Sustainable Irrigated Agriculture in Texas through Conservation of Ogallala Aquifer

Lal K. Almas
Associate Professor of Agricultural Business and Economics
Department of Agricultural Sciences, West Texas A&M University
WTAMU Box 60998, Canyon, Texas 79016 USA
lalmas@mail.wtamu.edu

Rachna Tewari
Graduate Student
Department of Agricultural Sciences, West Texas A&M University
WTAMU Box 60998, Canyon, Texas 79016 USA
rtewari1@buffs.wtamu.edu

Stephen H. Amosson
Regents Fellow Professor and Extension Economist
Texas AgriLife Extension Service,
Texas A&M University
samosson@ag.tamu.edu

Selected Paper prepared for presentation at the
International Conference on Policy Modeling (EcoMod 2010)
Istanbul, Turkey, July 7-10, 2010

Partial Funding for this project was provided by
Ogallala Aquifer Initiative, USDA-ARS, Bushland, Texas, Texas Water Development Board Austin Texas, and Dryland Agricultural Institute, West Texas A&M University, Canyon, Texas

Sustainable Irrigated Agriculture in Texas through Conservation of Ogallala Aquifer

Abstract: Witnessing a rapid surge in irrigation requirements as well as the pressure on natural resources to augment production for satisfying grain demand for the growing human and livestock population, ground water supply in the Texas Panhandle reflects itself as a limiting yet indispensable factor. This study evaluates the effectiveness of eight potential water management strategies in terms of water savings, implementation costs as well as the regional impact of each policy on the agricultural economy of the Texas Panhandle, comprising 26 counties in the North High Plains, over a fifty-year planning horizon. These strategies include Irrigation scheduling, Changes in crop variety, Irrigation equipment efficiency improvements, Changes in crop types, Conservation tillage methods, Precipitation enhancement, Conversion of irrigated land to dry land and Biotechnology adoption respectively. Biotechnology adoption emerged as the most promising water management strategy for the Panhandle region, given the high associated cumulative water savings and reduction in annual water use, however a careful analysis of implementation of each of the strategies is required to incorporate them in to the agricultural production systems of the region.

Key Words: Ogallala Aquifer, Water Conservation and Management Strategies, Texas Panhandle, Regional Impacts

Background: Witnessing a rapid surge in irrigation requirements as well as the pressure on natural resources to augment production for satisfying grain demand for the growing human and livestock population, ground water supply in the Texas Panhandle reflects itself as a limiting yet indispensable factor. The Texas High Plains area faces a semi-arid climate and experiences an average low rainfall as a result of which surface water availability as irrigation source cannot be considered as dependable, year round for agriculture. Thus, more than 90% of the water used in agriculture in the High Plains area comes from the Ogallala Aquifer (Stewart, 2003 and Jenson, 2004).

On an average, the aquifer recorded an approximate decline of 1.28 feet per year (Jenson, 2004). The problem is further aggravated due to the low recharge rate of the aquifer in the High Plains area, because of Ogallala being an unconfined aquifer where almost the entire recharge is constituted for by rainwater and snowmelt. These conditions call for development of conservation strategies which could look at reducing ground water usage for irrigation and subsequently reduce the rate of aquifer depletion over the planning horizon.

The Agricultural Demands and Projections Subcommittee of the Panhandle Water Planning Group for Region A in Texas Panhandle, suggested various water management strategies for potentially reducing irrigation demands to retain 50 percent of the groundwater currently in the Ogallala Aquifer over the 50 year period of 2010 to 2060. These strategies include the use of the North Plains Potential Evapotranspiration Network (NPPET) to schedule irrigation, changes in crop variety, irrigation equipment efficiency improvements, and changes in crop types, implementation of conservation tillage methods, precipitation enhancement and conversion of irrigated land to dry land. As an addition in the third senate bill, Biotechnology was also incorporated as a recommended water saving strategy. Each of these strategies was analyzed to calculate the anticipated annual water savings and subsequent direct regional impacts, if any of these strategies on the economy of the region.This study evaluates the application of these strategies, in the Texas Panhandle region as a whole, taking into account all the 26 counties of the region.

Objective: This research aimed at developing and analyzing water management strategies for potentially reducing irrigation demands in the Texas Panhandle (26 counties) with a long term objective of retarding excessive depletion as well as promoting conservation of groundwater for future use, in the Ogallala Aquifer over a 50 year planning horizon from 2010 to 2060.

Description of potential water management strategies

Use of NPET network: This network offers a uniform and independent source of crop water use for both irrigators and the public. It is comprised of 10 meteorological stations in Texas Panhandle and used to acquire localized crop weather data focusing on corn, sorghum, cotton, wheat, and soybeans (Comis, 2000). The detailed weather data are then used to compute daily reference evapotranspiration and crop water use. These computed parameters help farmers know exactly when conditions are optimal to plant and to irrigate. This information is especially critical when moisture is short, and when well capacity is limited, as producers must carefully schedules the timing of their applications to efficiently use their water resources (Marek et al., 1995).

The NPET offers potential regional information as well. The weather stations provide rainfall, soil temperature, climatic data, and water use data not previously representative of agriculturally based conditions. The data allows for the evaluation of sudden weather events like late spring or early fall freezes. The NPET does not provide storm warnings, but it provides just about everything else relating to agricultural production, including giving pest alerts. In fact, the summer of

2000 was the first time farmers and consultants woke up to corn rootworm alerts faxed from the network, providing advance notice that an outbreak was imminent (Comis, 2000).

The NPET Network has a wide range of both agricultural and non-agricultural users. Faxes are sent each day to growers, irrigators, crop consultants, and agribusinesses. Faxes are also sent to local newspapers, radio and television stations. For instance, data for lawn water needs is published in the *Amarillo Globe News* each day from May through November. In this publication, crop coefficients are used to estimate daily water use for bluegrass, Bermuda grass, and buffalo grass (Howell, 1998). The NPET is also used extensively by non-profit organizations to improve water research and planning estimates. For example, the Texas' North Plains Underground Water Conservation District recently employed the weather station data to more accurately estimate Ogallala Aquifer depletion (Comis, 2000).The cost of implementing this water conservation strategy is evaluated in terms of the purchase and maintenance of weather stations used throughout the NPET Network.

Change in Crop Variety: Shifting from long season to short season corn and sorghum varieties is another water savings strategy. Water savings are generated by reducing the length of the growing season. However, lower yields are associated with short season varieties (Timmer, 1994). This study also indicated that changes in cultural practices can affect the amount of water used. Substituting a shorter-season crop into a rotation appeared to be a viable option for saving water. It was determined that these varieties may not have as much yield potential, but will likely produce a crop. A significant point of this study was to apply one irrigation near a critical-growth stage, such as flowering.

Further analysis indicated that while substituting long season varieties with short season varieties can generate substantial water savings for corn, the result is minimal for sorghum. This is due to the fact that although short season sorghum generally has a shorter growing period than long season sorghum, late planted short season sorghum will remain in the field and continue to slowly mature as long as frost conditions do not occur. Therefore, the short season sorghum uses additional heat units even though the crop has initiated maturity stage development (Marek and New, 2004-personal communication). The cost of water savings is calculated by comparing the regional economic impact with the water savings produced. When evaluated, the cost to the region of saving an acre-foot of water is calculated by dividing the total regional impact by the total water savings from 2010 to 2060.

Irrigation Equipment Efficiency Improvements: The incorporation of more efficient irrigation equipment and technology in a farming/ranching operation provides a method of groundwater conservation. Specific problems associated with irrigation are water wasted by evaporation and runoff and leeching nutrients below the root zone. Current irrigation methods within the region include conventional furrow irrigation (CF), surge flow (SF), center pivot irrigation (MESA - Mid-Elevation Spray Application, LESA - Low Elevation Spray Application, LEPA - Low Elevation Precision Application) and subsurface drip irrigation (SDI). Switching systems can entail a considerable price tag but can also increase the producer’s bottom line by decreasing pumping costs while increasing convenience.

Definitions of the different methods of irrigation are needed to understand this unique strategy. Amosson et al., (2001) provide the following descriptions. Conventional furrow is a means of irrigation by laying poly or metal pipe on the ground and pumping water through “gates” which are lined up with the field’s furrows. Surge flow is similar to conventional furrow with the exception of a surge valve, which intermittently applies water to two areas of the field. This surge flow concept increases application efficiency by 15 percent. Subsurface drip irrigation (SDI) is the most efficient, in terms of water placement, of all the irrigation systems. SDI is a process of delivering precise amounts of water and nutrients directly to the plant’s root zone. A flat tape or hose is placed in a subsurface manner, thus minimizing surface evaporation losses. The most widely used irrigation system is the center pivot. Center pivot irrigation is allocated to three different systems; Mid-Elevation Spray Application (MESA), Low Elevation Spray Application (LESA), and Low Energy Precision Application (LEPA). New and Fipps (2000) describe MESA as an irrigation system in which water applicators are located halfway between the soil surface and the main line. LESA is defined by utilizing water applicators located only 12-18 inches above the soil. LESA can be converted to LEPA with either an attached drag sock or hose. LEPA utilizes either bubble applicators twelve to eighteen inches off the soil surface or a drag sock or hose that directly releases water to the surface.

Each irrigation system has a different level and range of efficiency and can be dramatically affected by operator management during the growing season. A study by Amosson et al., (2001), estimated conventional furrow, surge flow, mid-elevation spray application (MESA), low elevation spray application (LESA), low elevation precision application (LEPA) and drip with application efficiencies of 60 percent, 70 percent, 78 percent, 88 percent, 95 percent and 97 percent, respectively. These application efficiencies are the percentage of irrigation water that is actually used by the crop, while the rest is lost to runoff, evaporation or deep percolation and the differences were used as a basis of improvement for the strategy.

Change in Crop Type: Crops such as corn require a large amount of irrigation on the High Plains. By reducing the amount of acreage of high water use crops and shifting them to lower water use crops (cotton), substantial water savings could possibly be generated. The cost of implementing this water conservation strategy is evaluated in terms of reduced land values. It is assumed that land is being shifted away from corn production to generate water savings. Land that has more water available for irrigation is worth a premium compared to land with limited irrigation resources. Therefore, as land is shifted from corn to lower water use crops, its value is reduced.

Implementation of Conservation Tillage Methods: A definition of conservation tillage is needed to understand the different terms and scope of this strategy. Towery and Fawcett of the Conservation Technology Information Center (CTIC) give clear descriptions to conservation tillage and different types of conservation tillage according to the amount of crop residue that is left on the surface and the types of tillage tools used. *Conservation tillage* is defined as any tillage and planting system that covers more than 30 percent of the soil surface with crop residue after planting to reduce soil erosion by water. Where soil erosion by wind is the primary concern, any system that maintains at least 1,000 pounds per acre of flat, small grain residue equivalent on the surface throughout the critical wind erosion period is considered to be conservation tillage. Reduced tillage, which will be included under conservation tillage, is defined as a tillage type that leaves fifteen to thirty percent residue cover after planting or 500 to 1,000 pounds per acre of small grain residue after the operation. Conventional tillage is defined as leaving less than fifteen percent residue cover after planting. It typically involves plowing or other forms of intensive tillage. Conservation tillage is further categorized as no-till, ridge-till, and mulch-till. No-till leaves the soil undisturbed from harvest to planting. Ridge-till leaves the soil undisturbed from harvest to planting, and considers an exception of nutrient injection. In ridge-till practices, planting is done in seedbeds prepared on ridges while residue is left on the surface between the ridges. Mulch-till requires disturbing the soil prior to planting, and weeds are controlled with herbicides or mechanical cultivation as they are in the two previous methods.

Conservation tillage leaves plant residue on the soil surface to help reduce this evaporation loss and to aid in the infiltration of water into the soil where rain and irrigation occurs. Conservation tillage can not only save water, but it may have other benefits. Other benefits that are rarely analyzed from an economic standpoint are the environmental impacts such as topsoil protection, protection of water, such as less chemical runoff into water sources, more nutrient rich soil, and less carbon dioxide released into the air. Essentially, it can be concluded that converting from convention to conservation production practices involves replacing tillage operations with herbicide applications. This conversion strategy eventually results in reduced moisture losses as well as an improved soil profile and therefore carries water saving potential especially in arid areas.

Precipitation Enhancement: Precipitation enhancement introduces seeding agents to stimulate clouds to generate more rainfall. This process is also commonly known as cloud seeding or weather modification. The cloud seeding process involves the intentional treatment of individual clouds or storm systems in order to achieve a beneficial effect. Dr. Vincent J. Schaefer, the father of modern weather modification, conducted the first field experiments on cloud seeding following his basic discoveries in 1946 at the General Electric Laboratory in Schenectady, New York. According to information provided by member countries to the World Meteorological Organization, cloud seeding projects are now being conducted in over 40 countries (Weather Modification Association, 1996).

The benefits that can be realized from increased rainfall through precipitation enhancement projects include increased agricultural production, improved economic sustainability and future growth, decreased surface and ground water consumption, increased reservoir levels, increased and higher quality forage for livestock and wildlife, and fire and hail suppression.

Conversion from Irrigated to Dry land: Reducing the amount of irrigated acreage in Texas Panhandle will reduce the amount of water applied to crops in the area. While converting from an irrigated to dryland cropping system may be a viable economic alternative for many Texas Panhandle producers, research indicates that only a limited number of dryland crops can be produced profitability in this area. The primary dryland crops are winter wheat, grain sorghum, and upland cotton.

Musick et al.,(1994) state that winter wheat is a major dryland crop grown in the U.S. Southern High Plains, second only to cotton. The crop has excellent drought tolerance, is deep rooted and widely grown under limited (deficit) irrigation. Grain Sorghum also has dryland profit potential. Armah-Agyeman et al., (2002) assert that sorghum's leaves and root system are what make the crop drought tolerant and give it superiority over corn and other cereals. Cotton is another drought resistant crop whose deep root system enables it to produce some lint yields even under limited soil water conditions. A study conducted by Blackshear and Johnson (2001) found that dryland cotton production in the Texas High Plains was profitable in three out of every five years, and resulted in a positive net income when evaluated by the five-year average.

Biotechnology: Biotechnology has been identified as another potential water management strategy which could significantly enhance the long-run sustainability of agricultural activities in the Texas Panhandle. Specifically, biotechnology could extend the economic life of the Ogallala Aquifer through the development of crop varieties with high tolerance to water stress or reduced water requirements for crop growth (Arabiyat, 1998). Biotechnology is defined as: "An applied field of science whereby the scientific principles are used to discover new methodology and instrumentation to produce new forms of biological entities" (Quaslet, 1991).

Middleton (1996) conducted a study to analyze the effects of agricultural plant biotechnology on crop production profitability with the consideration of risk and uncertainty factors. Representative farms from the Northern Plains Region of Texas were used to study the effects of stress mitigation on profitability and enterprise selection. Four crops were used in the study; cotton, grain sorghum, winter wheat and com. The results showed that biotechnological advances can be expected to reduce the proportion of expected net revenues represented by risk premiums for each sub-region. The results also showed that biotechnology could encourage production of dry land sorghum and cotton at the expense of wheat and irrigated sorghum acreage.

Data and Methods: The irrigated acres that are utilized for calculation purposes for all 26 counties of Texas Panhandle are obtained from the Farm Service Agency (Table 3). Each strategy for water management was analyzed individually for annual water savings as a result of incorporation of such a strategy in each county of the region. Associated implementation cost as well as regional impact was also calculated for each strategy if applicable. Annual water savings were calculated by assuming certain water savings for each strategy in acre-feet.

The details of assumed annual water savings in acre feet per acre per year and percentage adoption goals for each decade associated with each water management are given in Table 1. It is assumed that by utilizing the North Plains Potential Evapotranspiration Network (NPPET) 0.083 acre-feet of groundwater will be saved annually. By changing from long season crop to a short season crop, 0.341 acre-feet and 0.054 acre-feet of irrigation water will be conserved per acre for corn and sorghum respectively. It is assumed that the incorporation of more efficient irrigation equipment/technology in a farming/ranching operation would provide another method of conserving groundwater. The application efficiencies of furrow irrigation, surge flow, low elevation sprinkler application (LESA), low energy precision application (LEPA), and drip are 60 percent, 75 percent, 88 percent, 95 percent, and 97 percent, respectively (New, 1999). The system with a higher efficiency rating is considered more efficient because it leads to less water usage while maintaining the same yields. The assumed water savings by utilizing the irrigation equipment changes strategy are 0.525 acre-feet.

Another strategy for reducing groundwater use is changing the crop type that is planted. The assumption is that corn acres will be converted to sorghum, cotton or soybean acres, and thereby conservation of water will be facilitated. The associated water savings are 0.692 acre-feet. By implementing conservation tillage methods strategy, it is assumed that at least 0.146 acre-feet of groundwater on an annual basis will be saved. Through the precipitation enhancement strategy, it is assumed that there will be no acres utilizing precipitation enhancement in the baseline year. However, assuming that over a 50 year period, 100 percent of the acres will be using this technology, the estimated water saving are 0.08 acre-feet annually.

By converting irrigated land to dry land, the annual associated water savings are 0.892 acre-feet. Incorporation of Biotechnology, the most recent of all strategies is assumed to result in annual water savings of 0.24 acre-feet for corn, 0.08 acre-feet for cotton and 0.12 acre-feet for soybean respectively, as assumed in the baseline year and subsequently increase in the further planning horizon.

The regional economic impact of strategies, wherever applicable are measured by the change in gross receipts on implementation of the strategy. Gross receipts are calculated by using five-year (2003-2008) average regional crop prices obtained from the Master Marketer website and five-year average yields obtained from the Texas Agricultural Statistics Service (TASS, 2003-2008). The estimated implementation costs and the direct regional impacts are both represented in terms of 2009-dollar values.

Results and Discussion: The potential water saving strategies were analyzed for various parameters to evaluate and predict the effectiveness and efficiency of each of the strategies during the planning horizon of 2010 to 2060. Biotechnology, as a water management strategy brought out the maximum cumulative water savings of 16.6 million acre-ft (Table 11), at the end of the planning horizon. The next highest water savings were recorded by the adoption of precipitation enhancement technique at 8.6 million acre-ft (Table 9). This was followed by Irrigation Equipment changes with a water savings of 7.6 million acre-ft (Table 6) and change in crop type, with cumulative water savings of 4.8 million acre-ft (Table 7) respectively. Converting irrigated land to dry land generated approximate water savings of 4.75 million acre-ft (Table 10). Change in crop variety projected cumulative water savings of 3.3 million acre-ft (Table 5).Use of NPET showed that about 1.8 million acre-ft water could be saved at the end of the planning horizon by implementation of the strategy (Table 4). Implementing conservation tillage methods showed the least water savings of 1.5 million acre-ft (Table 8).

The associated implementation costs and direct regional impacts, if any were calculated for individual strategies to evaluate the economic feasibility and outcomes of incorporating these strategies for water management. Irrigation equipment changes recorded the highest implementation costs followed by Change in crop type, Conversion of irrigated land to dry land and Biotechnology. Implementation of conservation tillage led to reduction in costs per acre when compared to conventional tillage.

On evaluating the investment costs associated with each acre feet of water saved , it was found that Irrigation equipment changes would require the highest implementation costs of $54.69 per acre-ft, followed by change in crop type for which the implementation costs for saving an acre-ft of water was $34.68. Converting irrigated land to dry land would require an investment of $29.90 to save an acre-ft of water. Precipitation enhancement technology and Use of NPET were found to incur implementation costs of $3.37 and $4.98 respectively. Biotechnology recorded an implementation cost of only $7.38 per acre-ft of water saved. Implementing conservation tillage methods, however led to a savings of $8.20, for reducing water use by one acre foot when compared to conventional tillage.

The associated implementation costs and direct regional impacts with each acre-ft of water saved, for each strategy is given in Table 2. Direct Regional Impact for implementation of Biotechnology, was the highest which was calculated as savings on variable cost incurred per acre feet for total water savings generated. This was estimated to be $1874 million. However, change in crop variety had a negative direct regional impact of loss in gross receipts for producers, which accounted to $1328 million. Change in crop type also led to a decrease in gross receipts of $468 million while converting irrigated land to dry land recorded a loss in gross receipts of $254 million. The strategies were also evaluated for the impact on the economy of the region with associated water savings for each acre foot. It was found that Biotechnology had the highest positive regional impact for each acre foot of water saved, which was estimated to be $112.32. Further, it was estimated that change in crop type led to a negative regional impact on the economy of $95.92 per acre-ft of water savings associated. Change in crop variety and converting irrigated land to dry land also had negative regional impacts on the regional economy due to loss in gross receipts, and was estimated to be $393 and $54 for an acre-ft of water saved respectively.

Conclusion: Prioritizing and implementing the eight irrigation conservation strategies will be affected by the farm level decisions of the individual irrigator and regional support of the strategy. Biotechnology could be looked at as one of the most promising water management strategy, given the high associated cumulative water savings and positive direct impacts on the economy of the region (Fig. 1). Also, it has been found to have a comparatively low implementation cost on an acre-ft basis which makes it a potential strategy of interest with feasible and economical investments on farm level. Another leading water saving strategy, change in crop type, yields significant water savings, but has a negative impact to the regional economy of $95.92 per ac-ft of water saved. The other two strategies that yield large water savings, change in crop variety and converting irrigated land to dry land, are projected to generate a significant negative impact to the regional economy, $393 and $54 per ac-ft of water saved, respectively. Changing to more efficient irrigation systems comes with the highest estimated implementation cost of $54.69 per ac-ft of water saved. Conservation tillage is a proven water management strategy that is already widely adopted in the region; however, further adoption would result in significant water savings. Implementation costs per acre-ft for this strategy are negative which implies that there are associated savings instead of costs because of reduction in field operations from conventional tillage. Precipitation enhancement and use of NPPET appear to carry the potential of significant water savings while positively impacting the regional economy. However, of all the strategies considered, there is less documentation of the effectiveness of these strategies.

Considering the cumulative projected water demand of 129 million ac-ft, for these 26 counties over a planning horizon of 50 years, it is expected that the Water Management strategies will together generate water savings of approximately 50 million ac-ft, over the planning horizon. The percent irrigation demand satisfaction for individual strategies, with respect to cumulative water savings generated is compared in Figure 2. These figures indicate that these strategies could meet only about 38% of the projected irrigation demand. This calls for further research on water conservation measures, so that the impending pressure on water resources to meet accelerating irrigation demands, could be reduced.

It is assumed that the recommended water conservation strategies will have a more thorough analysis prior to implementation. These analyses should include more detailed documentation of the selected strategies; a county level assessment of the water savings impacts;

and a complete cost analysis of the strategy or strategies including required government expenditures and producer borne costs. Completing these analyses will allow for development of an implementation plan of action that could maximize water savings given available funding for a specific strategy or combination of strategies on a county and regional basis. It is also noted that the associated water savings with these strategies are “potential” water savings. In the absence of water use constraints, most if not all the strategies considered will simply increase gross receipts. Therefore, a careful review and in depth analysis of every possible outcome, due to the implementation of each of the strategies can be thought of as a necessary prerequisite and only then an essential incorporation of these into the agricultural production systems of the region could prove reasonable.

Bibliography

Amosson, S., L. New, L. Almas, F. Bretz, and T. Marek. (2001). "Economics of Irrigation Systems." B-6113, Texas Cooperative Extension, Texas A &M University System Extension Publication, College Station, Texas

Arabiyat, T.S. (1998). Agricultural sustainability in the Texas High Plains: The Role of advanced irrigation systems and biotechnology. Unpublished Master's thesis, Texas Tech University, Lubbock, Texas.

Armah-Agyeman, Loiland, Karow, Payne, Trostle, Bean. (2002). "Dryland Cropping Systems – Grain Sorghum." Oregon State University Extension Service Publication.

Blackshear,J and Johnson,P (2001). "Profitability of Cotton Production in the Texas High Plains." Proceedings of the Beltwide Cotton Conference – Volume 1:241-244.

Comis, D (2000). "Saving North American's Greatest Aquifer by Fax."
Agricultural Research web-site. (http://www.ars.usda.gov)

Farm Service Agency (2008) – Irrigated crop acres by county

Fawcett, R. and D. Towery. "Conservation Tillage and Plant Biotechnology: How New Technology Can Improve the Environment by Reducing the Need to Plow"
Conservation Technology Information Center web-site.
http://www.citc.purdue.edu/

Howell. (1998). "Using the PET Network to Improve Irrigation Water Management." Proceedings of the 1998 Great Plains Symposium.

Jensen, R. (2004). Ogallala Aquifer: Using improved irrigation technology and water conservation to meet future needs. Texas Water Resource Institute.
http://twri.tamu.edu/newsarticles.php?view=2004-08-05, accessed December 8, 2005.

Marek, T. (2004). Personal Communication. Texas Agricultural Experiment Station, May 6.

Marek, New, Howell, Bean, Dusek, and Michels. (1995). "North Plains PET Network – The Concept and Current Status." Contribution from the U.S. Department of Agriculture, Agricultural Research Service, Southern Plains Area, Conservation and Production Research Laboratory, Bushland, Texas, and the Texas Agricultural Extension Service, Amarillo, TX.

Master Marketer Educational System. 2003-2008 Crop Prices. Master Marketer website (http://mastermarketer.tamu.edu/)

Middleton, M, (1996) "The Economics of Plant Stress Reduction through Biotechnology: An Application to the Northern Plains Region of Texas." Unpublished M.S. Thesis, Department of Agricultural and Applied Economics, Texas Tech University, Lubbock, Texas, 1996

Musick, Jones, Stewart, Dusek. (1994). “Water-Yield Relationships for Irrigated and Dryland Wheat in the U.S. Southern Plains.” Agronomy Journal – Volume 86, Number 6.

New L.L, (1999) Personal Communication. Texas Agrilife Extension Service, Amarillo, Texas

New, L. and Fipps, G. (2000). “Center Pivot Irrigation”

Quaslet, CO. (1991) "Plant Biotechnology, Plant Breeding, Population Biology and Genetic Resources, Perspectives from a University Scientist." in Agricultural Biotechnology at Crossroads Biological. Social and Institutional Concerns. McDonald J. F., Editor, National Agricultural Biotechnology Council Reports, Ithaca, New York.

Stewart, B.A. (2003). Aquifers, Ogallala. Encyclopedia of Water Science, pp. 43-44 (2003).

Texas Agricultural Statistics Service, (2008). “Texas Agricultural Statistics.” United States Department of Agriculture, National Agricultural Statistics Service, Austin, Texas.

Timmer, W. (1994). “Conserving Water in Agriculture: Stretching Irrigation Water Supplies. Pacific Northwest Extension Publication, Oregon

Weather Modification Association. (1996). “Weather Modification: Some Facts about Seeding Clouds.” Fresno, California.

Table 1. Potential water management strategies for reducing Irrigation demands

Water Management strategy	Assumed Annual Regional Water savings (acre-feet/ac/ year)	Baseline year (2010)	Goal for 2020	Goal for 2030	Goal for 2040	Goal for 2050	Goal for 2060
Use of NPPET	0.083	20%	27.5%	35%	42.5%	50%	50%
Change in Crop Variety	0.341-corn 0.054-sorghum	40%	70%	70%	70%	70%	70%
Irrigation equipment changes	0.525	80%	85%	90%	95%	95%	95%
Change in Crop type	0.692	20%	40%	40%	40%	40%	40%
Convert Irrigated Land to dry land	0.892	5%	10%	15%	15%	15%	15%
Conservation Tillage methods	0.146	60%	70%	70%	70%	70%	70%
Precipitation Enhancement	0.083	0%	100%	100%	100%	100%	100%
Biotechnology	Savings for each crop/year*	0%	50%	90%	100%	100%	100%

*Crops	2010	2020	2030-2060
Corn	0.24	0.32	0.31
Cotton	0.08	0.11	0.11
Soybeans	0.12	0.17	0.16

(These are the assumed annual water savings (acre-feet/ac/year) for Biotechnology)

Table 2. Impacts and associated costs of Implementation of Water saving strategies

Water Management strategy	Cumulative Water savings WS (ac-ft)	WS/ Total Irrigation demand %	*IC (1000$)	IC/ WS $/ac-ft	(DRI)[1] $1000	DRI/ WS $/ac-ft
Use of NPPET	1,806,541	1.40	9000	$4.98	+	+
Change in Crop Variety	3,378,541	2.62	-	-	-1,328,245	- $393.14
Irrigation equipment changes	7,617,944	5.92	416,622	$54.69	-	-
Change in Crop type	4,881,339	3.79	169,295	$34.68	-468,215	- $95.92
Convert Irrigated Land to dry land	4,750,994	3.69	142,033	$29.90	-254,878	- $53.65
Implement Conservation Tillage methods	1,513,224	1.18	-12,406	- $8.20	+	+
Precipitation Enhancement	8,602,576	6.68	28,994	$3.37	+	+
Biotechnology	16,690,237	12.96	123,120	$7.38	1,874,647	$112.32

[1]+indicates an anticipated positive impact that was not quantified for Direct Regional Impact (DRI)
*Implementation costs of Water Management strategy (IC)

Table 3. FSA Irrigated Acreages and Estimated Applied Irrigation

2010 Baseline				
	FSA Acreage	**Avg Irr (inches/acre)**	**Total Irr (Acre feet)**	**% Applied Irr**
Corn	705,396	18.52	1,088,661	45%
Cotton	273,029	10.69	243,223	10%
Hay	0	31.24	0	0%
Peanuts	17,417	17.05	24,747	1%
Sorghum	180,043	9.98	149,736	6%
Soybeans	10,489	9.95	8697	0%
Wheat	730,534	10.39	632,521	26%
Other	156,002	22.4	291,204	12%
Total	**2,072,910**		**2,438,788**	

Source: Farm Service Agency, 2008

Table 4. NPET-Estimated Affected Acreage, Implementation Costs and Water savings

	2010	**2020**	**2030**	**2040**	**2050**	**2060**	**Total**
Affected Acreage	414,582	155,468	310,936	466,405	621,873	621,873	-
Implementation cost (Millions)	-	$1.80	$1.80	$1.80	$1.80	$1.80	$9.00
Water savings (Acre Feet)	-	129,039	258,077	387,116	516,155	516,155	1,806,541
			Implementation cost /Water savings				**$4.98**

Table 5.Change in Crop variety-Estimated Affected Acreage, Regional Impact and Water savings

Corn							
	2010	**2020**	**2030**	**2040**	**2050**	**2060**	**Total**
Affected Acreage	253,942	190,457	190,457	190,457	190,457	190,457	-
Regional Impact (Millions)	-$218	-$218	-$218	-$218	-$218	-$218	-$1092
Water savings (Acre Feet)	649,458	649,458	649,458	649,458	649,458	649,458	3,247,289
			Regional Impact/ Water savings				**-$412.34**
Sorghum							
	2010	**2020**	**2030**	**2040**	**2050**	**2060**	**Total**
Affected Acreage	64,815	48,612	48,612	48,612	48,612	48,612	-
Regional Impact(Millions)		-$47.20	-$47.20	-$47.20	-$47.20	-$47.20	-$235.98
Water savings (Acre Feet)		26,250	26,250	26,250	26,250	26,250	131,251
			Regional Impact/ Water savings				**-$1592.36**

Table 6.Change in Irrigation Equipment-Estimated Affected Acreage, Implementation costs and Water savings

	2010	2020	2030	2040	2050	2060	Total
Acreage affected	-	103,645	207,291	310,936	414,582	414,582	-
Total Implementation cost (Millions)	-	-	-	-	-	-	$416.6
Water savings		544,139	1,088,278	1,632,417	2,176,555	2,176,555	7,617,944
			Implementation cost/Water savings				**$54.69**

Table 7. Change in Crop Type -Estimated Affected Acreage, Implementation Costs, Regional Impact and Water savings

	2010	2020	2030	2040	2050	2060	Total
Affected Acreage	141,079	141,079	141,079	141,079	141,079	141,079	
Implementation cost (Millions)	-	$169	-	-	-	-	$169
Regional Impact (Millions)	-	-$94	-$94	-$94	-$94	-$94	-$468
Water savings (Acre Feet)	-	976,268	976,268	976,268	976,268	976,268	4,881,339
			Implementation cost /Water savings				**$34.68**
			Regional Impact/ Water savings				**-$95.92**

Table 8. Conservation Tillage- Estimated Affected Acreage, Implementation costs and Water savings

	2010	**2020**	**2030**	**2040**	**2050**	**2060**	**Total**
Affected Acreage	1,243,746	207,291	207,291	207,291	207,291	207,291	-
Implementation costs (Millions)	-	-$2.48	-$2.48	-$2.48	-$2.48	-$2.48	-$12.40
Water savings (Acre Feet)	-	302,645	302,645	302,645	302,645	302,645	1,513,224
			Implementation cost /Water savings				**- $8.20**

Table 9. Precipitation Enhancement-Estimated Affected Acreage, Implementation costs and Water savings

	2010	**2020**	**2030**	**2040**	**2050**	**2060**	**Total**
Affected Acreage	-	2,072,910	2,072,910	2,072,910	2,072,910	2,072,910	-
[1]Operating Expense	-	$5.32	$5.32	$5.32	$5.32	$5.32	$26.60
[2]Aircraft Replacement	-	$0.80	-	$0.80	-	$0.80	$2.39
Water savings (Acre Feet)	-	1,720,515	1,720,515	1,720,515	1,720,515	1,720,515	8,602,576
			Implementation cost /Water savings				**$3.37**

Implementation cost (Millions)[1 2]

Table 10. Converting Irrigated land to dry land -Estimated Affected Acreage, Implementation Costs, Regional Impact and Water savings

	2010	2020	2030	2040	2050	2060	Total
Affected Acreage	59,180	59,180	59,180	59,180	59,180	59,180	-
Implementation cost (Millions)	-	$71.02	$71.02	-	-	-	$142.03
Regional Impact (Millions)	-	-$28.32	-$56.64	-$56.64	-$56.64	-$56.64	-$254.88
Water savings (Acre Feet)	-	527,888	1,055,776	1,055,776	1,055,776	1,055,776	4,750,994
			Implementation cost /Water savings				**$29.90**
			Regional Impact/ Water savings				**-$53.65**

Table 11.Biotechnology - Estimated Affected Acreage, Cost of Implementation, Regional Impact, Water savings, and cost of Water savings

	2010	2020	2030	2040	2050	2060	Total
Affected Acreage	-	496,477	892,052	988,914	988,914	988,914	-
Implementation cost (Millions)	-	$7.42	$26.70	$29.67	$29.67	$29.67	$123.12
Water savings (Acre Feet)	-	1,005,436	3,619,570	4,021,744	4,021,744	4,021,744	16,690,237
Regional Impact (Millions)	-	$113	$407	$452	$452	$452	$1875
			Implementation cost /Water savings				**$7.38**
			Regional Impact/ Water savings				**$112.32**

Fig.1 Cumulative water savings by Strategy during the Planning Horizon (2010-2060)

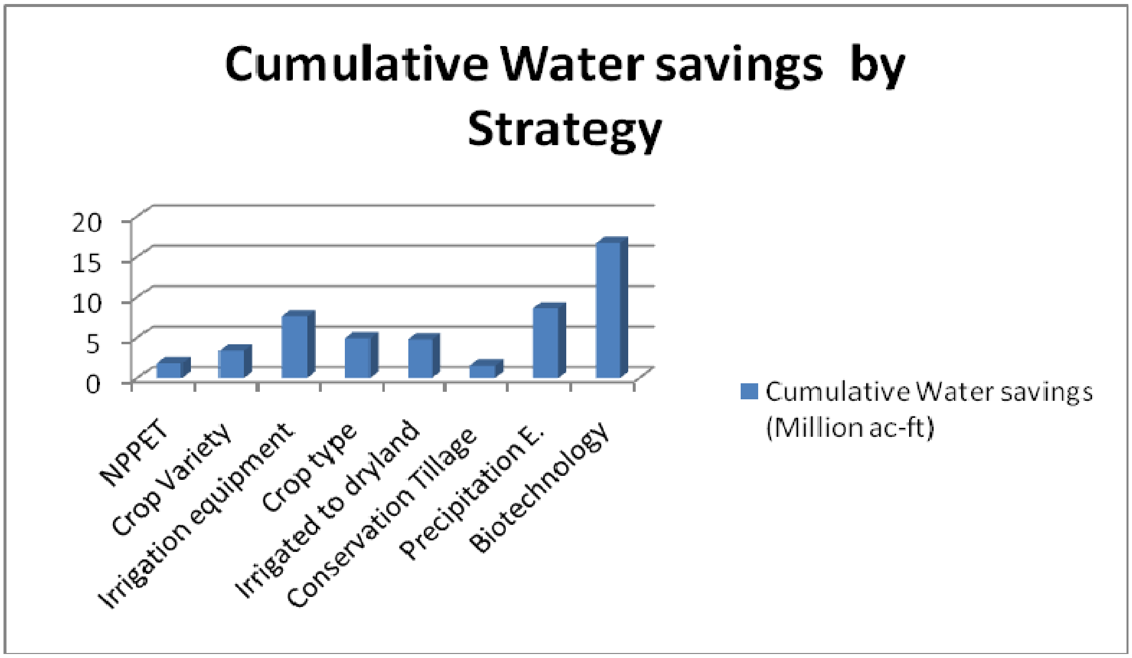

Fig.2 Water Savings and Total Irrigation demand (%) by Strategy during the Planning Horizon (2010-2060)