The Texas Journal of Agriculture and Natural Resources 29:23-38 (2016) 23

A Trans-Boundary Case Study of Water Conserving Agricultural Practices in the South Rio Grande Basin

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ABSTRACT

The purpose of this study was to explore the factors influencing agricultural use of water within the Southern Rio Grande River Basin. A case study approach was used and study areas included arid to semi-arid climatic regions in both Texas and Mexico such as Quemado, Texas in Maverick County, and three Coahuila, Mexico agricultural communities: Santa Maria, Madero del Rio, and Purisima in Piedras Negras *municipos*. Interviews of producers were conducted by the primary investigator. Qualitative analysis of responses included tallying and classifying data collected to create themes. Data collected contribute to understanding the implementation of water conservation practices in this region. Results showed that while these communities were practicing some water conservation methods, irrigation-related conservation seemed to be limited, perhaps due to the public nature of water in Mexico. Increased governmental incentives, education and research could help to make agriculture along the Rio Grande more efficient and sustainable in terms of irrigation.

KEYWORDS: Mexico; U.S. border; semiarid regions; comparative analysis; conservation practices; sustainable agriculture; organic agriculture; environment

INTRODUCTION

Years ago, Mark Twain said, "Whiskey is for drinking and water is for fighting" (Watkins and Berntell 2006). In many semiarid regions of the world, this is indeed the case (Singh 2007). Water is important to health, agriculture, and economic development. It is also necessary to maintain and enhance the biodiversity and quality of the environment (Singh 2007). In 2001, water conservation was identified as a primary agricultural policy objective by the United States Department of Agriculture (USDA) (USDA 2001). Water is a heavily disputed commodity in the Rio Grande/Rio Bravo River Basin, especially within farming communities since agriculture accounts for the largest percentage of water used in this region (Ward et al. 2007). Currently, research is

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being conducted in the basin to study water conservation, managing drought situations, farmer preferences for sustainable irrigation techniques, the effects of climate change in the region, resolving river basin conflicts, and methods for meeting diverse water needs (West 2003; International Boundary and Water Commission 2009).

Rio Grande Basin water use and rights background. Water rights between the U.S. and Mexico are governed by a treaty signed in 1944 regarding the utilization of the Colorado, Tijuana, and Rio Grande Rivers (West 2003). As a result, the International Boundary Commission was changed to the International Boundary and Water Commission (IBWC) and established a formal procedure for sharing water resources in these three international watersheds (IBWC 2009).

The diverse water uses throughout this region are central to human and ecosystem well-being. Water utilization in the Rio Grande River Basin is closely linked to food production, economic livelihoods, quality of life, ecosystem functions, energy, and human health (Schoik et al. 2004). Since 1994, however, the effects of regional population growth and record drought conditions have combined to create increasingly dire problems in these watersheds. Decreasing amounts of in-stream flow and a concomitant decrease in water availability in the last several years has exposed increasingly apparent system vulnerabilities, particularly for the Southern Rio Grande Basin, indicating a need for incentives encouraging sustainable water use practices (Ward et al. 2007). Issues of concern and influence within the region include water rights, irrigation methods, crop selection, population growth, invasive species, dams, agricultural pollution, maquiladoras (foreign owned factories in Mexico at which imported parts are assembled by lower-paid workers into products for export), mismanagement of natural resources, global climate change effects and relations between Mexico and the U.S. (Schoik et al. 2004). Although the trans-boundary portion of the Rio Grande Basin is now home to over 10 million people, irrigated agriculture still accounts for 80 to 90% of surface water diversions (Ward et al. 2007).

Surface water from the Rio Grande is pumped or released into a canal system from which it is delivered to U.S. and Mexican farms. Most canals are concrete lined with few earthen canals on either side of the Rio Grande. There are recommendations for improvements to these canals because of the current water loss due to cracks or leaks in the concrete canals that deter water movement throughout this system. Earthen canals also lose water through porous soils, which soak up water meant to flow freely to fields. Water conveyance system improvements could produce water savings of more than 243,000 acre-feet per year at an annual cost of $157 per acre-foot (Rio Grande RWPG 2016). Maverick County Water Control and Improvement District (WCID) No. 1 recently replaced 12 miles of the District’s Main Canal with concrete or urethane lining. The estimated cost of this project was $9.6 million (WCID No. 1 2002).

Water rights in Mexico. Water is considered a national asset in Mexico. The President of Mexico delegates the duty of allocating water to the National Water Commission. The National Water Commission in Mexico (*Comisión Nacional del Agua* or CONAGUA) is an administrative, normative, technical, consultative and decentralized agency of the Ministry of the Environment and Natural Resources (SEMARNAT). CONAGUA’s tasks include: a) administration of the National Waters; b) management and control of the hydrologic system; and c) promotion of social development (National Water Commission (CONAGUA) 2009). Under Article 27 of the Mexican Constitution, water is among the natural resources belonging to the Mexican State. Only by its authority can water be made private property. In addition, under Article 115, Mexican municipalities have the authority to determine the laws governing water distribution. The absence of private property rights concerning Mexico's water resources has made it difficult to provide incentives for conservation (Center for Strategic and International Studies 2003).

The development of major public irrigation projects was initiated under the Calles governorship in the 1920s; this government also emphasized agricultural research, established a public agricultural credit bank, and facilitated the provision of purchased inputs for farming (Freebairn 1983). In Mexico, the expansion of agriculture could not have happened without the development of large-scale irrigation projects. Because much of Mexico's farming is practiced in areas of marginal rainfall, the importance of water resource development has long been emphasized. Until the late 1960s, almost 90% of agricultural investment in Mexico was related to water development (Freebairn 1983). By 1970, about 70% of lands that included formal irrigation districts were located in Chihuahua, Coahuila, Nuevo Leon, and Tamaulipas in northern Mexico (Rodriguez 1972). Today, the state of Coahuila continues to maintain an irrigated agricultural system.

Water rights in Texas. The Water Control and Improvement District (WCID) No. 1 is a political subdivision of the State of Texas, organized in 1929 under Article XVI, Section 59 of the Texas Constitution, and operates under the provisions of Chapters 49 and 55 of the Texas Water Code. The WCID holds a State of Texas water rights permit, which authorizes the diversion and consumptive use of over 137,000 acre-feet of Rio Grande water for irrigation and municipal/domestic purposes. This permit also authorizes the non-consumptive diversion of approximately 1.1 million acre-feet of water annually for hydroelectric power generation (WCID No. 1 2002).

In the Rio Grande Basin, above the Amistad Dam (near Del Rio, Texas directly west of San Antonio), water rights are managed as a "first in time, first in right" fashion, as they are in other parts of Texas. Water rights below the dam are served by the Falcon-Amistad system, which is an account basis, much like having a bank account with a constantly changing balance. Priority is given to all municipal accounts so, at the beginning of each year, each municipal account's storage balance is set to the equal authorized water-right amount (Texas Commission on Environmental Quality (TCEQ) 2009). The municipal priority is guaranteed by the monthly reestablishment of a municipal reserve in the system of 225,000 acre-feet. That is equivalent to one year's average diversions for all municipal demands below Amistad Dam for Texas users.

Irrigation accounts, on the other hand, are not reset each year and must rely on balances carried forward. Each month, a determination is made as to how much unallocated water assigned to the United States is within the Falcon-Amistad system. If surplus water is identified, it is allocated to irrigation accounts on a monthly basis. When water is used, it is subtracted from the respective account by type of use from the account's usable balance. This system of accounting for water usage was put in place after an international treaty with Mexico was established and in accordance with a district court ruling of 1969 (TCEQ 2009). The responsibility to determine water use for agricultural purposes lies in the hands of the Rio Grande Watermaster, instead of the IBWC, if the water is available (TCEQ 2009).

Farmers have the option to buy and sell water rights. Offers to buy or sell water in the Rio Grande Basin, is governed in accordance with Section 49.504 (2) (A) of Senate Bill 3, as passed by the 80th Texas Legislature, 2007, Regular Session. Advertisements to buy or sell water are posted for a period of 90 days (TCEQ 2009). There are directions and a form to fill out if a farmer would like to sell or contract water which is then sent to TCEQ for approval.

Irrigation techniques. With flood irrigation, water is over-applied at the higher elevation end of a field and under-applied at the end of a field with lower elevation (Selley 1997). This technique utilizes run-off from the higher elevation areas of a field and pools that water in the lower elevation to reduce the area in which water is directly applied. However, the over-application of water at the higher elevation causes water to be lost from the field due to gravitational forces percolating water through the soil profile to below the crop-root zone (Schaible and Aillery 2012). Water is also lost in this system from evaporation and run-off in excess of the needed run-off to collect water in the lower elevation areas of the field. In the U.S. and in Mexico, this method has been in practice since the 1920s.

In the 1970s, center-pivot systems started to replace many flood irrigation systems (Schaible and Aillery 2012). Center-pivot systems have a number of metal frames (on rolling wheels) that either drip or spray the water onto the fields. Electric motors move each frame in a circle around the field (the tube is fixed at the water source at the center of the circle). The depth of water applied is determined by the rate of travel of the system. Single units are ordinarily about 1,250 to 1,300 feet long and irrigate about a 130-acre circular area (U.S. Geologic Survey 2009). Center-pivot systems decrease water-use by reducing loss due to the non-uniform nature of flood irrigation (Schaible and Aillery 2012). Center-pivot systems also allowed lands without a sloped topography to be irrigated (Schaible and Aillery 2012).

In the 2000s, drip, or micro-irrigation, increased in use (Schaible and Aillery 2012). Drip irrigation technology uses a network of pipes to carry a low-flow of water under pressure to plants. Drip irrigation delivers water immediately above, on or below the surface of the soil at a slow rate. This high precision application of water minimizes loss due to run-off, gravitational forces percolating water through the soil profile, wind and evaporation (Wilson and Bauer 2014).

In dead level irrigation, water is quickly applied to a completely level and enclosed area allowing infiltration throughout the whole area at the same rate (Fipps and Dainello 2009). Border strips are graded to a uniform slope lengthwise in the field and usually level at right angles to the flow direction which is possible with laser guided equipment (Burt 2000; Herrera and Sammis 2000).

Measuring water application takes time and requires instrumentation. If the farmer is present when water is released from an irrigation canal, measuring water and hence, reducing waste is possible by using a careful analysis of water-use efficiency. Water meters are also an effective alternative. For example, installation of a water meter where water is released to an irrigation canal monitors and measure the amount allocated, remotely. Water savings amount to significant levels if such measures are implemented effectively (O'Brien 2009).

Other agricultural water conservation techniques. Farmers can further reduce water use by practicing other sustainable agriculture techniques that are indirectly related to water usage. For example, farmers may select crops that require less water to be productive and water on specific schedules to reduce usage. Furthermore, by not tilling fields, farmers can save labor and fuel costs, reduce soil erosion and preserve organic matter and nutrients in the soil (Jain 2005). No-till also increases the accumulation of soil organic carbon, thereby resulting in sequestration of atmospheric carbon dioxide. No-till systems can improve the moisture retention of soils by building soil structure and soil biotic communities (Beck et al. 1998). Very low percentages of cropland in both the U.S. and in Canada are under no-till management (Jain 2005).

Furrow diking is a tilling system that reduces irrigation waste by reducing run-off (O'Brien 2009). Soils are plowed into ridge-like barriers running alongside row crops with the intent of increasing crop yields and reducing soil erosion. The ridges also hold irrigation and rain water, allowing it more time to soak rather than running off making the system an efficient water reduction practice (O'Brien 2009).

Land application of organic waste material is a desirable disposal and fertilizing alternative. Not only are costs usually lower relative to other disposal methods, but the waste material is beneficial for the soil and crop production. Organic material contains nutrients needed for crop growth and also improves soil structure, prevents wind and water erosion, improves aeration, and promotes soil biological activity (Ohio State University Extension 2009). The addition of organic matter to soils also helps increase water holding capacity of soils.

Land leveling, practiced in Mexico primarily, requires reshaping of the land-surface to specific grades which allows uniform and efficient irrigation (NRCS 2001). Land leveling is important not only in terms of saving water, but it also enhances drainage and reduces erosion and labor (Ahmad and Tinnermerie 1974).

The purpose of this study was to explore the factors influencing agricultural use of water within the Southern Rio Grande River Basin.

MATERIALS AND METHODS

Study sites. Case study areas were arid to semi-arid climatic regions in both Texas and Mexico and included Quemado, Texas in Maverick County, and three Coahuila, Mexico agricultural communities: Santa Maria, Madero del Rio, and Purisima in Piedras Negras *municipos* (Figure 1). This study area was surveyed because of availability of agriculture statistics from the USDA Census (USDA, National Agriculture Statistics Service 2009). Upon researching the counties in the Rio Grande River Basin, it was found that Maverick County stood out as an anomaly with regard to irrigation practices because they irrigated 3-6 times as many acres in comparison to neighboring counties (Table 1; USDA 2009). Along both sides of the border, the crops in production demand large amounts of water. Specific amounts of water applied to each crop is not known or calculated because of the flood and furrow system used.

Table 1. Irrigated area in select counties in a trans-boundary case study of water conserving agricultural practices in the South Rio Grande Basin.

Area of study	Irrigated area (acres)	Cropland area (acres)	Irrigated area (%)
Maverick County	13,044	30,800	42.35
Kinney County	2,254	11,632	19.38
Dimmit County	5,519	29,108	18.96
Val Verde County	2,622	24,755	10.59
Web County	5,082	57,689	8.81

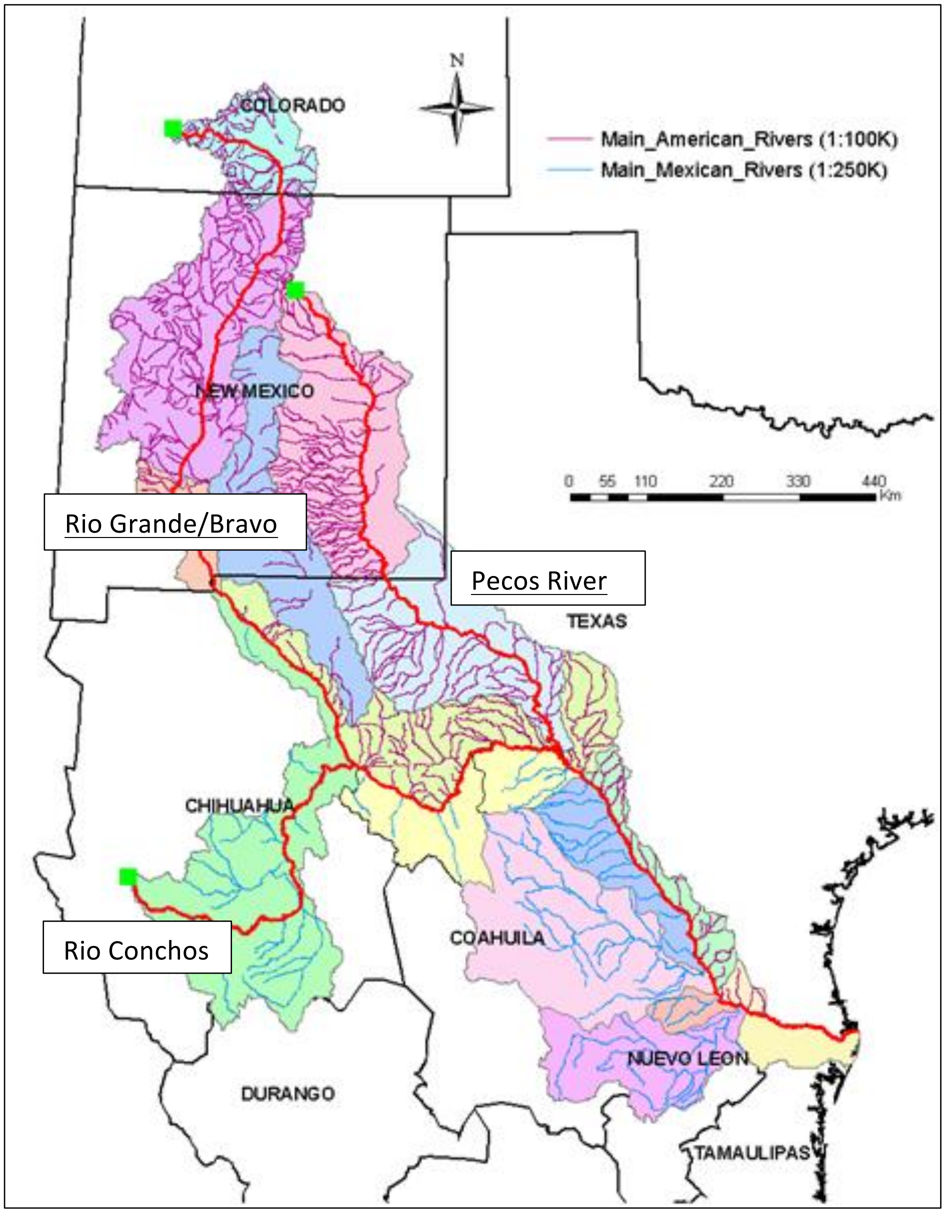

Figure 1. The Rio Grande River Basin and watershed areas of interest in a trans-boundary case study of water conserving agricultural practices in the South Rio Grande Basin. (Image used with permission by Carlos Patino and the Center for Research in Water Resources, University of Texas at Austin).

U.S. study area. Quemado, Texas is a small agricultural community located one and a half miles east of the Rio Grande and eighteen miles northwest of Eagle Pass in the Quemado Valley region of northwestern Maverick County. The Quemado Valley, for which the community is named, was designated the "burned valley" by Spanish explorers who believed the area had been parched by volcanic eruption (Germann and Janzen 1936).

Today, agriculture is the dominant means of livelihood in Quemado, Texas. Alfalfa and pecans are the primary crops that provide income to local farmers. Alfalfa grown for hay has a higher percentage of acres farmed compared to pecan production. In fact, over 990 acres are dedicated to alfalfa in Quemado (USDA 2009). Pecan production in Quemado has been a long established agricultural activity. Many of the trees in this area are 30 to 40 years old with over 235 acres in production. Other crops such as wheat, silage, klein grass, onions, tomatoes, jalapenos, and melons are also grown in this region on a smaller scale (USDA 2009).

In April, 1932, a large gravity-irrigation canal went into operation, due to an initiative from the local level, bringing Quemado Valley region under extensive cultivation for the first time (Texas AgriLife Extension 2009). The canal drew water from a Rio Grande intake 40 miles from Eagle Pass. A total of 34,500 acres in the area had been brought under gravity irrigation by the 1940s; by then, an additional 6,500 acres were irrigated by pumping water from the canal. By the early 1970s, the main canal was 108 miles long and fed more than 200 miles of lateral canals. At that time, the main canal was the largest of its type in the state (Pingenot 1971). The community of Quemado, Texas still uses these canals and laterals today for their delivery of water to farms.

Mexican study areas. Santa Maria, Madero del Rio, and Purisima, Mexico are small agricultural communities located about 17 miles south of Acuna, Mexico. The population of these communities is about 500 people each. These small communities irrigate their fields of alfalfa, oats, pecans, sorghum and canola with water from the Rio Grande. Flood or furrow irrigation is the primary technique used in this area according to the Agricultural Secretary in Coahuila, Mexico (Morris 2009). Little else is known about the history and establishment of these communities.

Agriculture in these three communities located directly across the Rio Grande River from Quemado, Texas coincides with the activities as their U.S. counterparts. Alfalfa and pecan production also provide a large percent of the income to Mexican farmers. Alfalfa for hay is grown on 86 acres in this region of Mexico, according to the Agricultural Secretary in Coahuila, Mexico (Morris 2009). Oats, which provide food to horses, cows, and other animals, is grown on 1,730 acres. The exact acreage of pecans in production in these communities is unknown, but estimates suggested that it is similar to the U.S. A non-GM (genetically modified) canola project was recently introduced to this region by the Mexican government. This project will help to provide oil from this canola to the local population of this area. Acreage for this new project has not been disclosed. Other crops such as sorghum, melons, and watermelons are also grown on a smaller scale.

Every farmer in each community also owns a small piece of land on the banks of the Rio Grande, that was inherited from his/her family. This land provides crops to sustain the farmers' families. For example, tomatoes, peppers, and onions are grown for daily consumption in each household (Morris 2009).

Survey. A survey was created to ascertain the degree to which water-related and other sustainable agriculture practices were in use on both the U.S. and Mexican sides of the Rio Grande River. The nine-question, multiple-choice survey questions were modeled after known reliable and valid case study approaches evaluating similar topics (Singh

2007; Ward et al. 2007). The questions were reviewed and validated by a panel of experts from agriculture, geography and water conservation backgrounds in the USA. The questions were meant to be posed as introductory exploratory-type interview questions giving the interviewees the option to expand on answers (Table 2). The primary objectives were to determine: (1) the types of crops grown and irrigation methods used, (2) soil fertility management methods, (3) the government or organizational incentives offered to farmers in this region to conserve water within irrigation practices, and (4) the conservation techniques implemented.

Table 2. Qualitative survey questions administered in Texas and Mexico to farmers in a trans-boundary case study of water conserving agricultural practices in the South Rio Grande Basin.

Survey questions
1. Is your farm located in Maverick County, TX or which Mexican *Municipos?*
2. What crops are you growing and what is their growth season? How many years have you grown these crops?
3. What kind of irrigation methods are used to irrigate your crops?
4. Where do you obtain information on how to irrigate specific crops?
5. How many years have you been practicing these types of irrigation?
6. Do you receive any government or other incentive(s) from any organizations to save water?
7. Do practice any conservation measures to save water?
8. Has recent drought affected your farm/crops? How? Long term effects?[z]
9. Size of the farm?

[z]Drought refers to the drought starting in 1994 and continuing until the date of the survey.

Sample. Ten surveys were administered and deemed representative for a case study of Quemado, Texas and an interview with the Agriculture Secretary of Santa Maria, Madero del Rio, and Purisima in Mexico's Piedras Negras *municipos* was used for information on the Mexican side of the border. According to the U.S. Census in 2010, the population of Quemado, Texas was 230. The population of each of the three villages in Mexico was estimated at no more than 500 people by the Agriculture Secretary (Morris 2009).

Data collection. Data from the U.S. sites were collected by administering the questionnaire during in-person interviews with individual farmers using one primary investigator. Data from the Mexican sites were collected in collaboration with the Agriculture Secretary in Acuna, Mexico. The Agricultural Secretary also toured the surrounding farms with the researcher and provided information on specific crops and irrigation practices in Mexico.

Data analysis. Data were qualitatively tallied to generate themes for each U.S. versus Mexico regions.

Figure 2. Study sites 1-10 (A) occurred in Quemado, Texas in Maverick County, and study site 11 (B) information was gathered from three Coahuila, Mexico agricultural communities: Santa Maria, Madero del Rio, and Purisima in Piedras Negras *municipos* in a trans-boundary case study of water conserving agricultural practices in the South Rio Grande Basin.

RESULTS

Crop distribution. Information gathered from farmers determined farm acreage devoted to specific crops grown. On the U.S. side of the border, alfalfa *(Medicago sativa L.)*, klein grass (*Panicum colaratum*), bermuda grass (*Cynodon dactylon*) and sorghum *(Sorgham vulgare)* were grown with the majority of agricultural acreage. Alfalfa accounted for 760 acres (16.1%). Klein grass accounted for 1600 acres (33.9%). Bermuda grass accounted for 220 acres (4.7%) and sorghum accounted for 75 acres (1.6%) in Quemado, Texas. Pecans *(Carya illinoinensis)* were grown on 235 acres (5%) in Quemado, Texas. Grapes (*Vitis spp*.) were grown on 14 acres (0.3%) just north of Quemado, Texas. Vegetables such as tomatoes (*Solanum lycopersicum*), peppers (*Capsicum spp*.), garlic (*Allium sativum*), cucumbers (*Cucumis sativus*), onions (*Allium cepa*), pomegranates (*Punica granatum*), and melons *(Citrullus lanatus* and *Cucumis melo)* are grown on 23 acres (0.5%) in Quemado, Texas. One farm, in particular, provided a local market for produce to surrounding farmers in the area. In each Mexican community, every family grew vegetable and tillage crops on plots divided along the banks of the Rio Grande. Oats (*Avena sativa*) and coastal alfalfa made up the majority of land under cultivation in Mexico. Oats accounted for 1,729 acres (36.6%) and alfalfa accounted for 86 acres (1.8%). Pecans, canola (*Brassica campestris*), sorghum, and melons were also grown in these Mexican communities, but specific acreage was not disclosed according to the Agriculture Secretary (Table 3; Morris 2009).

Table 3. Farm acreage devoted to specific crops grown in select areas in a trans-boundary case study of water conserving agricultural practices in the South Rio Grande Basin.

Area of study	Crop	Acreage/%
U.S. Quemado, Tx	alfalfa *(Medicago sativa L.)*	760/16.1
	klein grass (*Panicum colaratum*)	1600/33.9
	bermuda grass (*Cynodon dactylon*)	220/4.7
	sorghum *(Sorgham vulgare)*	75/1.6
	pecans *(Carya illinoinensis)*	235/5.0
	grapes (*Vitis spp*.)	14/0.3
	mixed vegetables	23/0.5
Mexico Santa Maria, Madero del Rio, and Purisima in Mexico's *Piedras Negras* municipos	*oats (Avena sativa)*	1,729/36.6
	alfalfa	86/1.8
	pecans	grown, but undisclosed
	canola *(Brassica campestris)*	grown, but undisclosed
	sorghum	grown, but undisclosed
	melons *(Citrullus lanatus* and *Cucumis melo)*	grown, but undisclosed
	mixed vegetables	grown, but undisclosed

Irrigation practices. The technique most used (100% of responses) to irrigate farms was flood or furrow irrigation. Other irrigation techniques used included drip irrigation (9% of responses) and pivot irrigation (9% of responses). Drip irrigation was limited in use and implemented only in Texas. Pivot irrigation was used on silage and klein grass production in Quemado, Texas. Two farms also reported using either drip irrigation or pivot irrigation in addition to flood or furrow irrigation; site 1 irrigated six acres by drip irrigation and site 4 irrigated 800 acres by pivot irrigation. Mexican study sites reported using only a single irrigation technique (flood/furrow irrigation).

Use of government or organizational programs. Farmers were asked whether or not their respective governments or organizations were encouraging on-farm water savings. Only one of ten farmers (10%) in Texas expressed some involvement in on-farm water savings. This involvement included attending educational meetings to encourage saving water and did not include incentive-driven savings. Texas AgriLife Extension Agents in the U.S. provide current information regarding federal programs, which could encourage individual farmers to save water, yet no farmers reported taking advantage of these programs.

In Mexico, PROCAMPO (*Programa de Apoyos Directos al Campo*, or Farmers Direct Support Program) was taking an active role to re-build infrastructure that would deliver water to farms more efficiently. PROCAMPO was designed to provide direct support to subsistence farmers who, in the words used by the government in setting up the program, "have not benefited greatly from Mexico's current system that compensated producers through guaranteed prices for crops that are marketed" (Weintraub 1994). In fact, PROCAMPO was financing this new system in Santa Maria, Mexico. According to the Agriculture Secretary, an equivalent of $80,000 U.S. dollars was slotted to be invested in this system.

Conservation methods utilized. Many of the farmers surveyed in both the U.S. and Mexico (91%) were practicing some methods of conservation to help reduce irrigation. The methods of conservation used included: no till practices (9%), furrow diking (27%), application of organic material (27%), measuring specific amounts of water applied to fields (9%), dead level irrigation (9%), and land leveling (9%) (Table 4).

A secondary conservation method found used in the study areas was brush control (9%). The USDA Natural Resources Conservation Service (NRCS) estimated that brush in Texas uses over 3.5 trillion gallons of water annually. Control of brush such as mesquite *(Prosopis glandulosa)*, salt cedar *(Tamarix ramosissima)*, poison ivy *(Toxicodendron radicans)*, and Russian olive *(Elaeagnus angustifolia)* present viable options for increasing the availability of water for other needs (TSSWCB 2009).

Table 4. Primary and secondary water conservation methods in U.S. and Mexico in a trans-boundary case study of water conserving agricultural practices in the South Rio Grande Basin.

Site	Primary conservation method	Secondary conservation method
Site 1	No till practices	
Site 2	Furrow diking	
Site 3	Application of organic material	Brush control
Site 4	Application of organic material	
Site 5	Measurements of water- No waste	
Site 6	Application of organic material	
Site 7	Furrow diking	
Site 8	Dead level irrigation	
Site 9	Furrow diking	
Site 10	none	
Mexico Site 11	Land leveling	

Soil fertility management. Five of the 11 sites surveyed (45%), including Mexico, fertilized organically. Applications of organic materials used as soil conditioners or as a source of nutrients included grape skins, chicken manure and compost (Table 5). Grape skins provide organic matter and potassium to the soils. Manures and composted plant materials also add organic matter, which helps retain soil moisture, improve soil structure, prevents compaction, and helps to prevent nutrients from leaching. Organic materials also balance extremes in soil pH (Owen 2009). Poultry manure (chicken in particular) is the richest animal manure in nitrogen, phosphorous and potassium. However, chicken manure is considered "hot" and must be composted before adding it soils. Otherwise, it will burn any plants with which it comes in contact (Owen 2009).

Liquid nitrogen and ammonium sulfate were used as fertilizers in the remaining six cases surveyed. In Mexico, synthetic nitrogen, phosphorous, and potassium (N-P-K) were applied only when financially viable. This application seemed to happen more often on larger parcels of acreage. Family plots located on the banks of the Rio Grande in Mexico tended to not use synthetic fertilizers (Table 5).

Table 5. Types of fertilizer or soil conditioners applied in U.S. and Mexico in a trans-boundary case study of water conserving agricultural practices in the South Rio Grande Basin.

Site	Type of fertilizer or soil conditioner applied
Site 1	Grape Skins
Site 2	Liquid Nitrogen
Site 3	Synthetic and organic materials
Site 4	Liquid Nitrogen
Site 5	Ammonium Sulphate
Site 6	Chicken Manure
Site 7	Liquid Nitrogen
Site 8	Organic Material
Site 9	Granulated Nitrogen
Site 10	Compost
Mexico Site 11	Compost and N-P-K (when affordable)

DISCUSSION AND CONCLUSIONS

Farmers in the U.S. practiced more commercial farming, whereas Mexican farmers were more involved in subsistence farming for their daily needs – as reported by the Agriculture Secretary in Mexico, every farm had a vegetable plot for family use. This suggested that agriculture was more of an occupation for U.S. farmers compared to a way of life for Mexican farmers. Farmers on both sides of the Rio Grande shared many of the same agricultural practices according to the findings of this qualitative case study, for example, forage crops and tree crops, such as alfalfa, sorghum, and pecans, were grown in the U.S. and Mexico. The majority of farmers also irrigated their crops the same way, with flood or furrow irrigation techniques predominantly. However, there were significant differences between these two nations with regard to governmental incentives for sustainable irrigation practices with Mexican farmers having little incentives for on-farm water conservation specifically, but PROCAMPO was working to support farmers through building efficient infrastructure. Differences also appeared between the U.S. and

Mexican farms in conservation methods and in soil fertility management methods utilized.

Crop selection for farmers in both countries depended upon many factors. Depending upon the weather, water availability, economic value, and overall production costs, the variety of species that can be grown is limited in each study area. Farmers that participated in this survey had been growing low forage crops and tree crops for many decades, and may have purchased the land with already established trees.

Farmers in this region have also been irrigating with the same methods since the canals were established in the 1920s and 1930s. Changing management practices may seem risky to many because many farmers have little room for economic error (Blesh and Barrett 2006). This principle is especially true for farmers in Mexico where sustenance is dependent upon crop growth. Changes in agricultural production and management practices require that tradeoffs be made among the often conflicting interests of producers, consumers, and the environment (Campbell 1991).

Vulnerability of the agricultural sector will continue to increase as the demand for water grows. This demand will most likely come from the growing municipal and generally increasing human water demand. The use of water produces considerable economic value in a modern household. Beyond satisfying basic human requirements, water has been extensively analyzed as an economic resource for which there is considerable urban demand, particularly in the desert southwest. Besides cooking, washing, cleaning, and sanitation, the typical Rio Grande Basin household in the U.S. uses water for outdoor cleaning and to sustain a domestic landscape environment (Ward et al. 2006). Changes need to be made in both the agricultural and municipal sectors with regards to water use practices to reduce the vulnerability of this area to water scarcity.

Despite the lack of sustainable irrigation techniques in use, many farmers in Texas and Mexico were taking the initiative to practice other sustainable agriculture methods that result in improving water-use efficiency without governmental or organizational incentives. Sustainability is often more than the actions of a single producer, but rather it is the composite of many decisions and actions by people in a region working together toward a common future (Schoik et al. 2004). However, there are limitations for some producers to sustainable farming such as that Mexican farmers do not have the government backed subsidies presented to U.S. farmers. Since the security of funds is not guaranteed and many farmers are simply struggling to survive, farming using practices considered sustainable is a luxury for many farmers in Mexico. Farmers in Quemado, Texas, were also practicing such methods as furrow diking, application of organic materials, brush control, no-till practices, and dead level irrigation. Farmers in Mexico were practicing land leveling methods. These sustainable agriculture methods not only benefit the farmer; they are benefitting the land on which the farms thrive. Many of these methods help protect the topsoil by preventing erosion from run-off. By preventing run-off and soil erosion, water-use efficiency is consequently improved. The incentive to use these techniques lies in protecting the farmers' investment in their land rather than monetary incentives to reduce water applied through irrigation.

While surveying agricultural communities in Santa Maria, Madero del Rio, and Purisima with the assistance of the Agricultural Secretary, many goals for Mexican agriculture were discussed. One goal in particular was to encourage Mexican farmers to continue farming in Mexico. The Mexican government was promoting and supporting family farms by off-setting 70% of some costs associated with the family farm. Examples of approved costs to offset included items such as windmills for the farm or community or sewing machines for the farm household. According to the Agricultural Secretary, these small steps have helped to revive these farming communities and not encourage further displacement and outmigration of Mexican families.

The majority of farmers in both the U.S. and Mexico surveyed in this case study had taken the initiative to promote a more sustainable Rio Grande Valley through various techniques designed to prevent soil erosion and run-off. There are future challenges, such as increasing water usage, which will continue to affect the ability to feed a growing population without degrading the environment and natural resource base. Improvement of agricultural practices along the Rio Grande depends critically on regional research to understand the dynamics of this River Basin, the human-environment interaction, as a whole. Future improvements to irrigation which may require governmental support in Mexico could help further reduce agricultural water demands.

The IBWC and its Mexican counterpart *Comision Internacional de Limites y Aquas* (CILA) manage water resources along the U.S.-Mexican border. Scholars of border water resource issues have suggested alternate means by which IBWC and CILA can address water resource management issues. Many advocate for some form of a border-wide science advisory council or board that would more aggressively bring academic-based research into the debate (Schoik et al. 2004). This border-wide science advisory council could also bring U.S. and Mexico farmers together through stakeholder meetings. Such meetings could encourage communication between agricultural producers. Ultimately, a more comprehensive understanding of agriculture in the Rio Grande Basin could be achieved.

Agriculture must become a primary concern for farmers and non-farmers alike, as safe and effective food production is necessary for the development and maintenance of a sustainable society (Blesh and Barrett 2006). Understanding agriculture on a regional scale is fundamental to the future of the Rio Grande River Basin. This small regional survey extrapolated clear data gaps between the U.S. and Mexico. Before this survey was conducted, little to no information was available for the agricultural communities of Santa Maria, Madero del Rio, and Purisima, Mexico. There is a need for accurate and reliable information on crop inventory, land cover, soils, distribution of irrigated areas, and irrigation techniques used throughout this Basin in both countries. Some of this data currently exists for the U.S., but most often this data does not include Mexico. Future GIS and remote sensing research could help to produce and relay such information on a Basin-wide scale.

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