Estimated Economic Impact From Adoption of Water-Related Agricultural Technology

John R. Ellis, Ronald D. Lacewell and Duane R. Reneau

This study estimates the expected benefits from adoption of new water-related technologies for the Texas High Plains, a region which is currently mining groundwater. Adoption rates for two improved irrigation systems and limited tillage practices are assumed, and changes in net returns, resource useage, and irrigated acres are examined as measures of adoption benefits. A recursive linear programming framework covering a 40-year period is employed, with results indicating that, contrary to what one might hope, adoption will not significantly lengthen the life of the aquifer. Annual water use changes very little with adoption, while irrigated acreages increase slightly. Adoption does provide a substantial increase in annual net returns, with discounted net returns increasing by 28 percent over those estimated for continued use of conventional technology.

Mining of groundwater is a serious issue in U.S. agriculture, especially in portions of the arid or semi-arid West. Groundwater use per year in the 17 western states[1] has almost tripled from 20 million acre-feet in 1950 to 58 million acre-feet in 1975. Ninety-six percent of the groundwater used in the entire U.S. occurs in the 17 western states [Office of Technology Assessment, 1983].

With this growing use of groundwater supplies, several western aquifers have been overdrafted or mined. Prime examples are in Texas, Oklahoma, and Kansas [High Plains Associates], as well as Arizona [Kelso *et al.*]. Estimates of overdraft in 1975 range from 0.7 million acre-feet (maf) in the Rio Grande river basin to 6.1 and 6.3 maf in the Arkansas-White-Red river basins and Texas Gulf-Coast region, respectively [Office of Technology Assessment, 1983].

The resulting greater pumplift and reduced saturated thickness[2] caused by groundwater mining combine to increase pumping costs and reduce well yields. Given the resulting increased production costs, transition from a solely irrigated or mixed irrigated-dryland economy to one

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[1] The western states include Washington, Oregon, California, Nevada, Arizona, Utah, Idaho, Montana, Wyoming, Colorado, New Mexico, Texas, Oklahoma, Kansas, Nebraska, South Dakota, and North Dakota.

[2] Saturated thickness is defined as the height of the water-bearing portion of the aquifer. Previous pumping or natural drainage may have depleted upper portions of the aquifer, resulting in an unsaturated layer overlying the saturated zone.

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based upon rangeland or dryland (rainfed) production is expected. Such a transition is of great concern, both to individual producers and the agriculturally based economies of many regions in the West. Large-scale importation of water from more water-rich areas is one remedy used in California [Highstreet *et al.*], but recent studies [High Plains Associates; Miller] have shown that current development costs of such projects are prohibitive as well as politically infeasible.

Alternatively, agricultural producers facing such a transition may seek to use their available water supplies more effectively via use of more water-efficient irrigation technology and cropping practices. The purpose of this study is to estimate benefits of adoption of such technologies and practices. Maximum rates of adoption were assumed, and a recursive linear programming framework was used to estimate the potential benefits of the use of two improved irrigation delivery systems as well as limited tillage practices. The research focused on the High Plains of Texas and covers a 40-year period of analysis (1980–2020).

Study Technologies

Numerous technologies and farming practices exist which could be employed to use a limited water supply more efficiently. Some of these techniques, designed to retain and use water in the field more effectively, are leveling, contour bench terracing, furrow diking, and limited tillage practices. Research has also concentrated on increasing irrigation application efficiency, resulting in development of surge flow techniques and lower pressure sprinkler systems (including the relatively new low energy precision application, or LEPA, systems). Adoption of a subset of the technologies and practices noted above were examined in this study. These were chosen because of their limited current yet probable increased future use.

Limited Tillage

Rising energy costs have prompted adoption of limited tillage practices in numerous areas. Such practices have the general objectives of (1) plant residue management for water and wind control, (2) reduced energy use, and (3) conservation of soil and water [Unger and McCalla]. These goals are generallly attained by reducing the number of trips across a field, leaving stubble from the previous year's crop to help retain rainfall moisture, and controlling weeds via the use of herbicides instead of sweep or disc tillage methods. Deep tillage operations, such as use of a moldboard plow, are also generally excluded [Office of Technology Assessment, 1982].

A great deal of research concerning reduced and no-tillage cropping systems has been conducted in recent years. Practices which retain wheat residue on the surface have been shown to increase precipitation storage 40 to 80 percent [Greb *et al.*; Unger; Unger *et al.*]. Grain yields for subsequent crops increased 16 to 38 percent. Irrigated corn yields in a Kansas study [Hayes] using limited tillage increased 10 to 30 bushels per acre above those obtained with three alternative conventional tillage systems.

One farm-level economic study [Harman *et al.*] examined the use of limited tillage in an irrigated wheat/limited tillage feedgrain/fallow crop rotation over a 10-year period. Crop acreages within a year were set at one-third of the farm for each option in the rotation. Results from a recursive linear programming model showed the use of limited tillage to be water, energy, and labor saving when compared to a similar scenario using conventional tillage practices. Of greater significance, however, were the increased returns to land, management, and risk. Ten-year discounted streams of net returns increased from 45 to 67 percent (five percent discount rate), depending upon the initially assumed pumping depth.

Improved Furrow

Techniques designed to increase the efficiency of gravity flow irrigation include: alternate furrow irrigation, furrow diking, surge flow, automated furrow, and recirculation (tailwater) pits. Furrow irrigation delivery efficiencies vary widely, ranging in one survey from 30 to 90 percent [Wyatt, 1978–81]. A recent study [Lee *et al.*] examined the benefits over time of increasing a furrow system's delivery efficiency from 50 to 80 percent. Use of a recursive linear programming model in a 20-year analysis on 160 acres showed significant benefits accruing to the investment and required increased management level. The increased delivery efficiency yielded a net present value (of returns to land, management, and risk) of $81,800 with a six percent discount rate over the 20-year period.

LEPA

One of the more promising irrigation distribution systems developed to date is the low energy precision application (LEPA) system [Lyle and Bordovsky], which distributes water through drop tubes and low pressure emitters directly to the furrow at very low pressures of five to ten psi. When combined with the use of furrow diking, the system maximizes water application and distribution efficiency while it minimizes energy costs and runoff. Either center-pivot or side-roll systems may be adapted to the LEPA configuration.

In field trials of the LEPA system, measured application efficiencies averaged greater than 98 percent and distribution efficiency averaged 96 percent. Runoff from irrigation and rainfall was essentially eliminated when furrow dikes were included. In a two-year test on soybeans at the Texas Agricultural Experiment Station, Halfway, Texas, pumping energy cost per bushel for undiked sprinkler irrigation averaged 67 percent more than for the LEPA system with furrow dikes. A similar comparison of sprinkler irrigation with furrow diking showed pumping energy costs per bushel of soybeans exceeded those for LEPA with furrow diking by 51 percent [Lyle *et al.*, 1981].

Improved delivery efficiency of the new technologies reduces variable costs per acre-inch of water applied and increases the effective water supply. For a specified quantity of water pumped, greater quantities of water can be delivered to the plant root zone. The same amount of water may therefore be used to irrigate greater acreages, or it may be used in a more timely manner within critical water periods.

The general hypothesis accompanying adoption of more water efficient technologies is that annual pumping levels of water will decline and the life of the aquifer will be extended. This is a typical physical science conclusion. The reduced energy use requirements of pumping and distributing water as well as the improved distribution efficiency, however, serve to reduce the cost per acre-inch of water and simultaneously increase the marginal value product of water pumped. In view of a single year, this suggests strong incentives to actually increase the amount of water pumped per year.

Research by Burt demonstrated that the optimal extraction rate of water from an exhaustible source is such that marginal profit with respect to water use should be equated with the discounted marginal profit with respect to the stock of groundwater. Adoption of greater delivery efficiency irrigation technology should shift the marginal profit curve for water use to the right. The effective stock of groundwater would increase; and optimal water use could increase or decrease, depending on the discount rate and magnitude of change in the effective stock of water.

Study Region

The Texas High Plains has many characteristics that qualify it for this study.

TABLE 1. Irrigation Distribution System Pressure and Delivery Efficiency.

Item	Unit	Furrow		Sprinkler	
		Standard	Improved	Standard	LEPA
Required Pressure	Psi	5	5	45	6
Delivery Efficiency	%	69	80	80	92

Sources: Lyle and Bordovsky; Lyle *et al.*, 1982; Wyatt [1978–81].

Irrigation development within the area began as early as 1911, preceding that of other areas of the Great Plains that pump groundwater from the vast Ogallala aquifer. Estimates of water use since predevelopment range from 25 to 33 percent of the recoverable total of 485 maf [Nieswiadomy; High Plains Underground Water Conservation District No. 1]. Irrigated acreages peaked in 1974 at 5.9 million acres, while 1980 irrigated acreage was 5.5 million acres [Texas Crop and Livestock Reporting Service, 1972–81a]. Aquifer recharge is generally less than 0.8 inches per year, and increased pumplifts due to mining average greater than 100 feet in numerous counties [Wyatt *et al.*; Nieswiadomy].

Agricultural production in the region averaged 40 percent, by value, of the state's crop production in the 1972–80 period. High Plains crop production for 1981 exceeded $1.69 billion [Texas Crop and Livestock Reporting Service, 1972–81a]. Concern over declining groundwater levels and their impact on the economy of the region and state prompted recent passage, subject to voter approval, of a bond program to subsidize low-cost loans for adoption of increased delivery efficiency irrigation technology [Lacewell *et al.*; Lacewell and Collins].

Model and Procedures

A recursive linear programming model [Reneau *et al.*, 1984] maximizing annual returns to land, management, and risk was used to analyze the impact of new technology on annual and long-term profits, water and energy use, and sustainability of irrigated acres. Four adoption scenarios were assumed (referred to as A, B, C, and D), with each of the latter three building upon its predecessor. Use of center-pivot sprinkler systems, conventional furrow irrigation, and conventional tillage practices formed the base scenario (A). Adoption of limited tillage practices using the same irrigation systems as in the base comprised the second scenario (B). Conversion from conventional to improved furrow irrigation systems and practices with limited tillage adoption allowed formed the third scenario (C). The final case (D) examined conversion of sprinkler and a limited amount of furrow acreages to use of LEPA systems while allowing the previously described conversions to take place as well.

Key assumptions concerning delivery efficiencies and operating pressures for the four irrigation delivery systems appear in Table 1. It was assumed that improved furrow practices used tailwater pits, recirculation pumps, reduced length furrows, and significantly improved levels of management. Furrow diking accompanied the use of LEPA systems. Yield increases for dryland crops using limited tillage ranged from 4 to 12 percent above those assumed possible with conventional tillage. Water requirements for irrigated crop activities using limited tillage were reduced from 3 to 11 percent, depending upon the crop.

Linear Programming Model

Crops in the model included irrigated cotton, sorghum, wheat, corn, sunflowers, and soybeans. Dryland crops included those listed above with the exception of corn and soybeans. Possible irrigation schemes varied from a single preplant to a preplant plus five postplant irrigations. Crop yields varied with the irrigation scheme employed, and some specific non-optimal (less than maximum yield for a given number of postplant irrigations) timing schemes were included as possible production activities to more adequately represent alternatives facing producers. Competition for water in the heavy water demand summer months often results in postplant irrigations occurring at other than the optimal timing.

Yield data used for the various irrigation intensities and timings originated with several years' research at Texas A&M research centers in Amarillo and Lubbock as well as the U.S.D.A. Southwestern Great Plains research center at Bushland [Jones *et al.*; Hardin and Lacewell]. Portions of the data summarized in Hardin and Lacewell were supplemented by current research findings concerning new wheat varieties and short season grain sorghum [Reneau *et al.*, 1983]. Commodity prices used were the average of the last 20 years' prices valued in 1982 dollars [Texas Crop and Livestock Reporting Service, 1962–81; U.S. Dept. of Agriculture].

Approximately 70 percent of the wells on the High Plains are fueled by natural gas. In addition, more than 95 percent of the pumping energy (measured in BTU equivalent units) comes from natural gas [Texas Crop and Livestock Reporting Service, 1976b]. Therefore, natural gas was specified as the pumping fuel used in the analysis. Annual recharge to the aquifer was assumed negligible, with the recursive model accounting for annual changes in pumplift, saturated thickness, well yield, and pumping costs as the aquifer was depleted.

Groundwater Situation Considerations

Four representative groundwater situations were assumed to apply in the region, with cropland acres, number of wells, contributing aquifer acres,[3] saturated thickness, and required pumplift for each situation shown in Table 2. The absence of cotton in the northern 15 counties of the study region yielded one natural division. Detailed county studies [Wyatt *et al.*] relating saturated thickness to surface acreage, as well as pumping lift to surface acreage, were used to further refine the representative groundwater situations.[4]

In addition, results from a previous study [Reneau *et al.*, 1983] prompted the use of upper bounds on water extraction within a given year. Work within that study examined the effect of various groundwater pumping constraints on the net present value of returns over fixed and variable costs for a 40-year period. Results indicated that extraction rates of approximately two and four feet of saturated thickness per year yielded the maximum net present value of net returns for initial groundwater conditions similar to the low and high groundwater situations assumed here. Both of these values could vary by as much as one foot without greatly affecting the net present value. In view of these results, the two- and four-foot annual withdrawal limits were used in the analysis, prompted by the hypothesis that

[3] The presence of roads, ditches, homes, and adjacent dryland or fallow acreage may allow a given irrigation well to draw water from an area greater than that which is actually irrigated. Contributing aquifer acres are a measure of this total area.

[4] Greater lifts were assumed to be associated with greater saturated thicknesses, and after aggregating the respective acreages for various lifts and saturated thicknesses across counties, natural break points were chosen to determine low and high representative groundwater situations in both the northern and southern portions of the study area. Several representative counties with groundwater availability conditions similar to those for the low or high groundwater situations were selected. Cropland acreages, number of wells, and contributing aquifer acres from those counties were then assumed to apply proportionately for the entire groundwater situation. Results of this process as well as the actual values for 1979 appear in Table 2.

TABLE 2. Assumed 1980 Cropland and Water Resource Situation: Texas High Plains.

Water Situation	Cropland Acres[a]	Wells	Contributing Aquifer Acres	Saturated Thickness	Pump Lift
	(000)		(000)	(ft)	(ft)
Southern Region					
Low	3,630	28,988	4,630	55	145
High	3,550	34,616	4,872	139	281
Total	7,180	63,604	9,502		
Actual (1979)	7,183	64,460	9,340		
% Error[b]	−0.04	−1.3	1.7		
Northern Region					
Low	263	513	471	77	82
High	2,671	8,740	5,209	207	284
Total	2,934	9,253	5,680		
Actual (1979)	2,623	8,890	5,765		
% Error[b]	11.85	4.0	−1.5		

[a] Values shown for cropland acres, wells, and contributing aquifer acres were obtained using extrapolation from data for representative counties with groundwater conditions similar to the saturated thickness and pumplift shown.
[b] % Error is the difference between Total and Actual (1979).

producers limit their annual withdrawals in order to maximize returns over time from their limited water supply. Use of such annual pumping limits should be noted in the interpretation of all results.

Adoption Rates

Producer age, education, and management capacity affect the rate at which a given technology is assimilated into common use. Farm size, availability of financing, cost of the technology, and accessibility of information are also important determinants [Office of Technology Assessment, 1982]. Meaningful quantification of such factors and their subsequent influence on technology adoption on a regional basis is beyond the scope of this study, thereby prompting the use of subjective assumptions concerning allowable rates of adoption. Such assumptions were required for the two major investment decisions under consideration: (1) conversion of furrow-irrigated acreage to LEPA, and (2) conversion of existing sprinkler equipment to a LEPA configuration.

A regression analysis of historical sprinkler irrigated acreages in the study region [New] indicated an average increase of 66,000 sprinkler irrigated acres per year. It was assumed that this major investment trend would continue for the first ten years of the analysis, and that such investment would be comprised of conversion from furrow to LEPA delivery systems. Purchase cost of a LEPA system varies, depending upon the relative health of the agricultural economy. Initial estimates of approximately $43,000 per unit [Lyle and Bordovsky] were common in 1980 but had declined to $35,000 by 1983 [Lacewell and Collins]. The latter figure was employed within this analysis. Acreage constraints, with right-hand side values which changed throughout the 10-year adoption period, were used to reflect the possible adoption of LEPA on previously furrow irrigated hardland soils.

The second case involves investment at a much smaller scale, such as that required for conversion of an existing 160 acre center-pivot or side-roll system to LEPA (ranging in cost from $5,000 to $8,000). This conversion consists of the addition of pressure regulators, drop tubes,

TABLE 3. Comparative Annual Net Returns and Resource Usage for Selected Years, Texas High Plains.

	Base Scenario A[a]			Percent Change[b] from A		
Year	Category	Unit	Value	B	C	D
1981	Net Returns	million $	1,116.0	8.1	8.4	9.1
	Water Use	(000) af	7,515.0	0.1	0.1	0.2
	Natural Gas Use	million mcf	173.2	−3.1	−3.1	−3.6
	Diesel Use	million gal	123.6	−10.9	−10.8	−11.1
1990	Net Returns	million $	1,037.0	14.4	20.6	28.5
	Water Use	(000) af	7,504.0	0.1	0.0	0.1
	Natural Gas Use	million mcf	189.2	−4.3	−4.8	−9.0
	Diesel Use	million gal	128.9	−17.5	−18.2	−16.1
2000	Net Returns	million $	911.0	20.4	26.9	36.0
	Water Use	(000) af	6,905.0	−0.6	−0.8	−0.2
	Natural Gas Use	million mcf	191.8	−5.6	−7.2	−12.1
	Diesel Use	million gal	132.3	−22.5	−22.6	−21.2
2010	Net Returns	million $	661.0	30.7	38.3	43.7
	Water Use	(000) af	4,606.0	−0.3	3.3	3.7
	Natural Gas Use	million mcf	134.9	−4.6	−2.6	−3.1
	Diesel Use	million gal	125.6	−24.8	−25.0	−24.6
2020	Net Returns	million $	520.0	38.5	43.5	48.1
	Water Use	(000) af	2,275.0	2.2	1.1	1.3
	Natural Gas Use	million mcf	80.0	−7.0	−8.0	−8.1
	Diesel Use	million gal	119.8	−27.6	−26.7	−26.5
40-Year Total						
	Water Use	(000) af	225,938	0.1	0.0	0.1
	Natural Gas Use	million mcf	6,181	−4.9	−5.8	−8.8
	Diesel Use	million gal	5,068	−21.6	−21.6	−20.9

[a] Scenarios: A—Base using center-pivot and conventional tillage and furrow systems, B—Same as A except limited tillage adoption allowed, C—Same as B except improved furrow adoption allowed, and D—Same as C except LEPA adoption allowed.

[b] Percent changes are with respect to scenario A's value within a given year.

and nozzles. Consultation with the head of the Texas High Plains Underground Conservation District No. 1 yielded estimates of conversion rates of five percent of sprinkler acreage the first year and ten percent per year for the next nine years. These estimates are based on observed historical conversion from high-pressure center-pivot to low pressure center pivot systems [Wyatt, 1982]. These adoption rates were assumed for the conversion of current sprinkler systems to LEPA, and also for the conversion of conventional furrow to improved furrow practices. As before, maximum allowable acreage constraints for a given technology on a particular soil type were used to reflect new technology adoption opportunities. Center-pivot and LEPA systems were restricted to mixed and sandy soils, with furrow and improved furrow practices restricted to the hardlands.

A function, relating year and estimated percentages of U.S. cropland expected to adopt limited tillage practices, was used to provide upper bounds on limited tillage acreages through time. This function assumes that 25 percent of current cropland used limited tillage practices in 1980, increasing to an approximate maximum of 75 percent by 2010 [Office of Technology Assessment, 1982]. The starting point of 25 percent in 1980 especially impacts the results of scenarios B, C, and D, and should be noted when interpreting comparative results among scenarios.

Results

Differences among scenarios in yearly net returns and/or resource usage are the major measures of benefits for new technology adoption used in this study. Selected values for these measures appear in Table 3, with percent changes reported for scenarios B, C, and D being with respect to scenario A's value within a given year. Selected results pertaining to sustaining irrigated agriculture in the region are also presented graphically. Results for the four subregions have been summed, yielding aggregate results for the entire Texas High Plains.

Care should be taken when interpreting the results presented. The various scenarios were specified assuming concurrent adoption of the various technologies, and interactive effects among the three technologies could occur. Benefit estimates for LEPA use, for example, might be looked upon as the difference in net returns between scenarios C and D in a given year. Such an estimate, however, should be tempered with the knowledge that limited tillage practices were employed in both those scenarios. Benefit estimates for LEPA, or any other technology, will vary depending upon the presence or absence of other technologies.

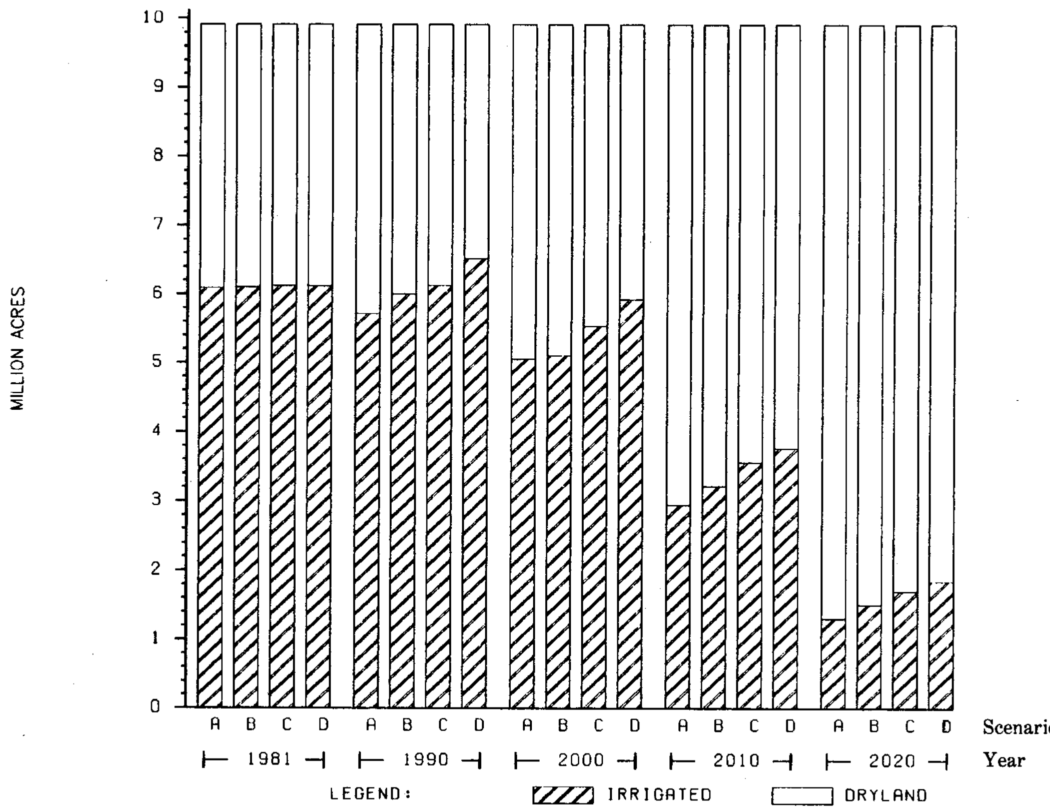
Water Use

Given the assumed decreased water requirements accompanying use of limited tillage as well as the increased delivery efficiency of the two improved irrigation systems examined, one might conclude that substantial water savings and possible extended life of the aquifer would occur with the adoption of new technology. Selected yearly water use values and percent changes from the base scenario A (Table 3) do not, however, support such a conclusion. Slight increases and decreases in annual water use across scenarios occur, ranging from decreases of 0.9 percent to increases of 3.8 percent. Total water use over the 40-year period in all four scenarios was essentially constant at 226 maf.

Several forces play a part in this general constancy of water use. Until approximately 2005, water use in the majority of the study region reaches the previously noted annual groundwater pumping limits. Water withdrawals are limited within a given year in the interest of greater present value of net returns over time. Greater delivery efficiencies of LEPA and improved furrow systems also reduce the variable cost per acre-inch of water applied. Once the system is in place, water will be a less expensive input. Producers will have economic incentive to apply more water per acre, perhaps on the same crop for greater yield or on more water-intensive crops. Improved delivery efficiencies might also allow greater acreages to be irrigated, increasing water use as well.

Energy Use

In 1981 Texas held approximately 27 percent of the nation's proven oil reserves and 37 percent of the proven natural gas reserves [Texas Almanac]. More than one-third of Texas' 1982 petroleum production occurred in the High Plains. These petroleum reserves, however, are expected to decline to one-tenth of their current levels by 2020 [High Plains Associates]. This anticipated reduction in energy supplies, as well as the overall dependence of both dryland and irrigated agriculture upon energy inputs, render any potential savings in natural gas or diesel use of interest. The technologies under consideration all have potential for less energy use via fewer trips over the field, reduced pumping pressure, or increased distribution efficiency. Due to the analysis' exclusion of electrically powered pumping units, absolute natural gas usage figures presented in Table 3 are inflated. Percent differences in natural gas usage between



Scenario: A=Base C=Base Plus Limited Tillage Plus Improved Furrow
B=Base Plus Limited Tillage D=Base Plus Limited Tillage Plus Improved Furrow Plus LEPA

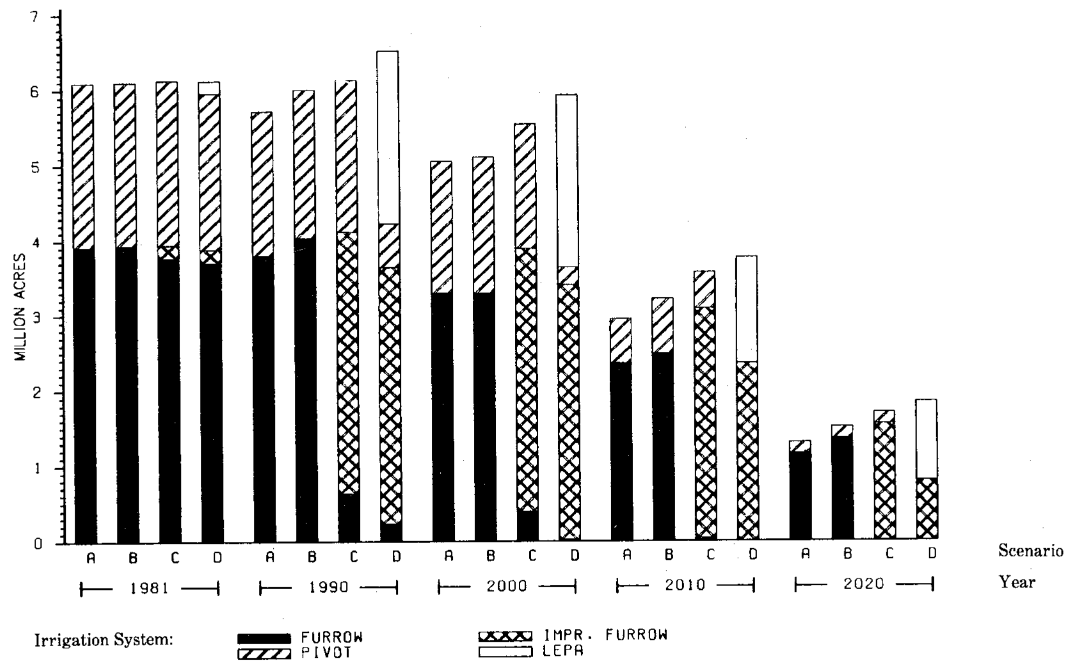
Figure 1. Dryland—Irrigated Acreage Mix Over Time, Texas High Plains.

scenarios, however, are expected to be reliable.

Results for the initial year of adoption (1981), with limited tillage at a possible maximum 25 percent of 1980 cropped acreages (scenario B in Table 3), show a slight decrease of 3.1 percent in natural gas use and reduced diesel usage of 10.9 percent. Energy savings in scenario B generally increase over time, due primarily to the reduced water requirements accompanying limited tillage use. Results for the improved furrow and LEPA scenarios (C and D) are similar to those of scenario B with even greater savings in natural gas use due to lower pressure requirements and greater distribution efficiency of those systems. Total natural gas use for the 40-year period for scenario A is 6.2 billion mcf, where one mcf is one thousand cubic feet of gas or one million BTUs. Projected savings of 4.9, 5.8, and 8.8 percent were realized over the period for scenarios B, C, and D respectively. Similar values for diesel usage over the study period were a total use of 5.1 billion gallons for scenario A and savings of approximately 21 percent for the remaining three scenarios.

Dryland and Irrigated Acreage Impacts

Dryland and irrigated acreage results for selected years are shown graphically



Scenario: A=Base
B=Base Plus Limited Tillage
C=Base Plus Limited Tillage Plus Improved Furrow
D=Base Plus Limited Tillage Plus Improved Furrow Plus LEPA

Figure 2. Irrigation System Mix For Selected Years, Texas High Plains.

in Figure 1 by scenario. At the end of the improved furrow and LEPA adoption period (1990), irrigated acres for scenarios C and D are actually greater than those found originally in 1981. These increases occur despite reduced water availability after ten years, and result mainly from greater distribution efficiencies of improved furrow and LEPA systems. These systems allow spreading the same amount of water across greater acreages while maintaining previous yields, or permit irrigation of more water intensive crops (or the same crop more times) at less cost. Reduced water requirements due to limited tillage also help to increase irrigated acreage. For the assumed set of relative input and output prices, no cropland went out of production. Approximately two percent of the assumed 10.1 million acres of cropland was fallow throughout the analysis.

One disadvantage of the model is the absence of provision for risk aversion behavior on the part of producers. In actual practice, a single preplant irrigation may be applied as a precautionary measure against drought. Such preplant activities exist in the model, yet cost and returns figures for those individual activities do not include a provision for risk aversion. Irrigated acreage values presented here may then understate those which would occur under the groundwater and price situations assumed.

Distribution System Mix

Estimated use of various irrigation distribution systems employed over time appear in Figure 2. Acreages are shown for furrow, improved furrow, center-pivot, and LEPA distribution systems for selected years. These results demonstrate the economic advantages of the improved distribution systems. The use of improved systems reached the assumed maximum allowable acreage in each year of the ten-year adoption period. For scenario A, total irrigated acreage declined through time with the proportion irrigated by conventional center-pivot systems dropping significantly by the year 2020. Adoption of limited tillage (scenario B) increased total irrigated acreage over that for scenario A in each time period with little or no effect on the proportion of pivot and furrow irrigated acreages. By the end of the improved furrow system adoption period in 1990, improved furrow techniques (scenario C) were in use on a majority of the hardlands, and total irrigated acreage increased over that found in both scenarios A and B. As water supplies and total irrigated acreages declined, the less efficient conventional furrow practices were replaced by improved furrow techniques. In the year 2000, only 396,000 acres (7.2 percent of the 5.5 million acres irrigated) employed conventional furrow practices. By 2010, the latter technology was no longer in use in scenario C.

Adoption of the more water efficient improved furrow and LEPA distribution systems (scenario D) allowed an increase in 1990 total irrigated acreages over those obtained in 1981, when greater water supplies were available. Improved furrow and LEPA systems begin to dominate relatively quickly, with both conventional furrow and center-pivot systems being totally replaced shortly after the year 2000.

Net Returns and Corresponding Present Values

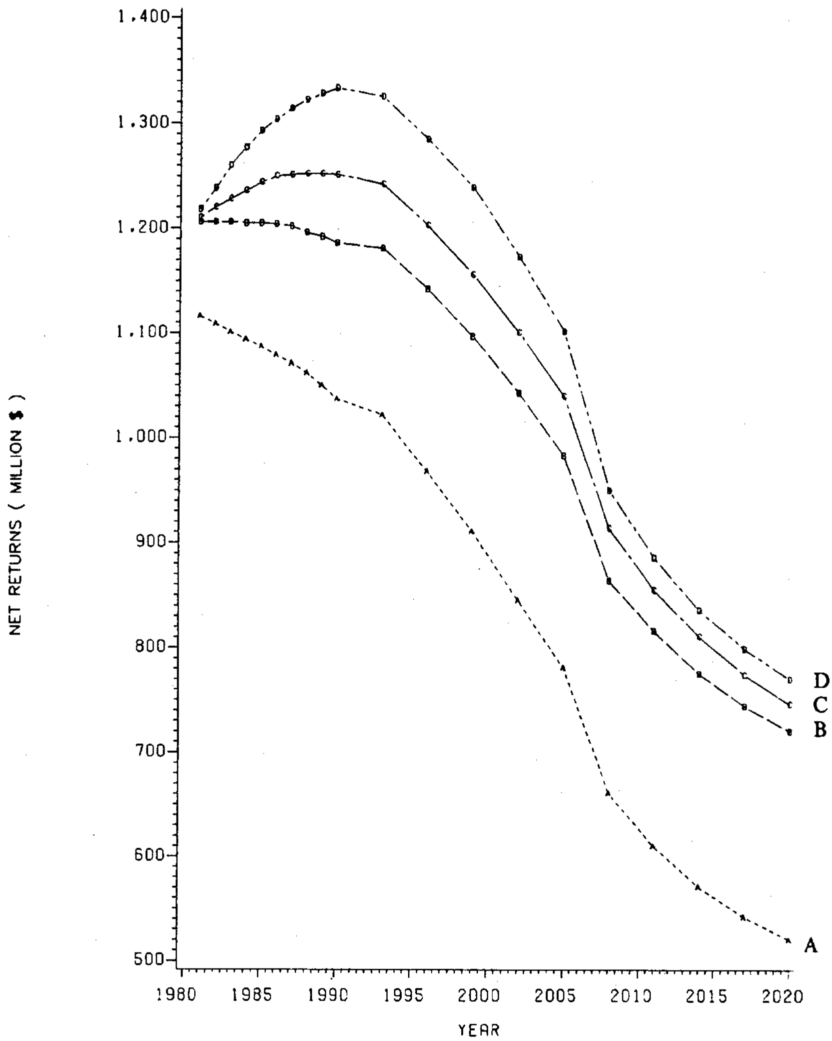
For adoption to occur, expected net returns to land, management, and risk should be at least as great with a new technology as those available under conventional means. Study results for projected annual returns to land, management and risk (Figure 3) demonstrate that such economic incentives do exist. Nominal net returns are presented for each year of the 40-year period of analysis.

Declining water supplies and increasing pumping costs due to greater pumping lifts for scenario A project a downward trend in net returns if no advanced technology is adopted. The shift in 1980 net returns depicted by the net returns curves for scenarios B, C, and D reflects the benefits of this instantaneous change from zero to 25 percent adoption of limited tillage practices.[5] As adoption proceeds, the difference between net returns for scenarios A and B continues to increase (Table 3). Adoption of limited tillage did not, however, delay the start of the downward trend in net returns as the water resource base declined.

Income effects associated with adoption of improved furrow and/or LEPA systems in combination with limited tillage practices (scenarios C and D in Figure 3) increased net returns above the 1981 level, despite declining groundwater supplies and increased pumping costs due to greater pumplifts. Increasing net returns continue to the approximate end of the assumed adoption period in 1990. At that point, a general decline in net returns begins for these scenarios, regardless of the continued adoption of limited tillage until 2010. At the end of the 40-year analysis, net returns curves for scenarios B, C, and D are significantly higher than for scenario A. Net returns in 2020 vary from that for the base by 38.5, 43.5, and 48.1 percent, respectively.

Present values for the net returns depicted in Figure 3 appear in Table 4 for several alternative discount rates. Limited tillage adoption, with an instantaneous change to 25 percent use in the first year, increases the present value of net returns by 17.4 percent for a four percent discount rate. The adoption of improved fur-

[5] Recall that the function employed to bound limited tillage acreages through time assumes that approximately 25 percent of the cropland would use that practice in 1980.



Scenario: A=Base

B=Base Plus Limited Tillage

C=Base Plus Limited Tillage Plus Improved Furrow

D=Base Plus Limited Tillage Plus Improved Furrow Plus LEPA

Figure 3. Nominal Returns to Land, Management and Risk Over Time by Scenario, Texas High Plains.

row and LEPA systems in conjunction with limited tillage increases this present value figure even more, showing increases of 22.4 and 28.3 percent above scenario A's present value. These changes in the present value of net returns, as well as the upward shift in the net returns curves themselves, offer strong support for the benefits of new technology adoption. Over 40 years, at a four percent discount rate, the present value of all technologies examined is an estimated $5.1 billion.

TABLE 4. Present Value of Returns to Land, Management, and Risk for the Period 1980 to 2020: Texas High Plains.[a]

Scenario	Discount Rate		
	2	4	6
	Million $		
A Base: Conventional Technology	23,921	18,150	14,348
B Base + Limited Tillage	28,501	31,314	16,644
Percent Increase from Base (A) Return	(19.1)	(17.4)	(16.0)
C Base + Limited Tillage + Improved Furrow	29,754	22,214	17,315
Percent Increase from Base (A) Return	(24.4)	(22.4)	(20.7)
D Base + Limited Till, LEPA and Improved Furrow	31,221	23,297	18,140
Percent Increase from Base (A) Return	(30.5)	(28.3)	(26.4)

[a] A total of 10,113,000 acres of cropland were included in the analysis.

Concluding Remarks

The purpose of this study was to quantify the expected impact and adoption value of new water-related technology on the Texas High Plains. As groundwater mining continues, technology's role in the transition to greater dryland acreages is especially important to High Plains agriculture. Results indicate new technology, especially the improved furrow and LEPA distribution systems, will not significantly extend the aquifer's life. In general, use of these technologies lowers the per unit cost of obtaining and distributing groundwater and results in constant or even greater annual water use. Greater distribution efficiency essentially increases the available water supply within a given time period, thus allowing more effective and timely application of irrigation water. Both effects encourage greater use of the limited water supply. Adoption of lower pressure distribution systems, however, could extend the economic life of the aquifer for those subregions with relatively large required pumping lifts. The accompanying lower energy costs would then allow a longer period before economic exhaustion of the groundwater supply occurs (e.g., more water could be withdrawn profitably from the aquifer).

Although systems with improved distribution efficiency do not appear to result in less water use, those technologies as well as limited tillage practices were found to be energy-saving. As energy resources in the region and nation decline with resulting price increases, these energy-saving effects could prove significant. Use of improved technologies was also shown to greatly aid in sustaining irrigated acreages in the region, with this latter result significantly increasing net returns to the farmer as well as helping to maintain production input demand and the region's economic base. Even with adoption of new technology, declining farmer net revenues associated with the dwindling resource base indicate a decline in individual community and regional economies. New technology delays the point of decline and lessens the degree. Results also suggest that agriculture will not return to practices used preceding irrigation development but will employ more productive and profitable dryland systems.

Additional analysis is needed with emphasis on the individual producer making investment decisions regarding use of improved furrow or LEPA systems. Studies similar to that of Lee *et al.* could be of great value in tailoring the adoption decision analysis to the particular groundwater situation, set of preferred crops, machinery complement, and management skills of an individual farmer. Such research emphasizes the need to begin analysis of potential optimal transition paths for producers mining groundwater as they adjust to changing resource constraints.

Study limitations include the single assumed set of input and output prices, and the relatively few groundwater situations examined. The analysis also lacks a formal consideration of changing risk aspects of production as the region reverts to dryland production. Despite these factors, this analysis provides reasonable and reliable estimates of new technology adoption benefits. Adoption of currently available technologies can benefit the region, while mitigating some effects of dwindling groundwater supplies. Further, under the assumed price structure, dryland production of several crops is possible and profitable. Individual producers would do well to investigate the possible benefits of adopting new technologies/practices, subject to their own financial and physical constraints.

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