrigators, retired irrigators, or deceased irrigators. No distinction could be made between such addresses and addresses of actual irrigators. Thus, the irrigation survey was sent to many people who were unable to respond to the questions. Second, the survey was relatively long and complex. The survey ranged from six pages for irrigators operating less than five irrigation systems to nine pages for irrigators operating five or more irrigation systems.

A second limitation of the study is that it ignored irrigators from the Oklahoma Panhandle. This researcher was unable to obtain a mailing list for the Oklahoma Panhandle. Thus, the results of the survey are probably not representative of the entire Central High Plains region.

A third limitation of the study is that not every important irrigation technology adoption factor was included in the multinomial logit analysis. Results from Question B5 of the Central High Plains Irrigation Survey indicate that greater water savings, energy cost, better timing of water application, the possibility of higher crop yields, and irrigation system cost are important factors affecting irrigation technology adoption in the Central High Plains. The soil type dummy variables, the well yield variable, and the acres per well variable captured the effects of greater water savings on irrigation technology adoption in the Central High Plains, while the pump lift variable served as a proxy for energy savings. However, variables measuring better timing of water application and potential for higher crop yields were excluded from the multinomial logit analysis. Even though irrigators were asked if these factors are important, no data were available from the survey to measure these variables. Finally, financial variables measuring irrigation system cost or irrigator net worth were excluded from the multinomial logit analysis. Data for such variables were not collected by the survey due to sensitivity of answering questions about financial information. However, the results from Question B5 indicate that irrigation system cost is not as important to Central High Plains irrigators as greater water savings and energy cost. Also, only two percent of irrigators identified credit availability as being an important factor affecting their decision to adopt water-conserving irrigation technologies. These results imply that Central High Plains irrigators have little difficulty in obtaining credit for the purchase of water-conserving irrigation technologies.

This study demonstrates that field characteristics, irrigator characteristics, farm characteristics, and information sources have significant effects on irrigation method adoption in the Central High Plains. The multinomial logit models can be used to predict unique irrigation method adoption probabilities for different areas in the Central High Plains based on spatial characteristics such as soil type and pump lift. However, this study is concerned with cross-sectional effects alone and ignores the effects of time. More work is needed to determine how irrigation method adoption probabilities change over time in the Central High Plains. Also, the predicted irrigation method adoption probabilities in this study are independent of the current system being used by the irrigator. For example, the multinomial logit model for this study cannot be used to predict the probability of adopting LEPA irrigation given that furrow irrigation is currently being used. Future research should focus on estimating irrigation method adoption probabilities that are conditional on the current irrigation method used.

REFERENCES

Burt, Charles. "Technological Developments in the United States." Chapter 5 of Technological and Institutional Innovation in Irrigation, edited by Guy Le Moigne, Shawki Barghouti, and Herve Plusquellec. World Bank Technical Paper Number 94. 1989.

Caswell, Margriet F. "Irrigation Technology Adoption Decisions: Empirical Evidence." In: Dinar, Arieal and David Zilberman (Ed.) The Economics and Management of Water and Drainage in Agriculture. Kluwer Academic Publishers, Norwell, Massachusetts, 1991.

Caswell, Margriet F. and David Zilberman. "The Choices of Irrigation Technologies in California." American Journal of Agricultural Economics. 67(1985):224-234.

Caswell, Margriet F. and David Zilberman. "The Effects of Well Depth and Land Quality on the Choice of Irrigation Technology." American Journal of Agricultural Economics. 68(1986):798-811.

Caswell, Margriet, Erik Lichtenberg, and David Zilberman. "The Effects of Pricing Policies on Water Conservation and Drainage." American Journal of Agricultural Economics. 72(1990):883-890.

Christenson, James A. "A Procedure for Conducting Mail Surveys with the General Public." Journal of Community Development Society. Vol.6, No.1(1975):135-146.

Coupal, Roger H. and Paul N. Wilson. "Adopting Water-Conserving Irrigation Technology: The Case of Surge Irrigation in Arizona." Agricultural Water Management. 18(1990)15-28.

Dinar, Ariel and Dan Yaron. "Influence of Quality and Scarcity of Inputs on the Adoption of Modern Irrigation Technologies." Western Journal of Agricultural Economics. 15(1990):224-233.

Domencich, T. A. and D. McFadden. Urban Travel Demand: Behavioral Analysis. Amsterdam: North-Holland Publishing Company, 1975.

Earls, Raylon, Oklahoma Panhandle farmer and former Oklahoma State University Extension Agricultural Economics Specialist (Personal Communication, 1994).

Elliott, Ronald L. Department of Agricultural Engineering, Oklahoma State University (Personal Communication, 1994).

Feder, Gershon, Richard E. Just, and David Zilberman. "Adoption of Agricultural Innovations in Developing Countries: A Survey." Economic Development and Cultural Change. 33(1985):255-298.

Feder, Gershon and Gerald T. O'Mara. "Farm Size and the Diffusion of Green Revolution Technology." Economic Development and Cultural Change. 30(1981):59-76.

Fipps, G. and L.L. New. "Six Years of LEPA in Texas - Less Water, Higher Yields." Proceedings of the Third National Irrigation Symposium, Phoenix, Arizona, Oct. 28-Nov. 1 (ASAE Publication 04-90). 1990.

Frost, Steven, Director. Southwest Kansas Groundwater Management District #3. Garden City, Kansas (Personal Communication, 1994).

Gollehon, Noel R. USDA ERS Water Branch. Washington, D.C. (Personal Communication, 1994).

Griliches, Zvi. "Hybrid Corn: An Exploration in the Economics of Technological Change." Econometrica. Vol. 25, No.4(1957):504-522.

Gutentag, Edwin D., Frederick J. Heimes, Noel C. Krothe, Richard R. Lucky, and John B. Weeks. Geohydrology of the High Plains Aquifer in Parts of Colorado, Kansas, Nebraska, New Mexico, Oklahoma, South Dakota, Texas, and Wyoming. U.S. Geological Survey Professional Paper No 1400-B. 1984.

Hiebert, Dean L. "Risk, Learning, and the Adoption of Fertilizer Responsive Seed Varieties." American Journal of Agricultural Economics. 56(1974):764-768.

Hodges, Mark. Extension Agronomy Specialist. Oklahoma State University Cooperative Extension Service (Personal Communication, 1994).

Hornbaker, Robert H. and Harry P. Mapp. "A Dynamic Analysis of Water Savings from Advanced Irrigation Technology." Western Journal of Agricultural Economics. 13(1988):307-315.

Jarvis, Lovell S. "Predicting the Diffusion of Improved Pastures in Uruguay." American Journal of Agricultural Economics. 63(1981):495-502.

Judge, George G., William E. Griffiths, R. Carter Hill, Helmut Lütkepohl, and Tsoung-Chao Lee. The Theory and Practice of Econometrics. John Wiley and Sons Inc. 1985.

Judge, George G., R. Carter Hill, William E. Griffiths, Helmut Lütkepohl, and Tsoung-Chao Lee. Introduction to the Theory and Practice of Econometrics. John Wiley and Sons Inc. 1988.

Kansas Agricultural Statistics Service, 1993 Kansas Farm Facts, 1993.

Kansas State University Cooperative Extension Service, "1978 Kansas Irrigation Survey."

Kansas State University Cooperative Extension Service, "1982 Kansas Irrigation Survey."

Kastner, William M., Donald E. Schild, and Debra S. Spahr. Water-Level Changes in the High Plains Aquifer Underlying Parts of South Dakota, Wyoming, Nebraska, Colorado, Kansas, New Mexico, Oklahoma, and Texas--Predevelopment Through Nonirrigation Season 1987-88. U.S. Geological Survey Water-Resources Investigations Report No. 89-4073. 1989.

Kletke, Darrel D., Thomas R. Harris, and Harry P. Mapp, Jr. Irrigation Cost Program Users Reference Manual Oklahoma State University. Oklahoma Agricultural Experiment Station Report P-770, Stillwater, Ok, May, 1978.

Kizer, Michael A. Department of Agricultural Engineering, Oklahoma State University (Personal Communication, 1994).

Kromm, David E. and Stephen E. White. "Adoption of Water-Saving Practices by Irrigators in the High Plains." Water Resources Bulletin. 26(1990):999-1012.

Kromm, David E. and Stephen E. White. "Groundwater Problems," Chapter 3 of Groundwater Exploitation in the High Plains, edited by David E. Kromm and Stephen E. White. Lawrence: University Press of Kansas, 1992.

Kromm, David E. and Stephen E. White. "Reliance on Sources of Information for Water-Saving Practices by Irrigators in the High Plains of the U.S.A." Journal of Rural Studies. 7(1991):411-421.

Lee, John G., John R. Ellis, and Ronald D. Lacewell. "Valuation of Improved Irrigation Efficiency From an Exhaustible Groundwater Source." Water Resources Bulletin. 21(1985):441-447.

Lee, Linda K. and William H. Stewart. "Landownership and the Adoption of Minimum Tillage." American Journal of Agricultural Economics. 65(1983):256-264.

Letey, J., A. Dinar, C. Woodring, and J. D. Oster. "An Economic Analysis of Irrigation Systems." Irrigation Science. 11(1991):37-43.

Lichtenberg, Eric. "Land Quality, Irrigation Development, and Cropping Patterns in the Northern High Plains." American Journal of Agricultural Economics. 71(1989):187-194.

Luckey, Richard R., Edwin D. Gutentag, Frederick J. Heimes, and John B. Weeks. Digital Simulation of Ground-Water Flow in the High Plains Aquifer in Parts of Colorado, Kansas, Nebraska, New Mexico, Oklahoma, South Dakota, Texas, and Wyoming. U.S. Geological Survey Professional Paper No. 1400-D. 1986.

Lyle, W.M. and J.P. Bordovsky. "LEPA Irrigation System Evaluation." Transactions of the ASAE. Vol.26, No.3(1983):776-781.

Mansfield, Edwin. "Technical Change and The Rate of Imitation." Econometrica. Vol. 29, No.4(1961):741-765.

Mapp, Harry P., "Irrigated Agriculture on the High Plains: An Uncertain Future." Western Journal of Agricultural Economics. 13(1988):339-347.

Mapp, Harry P., Daniel J. Bernardo, George J. Sabbagh, Samuel Geleta, Mark L. Teague, K. Bradley Watkins, JunJie Wu, Ronald L. Elliott, and John F. Stone, Agricultural Practices and Groundwater Quality in the High Plains: Impacts of State, Regional, and National Policies. Final Report, U.S. Geological Survey, Washington, D.C., May, 1994.

Mapp, Harry P., Daniel J. Bernardo, George J. Sabbagh, Samuel Geleta, K. Bradley Watkins, Ronald L. Elliott, and John F. Stone, Impacts of Agricultural Production Practices on the Quantity and Quality of Groundwater in the Central High Plains. Final Report, U.S. Geological Survey, Washington, D.C., November, 1991.

Masud, Sharif M. and Ronald D. Lacewell. "Energy, Water, and Economic Savings of Improved Production Systems on the Texas High Plains." American Journal of Alternative Agriculture. Vol.5, No.2(1990):69-75.

McClain, Thomas J. and Robert W. Buddemeiser. January 1993 Kansas Water Levels and Data Related to Water-Level Changes. Kansas Geological Survey, Technical Series No. 4, 1994.

McGrath, Timothy and Jack T. Dugan. Water-Level Changes in the High Plains Aquifer--Predevelopment to 1991. U.S. Geological Survey Water-Resources Investigations Report No. 93-4088. 1993

Musick, J.T., F.B. Pringle, W.L. Harman, and B.A. Stewart. "Long-Term Irrigation Trends - Texas High Plains." Applied Engineering in Agriculture. Vol. 6, No. 6(1990):717-724.

Musick, J.T., F.B. Pringle, and J.D. Walker. "Sprinkler and Furrow Irrigation Trends -Texas High Plains." Applied Engineering in Agriculture. Vol. 4, No. 1(1988):46-52.

Negri, Donald H., and Douglas H. Brooks. "Determinants of Irrigation Technology Choice." Western Journal of Agricultural Economics. 15(1990):213-223.

Negri, Donald H. and John J. Hanchar. "Water Conservation Through Irrigation Technology." USDA, ERS, Agricultural Information Bulletin No. 576. November 1989.

Nieswiadomy, Michael L., "Input Substitution in Irrigated Agriculture in the High Plains of Texas, 1970-80." Western Journal of Agricultural Economics. 13(1988):63-70.

Piatt, Donald. Field Engineer. North Plains Underground Water Conservation District #2. Dumas, Texas (Personal Communication, 1994).

Pindyck, Robert S. and Daniel L. Rubinfeld. Econometric Models and Economic Forecasts. McGraw-Hill, Inc., 1981.

Pulter, Daniel S. and David Zilberman. "Computer Use in Agriculture: Evidence from Tulare County, California." American Journal of Agricultural Economics. 70(1988):790-802.

Rahm, Michael R. and Wallace E. Huffman. "The Adoption of Reduced Tillage: The Role of Human Capital and Other Variables." American Journal of Agricultural Economics. 66(1984):405-413.

Rogers, Everett. Diffusion of Innovations. New York: Free Press of Glencoe, 1962.

Schmidt, Peter and Robert P. Strauss. "Prediction of Occupation Using Multiple Logit Models." International Economic Review. Vol.16, No.2(1975):471-486.

Shrestha, Rajendra B. and Chennat Gopalakrishnan. "Adoption and Diffusion of Drip Irrigation Technology: An Econometric Analysis." Economic Development and Cultural Change. 41(1993):407-418.

Texas Agricultural Statistics Service, 1992 Texas Crop Statistics, 1993.

Texas Water Development Board, Surveys of Irrigation in Texas-1958, 1964, 1969, 1974, 1979, 1984, and 1989. Report No. 329, January, 1991.

Weeks, John B., "High Plains Regional Aquifer-System Study." Regional Aquifer-System Analysis Program of the U.S. Geological Survey Summary of Projects, 1978-84, Edited by Ren Jen Sun. U.S. Geological Survey Circular No. 1002. 1986.

APPENDIXES

APPENDIX A

SURVEY, COVER LETTERS, AND REMINDER

CENTRAL HIGH PLAINS IRRIGATION SURVEY

A. FARM OPERATOR CHARACTERISTICS.

1. In which region is the largest part of your farm operation located (Please circle one):
   a. Southwest Kansas
   b. Oklahoma Panhandle
   c. North Plains (northern Texas Panhandle)
   d. None of the above (If none of the above, please mail this survey form back in the enclosed envelope. Otherwise, continue to the next question.)

2. Do you practice irrigation on your farm operation?
   ___ If no, please mail this survey form back in the enclosed envelope. ___ If yes, please continue to the next question.

3. In what county or counties is your farm operation located? ______________________

4. What is your age? (Please circle one):
   a. less than 25 years
   b. between 25 and 29 years
   c. between 30 and 34 years
   d. between 35 and 39 years
   e. between 40 and 44 years
   f. between 45 and 49 years
   g. between 50 and 54 years
   h. between 55 and 59 years
   i. between 60 and 64 years
   j. 65 or older

5. How many years have you farmed? __________

6. Number of years of education. (Please circle one):
   a. Less than 12
   b. 12 but less than 14
   c. 14 but less than 16
   d. 16 but less than 18
   e. 18 or more

7. Does your education include any vocational/technical training? **YES** **NO**

B. GENERAL FARM INFORMATION.

		OWNED	RENTED
1.	How many acres of cropland do you farm?	________	________
2.	How many farmed cropland acres are irrigated?	________	________
3.	How many acres of cropland are devoted to the Conservation Reserve Program (CRP)?	________	

4. What information source or sources do you use when choosing irrigation systems or water management practices? (Please circle all that apply):
   a. Extension agents
   b. Irrigation dealers
   c. Groundwater management district
   d. Private consulting firm
   e. Chemical dealers
   f. Soil Conservation Service
   g. Talking to neighbors (word of mouth)
   h. Other (please specify) ______________________

   If you use more than one information source, which of the above information sources do you use most often? _____

5. Listed below is a set of factors that have been identified from previous research as being important in the choice of adopting water conserving irrigation technologies. Indicate the relative importance of each by circling a number between 1 (not important) and 5 (very important).

ADOPTION FACTORS	NOT IMPORTANT				VERY IMPORTANT
a. Possibility of higher yields	1	2	3	4	5
b. Better timing of water application (better application control)	1	2	3	4	5
c. Greater water savings (or better utilization of water applied)	1	2	3	4	5
d. Credit availability	1	2	3	4	5
e. Labor availability	1	2	3	4	5
f. Irrigation system cost	1	2	3	4	5
g. Energy cost	1	2	3	4	5
h. Reductions in nitrogen and pesticide losses	1	2	3	4	5
i. Other ________________	1	2	3	4	5

Which of the above adoption factors do you consider to be most important when choosing new irrigation technologies? _____

6. How do you determine when to apply irrigation water? (Please circle all that apply):
   a. Condition of crop (observation)
   b. Feel of the soil
   c. Use of soil moisture sensing devices such as moisture blocks, neutron probes, or tensiometers
   d. Use of commercial scheduling service
   e. Media reports on crop-water needs (newspapers, radio, and TV)
   f. By calendar schedule
   g. Other (please specify) ____________________________

7. Please indicate the types of irrigation management practices you use. (Please circle all that apply):
   a. Preplant irrigation
   b. Water the crop up
   c. Measure rainfall
   d. Alternate row irrigation
   e. Re-circulating surface water runoff
   f. Limited irrigation
   g. Meter water use
   h. Other (please specify) ____________________________

8. Please indicate the types of field practices you use on irrigated land. (Please circle all that apply):
   a. Precision field leveling (or laser leveling)
   b. Compact furrows to speed stream advance
   c. Inter-furrow ripping
   d. Furrow diking
   e. Other (please specify) ____________________________

C. IRRIGATION SYSTEM QUESTIONS

The following questions were developed to obtain specific information about each irrigation system used on your farm. Please fill in one column of answers for every irrigation system you operate. Four additional columns are provided on the back of the survey form if you operate more than four irrigation systems (if you operate more than eight systems, you need only answer for eight). The following definitions should be helpful when answering questions concerning irrigation system type:

High pressure center pivot - any center pivot system with a pressure of approximately 60 or more pounds per square inch (PSI) at the pivot point.

Low pressure center pivot - any center pivot system with a pressure under 60 pounds per square inch (PSI) at the pivot point.

Low energy precision application (LEPA) - a center pivot system that applies water below the leaf canopy through drop tubes and either trailing hoses or low-pressure emitters.

		SYSTEM 1	SYSTEM 2	SYSTEM 3	SYSTEM 4
1.	Current System used (please check one for each system):				
	a. Open ditch, siphon tubes	____	____	____	____
	b. Open ditch with tailwater recovery pits	____	____	____	____
	c. Gated pipe	____	____	____	____
	d. Gated pipe with surge-flow valves, cablegation, and/or tailwater recovery pits	____	____	____	____
	e. Side roll sprinkler	____	____	____	____
	f. Hand move sprinkler	____	____	____	____
	g. Linear move sprinkler	____	____	____	____
	h. High pressure center pivot	____	____	____	____
	i. Low pressure center pivot	____	____	____	____
	j. Low energy precision application (LEPA)	____	____	____	____
	k. Other __________	____	____	____	____
2.	System Includes the following modifications (check if appropriate):				
	a. Drop tubes	____	____	____	____
	b. Low pressure spray heads	____	____	____	____
	c. Chemigation equipment	____	____	____	____
	d. Wheel track closing devices	____	____	____	____
	e. Other __________	____	____	____	____
	f. None	____	____	____	____
3.	Year current system was installed	________	________	________	________
4.	Average cost per unit of fuel used by current system				
	a. Natural gas ($ per MCF)	________	________	________	________
	b. Electric ($ per KWH)	________	________	________	________
	c. Diesel ($ per Gallon)	________	________	________	________
	d. Gasoline ($ per Gallon)	________	________	________	________
	e. LPG ($ per Gallon)	________	________	________	________
5.	Number of wells serving system	________	________	________	________
6.	Average pump lift (in feet) of well(s) serving system	________	________	________	________
7.	Total gallons per minute from well(s) serving system	________	________	________	________

		SYSTEM 1	SYSTEM 2	SYSTEM 3	SYSTEM 4
8.	Predominant soil type irrigated by system (please check one for each system):				
	a. Sand	____	____	____	____
	b. Sandy loam	____	____	____	____
	c. Loam	____	____	____	____
	d. Clay loam	____	____	____	____
	e. Clay	____	____	____	____
9.	Predominant slope of acres irrigated by system (please check one for each system):				
	a. Low slope (less than one percent)	____	____	____	____
	b. Moderate slope (1 to 3 percent)	____	____	____	____
	c. High slope (Greater than 3 percent)	____	____	____	____
10.	Acres of crops irrigated in most recent crop year:				
	a. Corn	________	________	________	________
	b. Wheat	________	________	________	________
	c. Grain sorghum	________	________	________	________
	d. Alfalfa hay	________	________	________	________
	e. Cotton	________	________	________	________
	f. Other __________	________	________	________	________
11.	Approximate inches of irrigation water applied per season to:				
	a. Corn	________	________	________	________
	b. Wheat	________	________	________	________
	c. Grain sorghum	________	________	________	________
	d. Alfalfa hay	________	________	________	________
	e. Cotton	________	________	________	________
	f. Other __________	________	________	________	________
12.	Number of times water was applied to:				
	a. Corn	________	________	________	________
	b. Wheat	________	________	________	________
	c. Grain sorghum	________	________	________	________
	d. Alfalfa hay	________	________	________	________
	e. Cotton	________	________	________	________
	f. Other __________	________	________	________	________

		SYSTEM 1	SYSTEM 2	SYSTEM 3	SYSTEM 4
13.	Approximate number of hours required to complete one irrigation of:				
	a. Corn	____	____	____	____
	b. Wheat	____	____	____	____
	c. Grain sorghum	____	____	____	____
	d. Alfalfa hay	____	____	____	____
	e. Cotton	____	____	____	____
	f. Other ____________	____	____	____	____
14.	System used prior to the current system (please check one):				
	a. Open ditch, siphon tubes	____	____	____	____
	b. Open ditch with tailwater recovery pits	____	____	____	____
	c. Gated pipe	____	____	____	____
	d. Gated pipe with surge-flow valves, cablegation, and/or tailwater recovery pits	____	____	____	____
	e. Side roll sprinkler	____	____	____	____
	f. Hand move sprinkler	____	____	____	____
	g. Linear move sprinkler	____	____	____	____
	h. High pressure center pivot	____	____	____	____
	i. Low pressure center pivot	____	____	____	____
	j. Low energy precision application (LEPA)	____	____	____	____
	k. Other ____________	____	____	____	____
	l. None	____	____	____	____
15.	Year previous system was installed	____	____	____	____

16. Soil conservation programs have often included cost sharing provisions. If conservation programs were available to encourage adoption of new irrigation technologies, which of the following would you prefer: (please circle one):

a. A program involving sharing of the cost of a new irrigation system.

b. A program involving a low interest loan on the purchase of a new irrigation system.

c. I would prefer neither policy.

SOUTHWEST KANSAS COVER LETTER

Date: March 2, 1994

To: IRRIGATORS IN SOUTHWEST KANSAS

From: Brad Watkins, Ph.D. candidate, Agricultural Economics

Subject: 1994 CENTRAL HIGH PLAINS IRRIGATION SURVEY

The purpose of this survey is to gain a better understanding of the factors involved in your decision to adopt new or improved irrigation technologies. Researchers are interested in the reasons one irrigation system is preferred over another. The only way to obtain information of this nature is by surveying farmers. Thus, your response to the survey will provide us with much needed knowledge about the economic and physical factors involved in your irrigation technology adoption decision.

This research project is funded by the Department of Agricultural Economics at Oklahoma State University and is being conducted with the cooperation of the Southwest Kansas Groundwater Management District headquartered in Garden City, Kansas. The survey will be sent to irrigators throughout the entire Central High Plains region (from Southwest Kansas through the North Plains region of the Texas Panhandle). The results of the survey will be used to identify the factors most important to irrigation system adoption and to estimate the rate of adoption of specific irrigation technologies within your region.

Information will be summarized only for the region in which your farm is located. No individual information will be divulged. The number on the survey form allows us to know you have responded (we may need to send a reminder to those who have not). When you respond, the individual identification will be destroyed. However, if you have strong objections to the identification, mark out the number before you mail. We pledge full confidentiality.

Please take some time to complete the survey and mail it back using the enclosed, addressed, postage paid return envelope. If your farm is not located in Southwest Kansas or in the Central High Plains, you need not answer the survey. Simply mail the survey back in the enclosed envelope. Thank You.

Sincerely

Brad Watkins,
Ph.D. Candidate, O.S.U.

NORTHERN TEXAS PANHANDLE COVER LETTER

Date: March 2, 1994

To: IRRIGATORS IN THE NORTH PLAINS REGION OF THE TEXAS PANHANDLE

From: K. Bradley Watkins, Ph.D. candidate, Agricultural Economics.

Subject: 1994 CENTRAL HIGH PLAINS IRRIGATION SURVEY

The purpose of this survey is to gain a better understanding of the factors involved in your decision to adopt new or improved irrigation technologies. Researchers are interested in the reasons one irrigation system is preferred over another. The only way to obtain information of this nature is by surveying farmers. Thus, your response to the survey will provide us with much needed knowledge about the economic and physical factors involved in your irrigation technology adoption decision.

This research project is funded by the Department of Agricultural Economics at Oklahoma State University. The survey will be sent to irrigators throughout the entire Central High Plains region (from Southwest Kansas through the North Plains region of the Texas Panhandle). The results of the survey will be used to identify the factors most important to irrigation system adoption and to estimate the rate of adoption of specific irrigation technologies within your region.

Information will be summarized only for the region in which your farm is located. No individual information will be divulged. The number on the survey form allows us to know you have responded (we may need to send a reminder to those who have not). When you respond, the individual identification will be destroyed. However, if you have strong objections to the identification, mark out the number before you mail. We pledge full confidentiality.

Please take some time to complete the survey and mail it back using the enclosed, addressed, postage paid return envelope. If your farm is not located in the North Plains region of the Texas Panhandle or in the Central High Plains, you need not answer the survey. Simply mail the survey back in the enclosed envelope. Thank You.

Sincerely

Brad Watkins,
Ph.D. Candidate

REMINDER POST CARD

Dear Irrigator:

A few weeks ago, we sent you a survey concerning irrigation system adoption in Southwest Kansas (North Plains region of the Texas Panhandle). We at Oklahoma State University have not received your completed survey. With your assistance, we want to identify the economic and physical factors considered most important in the irrigator's decision to adopt new or improved irrigation technologies. You can provide important information that can benefit both yourself and other irrigators in Southwest Kansas (North Plains region of the Texas Panhandle). We pledge that your individual information will be kept strictly confidential.

Won't you please send us your completed survey? We need a good representative sample of irrigators, including you! If you have already mailed your survey, please disregard this reminder. If you need another copy of the survey or have questions, please call (405) 744-6702. Thank you for your cooperation.

Brad Watkins
Ph.D Candidate, O.S.U.

APPENDIX B

STATISTICS USED TO ESTIMATE IRRIGATION METHOD ADOPTION PROBABILITIES AND PREDICTED IRRIGATION METHOD ADOPTION PROBABILITIES FOR CONTINUOUS VARIABLES

TABLE 57

STATISTICS USED IN THE ESTIMATION OF IRRIGATION METHOD ADOPTION PROBABILITIES FOR THE CENTRAL HIGH PLAINS REGION, SOUTHWEST KANSAS, AND THE NORTHERN TEXAS PANHANDLE

Means of the Explanatory Variables			
Variable	Central High Plains	Southwest Kansas	Northern Texas Panhandle
Well yield (GPM/well)	744	814	670
Pump lift (feet)	261	228	341
Sand	0.502	0.511	0.479
Clay	0.215	0.173	0.325
Low slope	0.392	0.356	0.485
High slope	0.096	0.091	0.109
Acres per well	116	114	120
CRP	0.331	0.335	0.318
Rented irr. cropland (percent)	0.394	0.466	0.337
Age between 40 and 54 years	0.393	0.393	0.394
Age greater than 55 years	0.490	0.476	0.530
Education greater than 14 years	0.520	0.489	0.606
Vocational/Technical Training	0.331	0.325	0.348
Irrigation Dealer	0.734	0.747	0.712
Private consulting firm	0.273	0.311	0.167
Soil Conservation Service	0.359	0.353	0.379
Extension	0.305	0.290	0.349
Friends and Neighbors	0.750	0.732	0.803
Print	0.035	0.032	0.046
Own experience	0.086	0.090	0.076

TABLE 57 CONTINUED

Means of the Explanatory Variables			
Variable	Central High Plains	Southwest Kansas	Northern Texas Panhandle
Groundwater districts	0.305	0.300	0.318
Other information sources	0.047	0.042	0.061
Southwest Kansas	0.723	---	---

Standard Deviations of Continuous Variables			
Variable	Central High Plains	Southwest Kansas	Northern Texas Panhandle
Well yield (GPM/well)	335.9	367.4	200.4
Pump lift (feet)	108.4	95.5	95.7
Acres per well	57.9	54.5	66.0

TABLE 58

PREDICTED PROBABILITIES OF IRRIGATION METHOD ADOPTION BY PUMP LIFT, CENTRAL HIGH PLAINS REGION

Pump Lift (feet)	Irrigation Method			
	Furrow	Improved Furrow	Sprinkler	LEPA
150	0.116	0.086	0.730	0.068
170	0.120	0.097	0.709	0.075
190	0.123	0.109	0.685	0.082
210	0.126	0.123	0.661	0.090
230	0.129	0.138	0.635	0.098
250	0.131	0.154	0.608	0.107
270	0.133	0.171	0.580	0.116
290	0.134	0.190	0.551	0.125
310	0.135	0.210	0.521	0.134
330	0.135	0.230	0.491	0.144
350	0.134	0.252	0.460	0.153
370	0.133	0.275	0.430	0.162
Region	0.132	0.163	0.593	0.112

TABLE 59

PREDICTED PROBABILITIES OF IRRIGATION METHOD ADOPTION BY WELL YIELD, CENTRAL HIGH PLAINS REGION

Well Yield (GPM)	Irrigation Method			
	Furrow	Improved Furrow	Sprinkler	LEPA
430	0.081	0.091	0.737	0.090
480	0.088	0.100	0.719	0.094
530	0.094	0.109	0.699	0.097
580	0.102	0.119	0.679	0.100
630	0.109	0.130	0.658	0.103
680	0.117	0.141	0.636	0.106
730	0.125	0.152	0.613	0.109
780	0.133	0.165	0.590	0.112
830	0.141	0.178	0.567	0.114
880	0.150	0.191	0.542	0.116
930	0.159	0.205	0.518	0.118
980	0.167	0.219	0.493	0.120
1030	0.176	0.234	0.468	0.121
1080	0.185	0.249	0.444	0.122
1130	0.193	0.264	0.419	0.123
Region	0.132	0.163	0.593	0.112

TABLE 60

PREDICTED PROBABILITIES OF IRRIGATION METHOD ADOPTION BY THE NUMBER OF ACRES PER WELL, CENTRAL HIGH PLAINS REGION

Acres per Well	Irrigation Method			
	Furrow	Improved Furrow	Sprinkler	LEPA
55	0.247	0.267	0.406	0.080
65	0.226	0.250	0.438	0.086
75	0.206	0.233	0.470	0.091
85	0.186	0.215	0.502	0.097
95	0.168	0.198	0.533	0.102
105	0.150	0.181	0.562	0.107
115	0.134	0.165	0.591	0.111
125	0.118	0.149	0.617	0.115
135	0.104	0.134	0.642	0.119
145	0.092	0.121	0.665	0.123
155	0.080	0.108	0.686	0.126
165	0.070	0.096	0.706	0.128
175	0.061	0.085	0.723	0.130
Region	0.132	0.163	0.593	0.112

TABLE 61

PREDICTED PROBABILITIES OF IRRIGATION METHOD ADOPTION BY PERCENT OF IRRIGATED CROPLAND RENTED, CENTRAL HIGH PLAINS REGION

Rented Irrigated Cropland (percent)	Irrigation Method			
	Furrow	Improved Furrow	Sprinkler	LEPA
0	0.156	0.155	0.560	0.128
10	0.150	0.158	0.569	0.124
20	0.144	0.160	0.577	0.120
30	0.138	0.162	0.585	0.115
40	0.132	0.163	0.593	0.111
50	0.126	0.165	0.601	0.107
60	0.121	0.167	0.609	0.103
70	0.115	0.169	0.616	0.100
80	0.110	0.170	0.624	0.096
90	0.105	0.172	0.631	0.092
100	0.100	0.173	0.638	0.089
Region	0.132	0.163	0.593	0.112

TABLE 62

PREDICTED PROBABILITIES OF IRRIGATION METHOD ADOPTION BY PUMP LIFT, SOUTHWEST KANSAS

Pump Lift (feet)	Irrigation Method			
	Furrow	Improved Furrow	Sprinkler	LEPA
130	0.078	0.098	0.779	0.045
150	0.083	0.114	0.752	0.051
170	0.089	0.131	0.723	0.057
190	0.094	0.151	0.692	0.064
210	0.098	0.172	0.658	0.071
230	0.103	0.196	0.623	0.079
250	0.107	0.221	0.586	0.087
270	0.110	0.248	0.547	0.095
290	0.113	0.276	0.508	0.103
310	0.115	0.305	0.469	0.111
330	0.117	0.335	0.429	0.119
Subregion	0.102	0.193	0.626	0.078

TABLE 63

PREDICTED PROBABILITIES OF IRRIGATION METHOD ADOPTION BY PUMP LIFT, NORTHERN TEXAS PANHANDLE

Pump Lift (feet)	Irrigation Method			
	Furrow	Improved Furrow	Sprinkler	LEPA
240	0.077	0.061	0.811	0.051
260	0.087	0.069	0.783	0.061
280	0.098	0.076	0.753	0.073
300	0.109	0.084	0.720	0.086
320	0.121	0.093	0.684	0.102
340	0.134	0.102	0.646	0.119
360	0.146	0.110	0.605	0.138
380	0.159	0.119	0.563	0.159
400	0.171	0.127	0.519	0.182
420	0.183	0.135	0.475	0.207
440	0.194	0.141	0.432	0.233
Subregion	0.134	0.102	0.644	0.120

TABLE 64

PREDICTED PROBABILITIES OF IRRIGATION METHOD ADOPTION BY WELL YIELD, SOUTHWEST KANSAS

Well Yield (GPM)	Irrigation Method			
	Furrow	Improved Furrow	Sprinkler	LEPA
440	0.051	0.096	0.796	0.058
490	0.056	0.106	0.777	0.061
540	0.062	0.117	0.757	0.063
590	0.069	0.129	0.736	0.066
640	0.075	0.142	0.714	0.069
690	0.083	0.156	0.690	0.072
740	0.090	0.170	0.665	0.074
790	0.098	0.186	0.639	0.077
840	0.107	0.202	0.612	0.079
890	0.116	0.218	0.585	0.081
940	0.125	0.236	0.556	0.083
990	0.134	0.254	0.527	0.085
1040	0.144	0.272	0.498	0.086
1090	0.153	0.290	0.469	0.087
1140	0.163	0.309	0.440	0.088
1190	0.173	0.328	0.411	0.088
Subregion	0.102	0.193	0.626	0.078

TABLE 65

PREDICTED PROBABILITIES OF IRRIGATION METHOD ADOPTION BY WELL YIELD, NORTHERN TEXAS PANHANDLE

Well Yield (GPM)	Irrigation Method			
	Furrow	Improved Furrow	Sprinkler	LEPA
470	0.110	0.098	0.698	0.094
520	0.116	0.099	0.685	0.100
570	0.122	0.100	0.672	0.106
620	0.128	0.101	0.658	0.113
670	0.134	0.102	0.644	0.120
720	0.141	0.103	0.629	0.127
770	0.148	0.104	0.615	0.134
820	0.154	0.104	0.599	0.142
870	0.161	0.105	0.584	0.150
Subregion	0.134	0.102	0.644	0.120

TABLE 66

PREDICTED PROBABILITIES OF IRRIGATION METHOD ADOPTION BY THE NUMBER OF ACRES PER WELL, SOUTHWEST KANSAS

Acres per Well	Irrigation Method			
	Furrow	Improved Furrow	Sprinkler	LEPA
60	0.243	0.300	0.404	0.053
70	0.212	0.282	0.447	0.058
80	0.183	0.264	0.490	0.063
90	0.156	0.243	0.532	0.068
100	0.132	0.223	0.573	0.072
110	0.111	0.202	0.611	0.076
120	0.092	0.182	0.646	0.080
130	0.076	0.163	0.678	0.083
140	0.063	0.144	0.707	0.086
150	0.051	0.127	0.734	0.088
160	0.041	0.112	0.757	0.090
170	0.034	0.098	0.777	0.091
Subregion	0.102	0.193	0.626	0.078

TABLE 67

PREDICTED PROBABILITIES OF IRRIGATION METHOD ADOPTION BY THE NUMBER OF ACRES PER WELL, NORTHERN TEXAS PANHANDLE

Acres per Well	Irrigation Method			
	Furrow	Improved Furrow	Sprinkler	LEPA
55	0.158	0.144	0.613	0.085
65	0.154	0.137	0.619	0.090
75	0.151	0.130	0.625	0.095
85	0.147	0.123	0.630	0.100
95	0.143	0.117	0.634	0.105
105	0.140	0.111	0.639	0.111
115	0.136	0.105	0.642	0.117
125	0.132	0.099	0.646	0.123
135	0.129	0.094	0.648	0.129
145	0.125	0.088	0.651	0.136
155	0.121	0.083	0.652	0.143
165	0.118	0.079	0.654	0.150
175	0.114	0.074	0.655	0.157
185	0.111	0.070	0.655	0.164
Subregion	0.134	0.102	0.644	0.120

TABLE 68

PREDICTED PROBABILITIES OF IRRIGATION METHOD ADOPTION BY PERCENT OF IRRIGATED CROPLAND RENTED, SOUTHWEST KANSAS

Rented Irrigated Cropland (percent)	Irrigation Method			
	Furrow	Improved Furrow	Sprinkler	LEPA
0	0.128	0.211	0.553	0.108
10	0.122	0.208	0.569	0.101
20	0.117	0.204	0.585	0.094
30	0.111	0.200	0.601	0.088
40	0.106	0.196	0.616	0.082
50	0.101	0.192	0.632	0.076
60	0.096	0.187	0.646	0.071
70	0.091	0.183	0.661	0.065
80	0.086	0.178	0.675	0.061
90	0.082	0.174	0.689	0.056
100	0.077	0.169	0.702	0.052
Subregion	0.102	0.193	0.626	0.078

TABLE 69

PREDICTED PROBABILITIES OF IRRIGATION METHOD ADOPTION BY PERCENT OF IRRIGATED CROPLAND RENTED, NORTHERN TEXAS PANHANDLE

Rented Irrigated Cropland (percent)	Irrigation Method			
	Furrow	Improved Furrow	Sprinkler	LEPA
0	0.129	0.060	0.682	0.129
10	0.131	0.070	0.672	0.127
20	0.133	0.082	0.661	0.124
30	0.134	0.096	0.649	0.121
40	0.135	0.112	0.635	0.118
50	0.135	0.131	0.620	0.114
60	0.135	0.152	0.603	0.110
70	0.135	0.175	0.584	0.106
80	0.134	0.201	0.563	0.102
90	0.132	0.230	0.540	0.097
100	0.130	0.262	0.516	0.092
Subregion	0.134	0.102	0.644	0.120

VITA

Kenton Bradley Watkins

Candidate for the Degree of

Doctor of Philosophy

Dissertation: ADOPTION OF WATER-CONSERVING IRRIGATION TECHNOLOGIES IN THE CENTRAL HIGH PLAINS

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OKLAHOMA STATE UNIVERSITY
INSTITUTIONAL REVIEW BOARD
FOR HUMAN SUBJECTS RESEARCH

Date: 02-02-94 **IRB#:** AG-94-014

Proposal Title: ADOPTION OF WATER-CONSERVING IRRIGATION TECHNOLOGIES IN THE CENTRAL HIGH PLAINS

Principal Investigator(s): Dr. Harry P. Mapp, Dr. Daniel J. Bernardo, K. Bradley Watkins

Reviewed and Processed as: Exempt

Approval Status Recommended by Reviewer(s): Approved

APPROVAL STATUS SUBJECT TO REVIEW BY FULL INSTITUTIONAL REVIEW BOARD AT NEXT MEETING.
APPROVAL STATUS PERIOD VALID FOR ONE CALENDAR YEAR AFTER WHICH A CONTINUATION OR RENEWAL REQUEST IS REQUIRED TO BE SUBMITTED FOR BOARD APPROVAL. ANY MODIFICATIONS TO APPROVED PROJECT MUST ALSO BE SUBMITTED FOR APPROVAL.

Comments, Modifications/Conditions for Approval or Reasons for Deferral or Disapproval are as follows:

Signature: John H. Wycliffe
Chair of Institutional Review Board

Date: February 4, 1994