ESSAYS ON PRODUCER PROFITABILITY, STRATEGIES, AND ATTITUDES FOR WATER CONSERVATION IN THE TEXAS HIGH PLAINS

by
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ABSTRACT

Water is a vital resource for agricultural crop production in the Texas Panhandle and greater Texas High Plains Area. This semi-arid region relies almost solely on the Ogallala Aquifer as the primary source of water. Three studies were conducted to evaluated producer profitability, water management strategies, and producers' attitudes towards water conservation for the region. Study one focuses on the top 26 counties, known as the Texas Panhandle. Producers in the area are evaluating new strategies to diversify their operations. Vegetable and vegetable seed production are examined for potential impacts on producers' profitability. Analyzing the feasibility of specialty high-value crops will allow producers to make informed decision regarding the addition of vegetables and vegetable seed to their operations. Yields, costs, and revenue from high tunnel productions systems are compared to the standard open field systems. The study suggests high tunnels produce higher yields, but require a higher initial investment cost. With the support of the USDA Natural Resource Conservation Service's High Tunnel Initiative program, producers can decrease their initial investment costs to increase overall profit.

Agricultural production dominates water use in the area and is projected to account for 92 percent of total water use by 2020. Since agriculture is such an essential sector of the regional economy, prolonging irrigation capability through improvements in crop production methods is warranted. The area of concern and evaluation in study two

consists of Texas' northernmost 21 counties where groundwater withdrawal rates continue to exceed the aquifer's recharge rate, resulting in less available irrigation resources. Within the region, seven counties in the Panhandle Water Planning Area of Texas are projected to incur water shortages in the 2020-2070 planning horizon. A regional analysis evaluating several agricultural water conservation strategies and combinations to address the decline of water use in the region is presented. The analysis examines potential water savings and implementation costs associated with the alternative strategies to provide useful information to stakeholders such as producers, groundwater conservation districts, and regional water planning groups.

Study number three evaluates the counties within the greater Texas High Plains. Twenty producers were surveyed to obtain information on their water conservation management practices and attitude towards such efforts. Results indicated producers are implementing multiple irrigation technologies and management practices. Respondents were all concerned with the future water availability in the area. This study provided researchers feedback to reassess the survey for future studies.

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Introduction

The agricultural industry has a colossal impact on the Texas Panhandle economy. In the area, 14.8 million acres are dedicated to agricultural production, which is approximately 90 percent of the panhandle region. Thirty-five percent of the land is devoted to dryland and irrigated crop production with the remaining acres used for pastureland (Benavidez et al., 2019). Conventional field crops produced in the area include corn, grain sorghum, wheat, and cotton.

Agricultural production in the Texas Panhandle relies significantly on the Ogallala Aquifer for water. However, the current withdrawal rate of the aquifer exceeds the recharge rate (McGuire, 2017). Producers are adapting to the decline of the aquifer through the implementation of new production strategies, such as utilizing new irrigation technology or crop varieties and, in some instances, transitioning to dryland production. The Texas Panhandle is a semi-arid region that has a favorable climate and long growing season for producing high-value crops and seeds. Seed production is an alternative production strategy being considered by producers to enhance farm profitability as water levels diminish.

The Texas Panhandle is one of the most diversified agricultural areas in the world (Almas, Colette, and Wu, 2004). Crop production and livestock production, including fed beef, hogs, dairy, and cow-calf and stocker operations, account for $5.6 billion in annual cash receipts (Benavidez et al., 2019). Vegetables are high-value crops that producers can consider adding to diversify their operations and increase overall profitability. However, while previous studies have been completed in other regions of the United States, there is no existing literature that evaluates the economic viability of vegetable seed production, in particular, for the Texas Panhandle.

Producers are also implementing new production systems to increase their profitability (Khanal, et al., 2008). High tunnels are becoming an increasingly important production system used by vegetable producers. The increased adoption of high tunnels is due to the opportunity for crop protection and extending growing seasons. Boychuk (2019) revealed, by surveying producers in the Texas High Plains region, that high tunnels are being implemented into regional operations. High tunnels are reported to provide increased overall farm profit and positive effects on producers' quality of life (Bruce et al., 2017; Wallace et al., 2012; 2013).

The overall objective of this study is to analyze the economic feasibility of high-value fresh vegetables and vegetable seed production within the Texas Panhandle. Important economic factors will be analyzed in this study to allow producers to make informed strategic decisions for their existing operations. Specifically, enterprise budgets for fresh market tomatoes and jalapeño peppers will be reevaluated for open field production and created for high tunnel production. In addition, jalapeño pepper seed and basil seed enterprise budges will be developed for both open field and high tunnel production systems, respectively. Vital economic measures, such as revenue, costs, yields, profit, return on investment, and breakeven prices will be utilized to determine the economic feasibility of each crop and comparisons will be made between high tunnel and open field production.

Review of Literature

While current literature analyzing vegetable seed production in the study region is limited (Fess, et al., 2018; OFRF, 2011), this literature review examines studies focused on vegetable production and production practices. The literature review is allocated into two segments: vegetable seed production practices and high tunnel production systems.

Vegetable Seed Production

Health-conscious consumers' demand is increasing the importance of vegetable production in America (McDonald, 1998).The demand for fresh market vegetables is increasing producers' demand for high-value vegetable seeds. Producers can ensure seed supply for the next generation of vegetable crops by either retaining seed from previous crops or purchasing from elsewhere (George, 2009). Producing quality seeds initiate the opportunity for quality fresh vegetable production (Welbaum, 2005). Although limited, the following studies discuss vegetable production activities, current specialty seed crops, and impact on agricultural industry.

Numerous production actives must occur to produce quality seed. An article by Delouche (1980) discussed important factors to the seed industry. Production area was a section discussed. Vegetable seed production is most common in the arid and irrigated areas of California, Idaho, and Arizona. Location of production is also determined by other factors. Hybrid flower and vegetable crops are produced in India and other Asian countries and Central America due to the abundance and low cost of hand labor. Delouche (1980) discussed the importance of soil fertility and moisture in seed production. Nutrient and moisture deficiencies do not affect the quality of the seeds as much as the quantity produced. Moisture amounts are often determined by the production region. The climate of production region can drastically affect seed production. Severe drought, extreme heat, or cool temperatures can affect the development of seed within various crops. These factors have caused seed production to shift to specific areas within the United States and to other countries (Delouche, 1980).

One of the main objectives of this study is to increase producers profit by diversifying their operation with high-value vegetable seed production. The University of Kentucky created a variety of chia seed compatible with the Midwest's growing season. Kaiser and Ernst (2016) evaluated the new chia seed production in Kentucky. Chia seed has become a popular source of omega-3 fatty acids, and the market is expected to grow due to nutritional trends. This report discusses production considerations including soil type, planting techniques, pest management, harvest methods, and labor requirements. Chia seed prefers moderately fertile soil and is highly intolerant of wet soil. A standard grain drill is used to plant chia seed, and a standard combine with slight modifications can be used to harvest the seed. In 2016, the University of Kentucky's Department of Agriculture Economics estimated no-till soybeans to cost $470 per acre. Chia seed production costs were estimated to be less per acre than soybeans. Kaiser and Ernst (2016) also expect returns to land, capital and management for chia to be higher than returns for soybeans grown on the same land.

Although previous literature evaluating the economics of seed production is limited, Matthews (2009) reported on California seed production for the year of 2008 with the goal to document the importance of seed production for agriculture in California. California is large production area supplying seeds for the next generation of crops. During the 2008 production year California generated $1.1 billion from seed sales in the

U.S. and $2.9 billion in seed sales worldwide. Seed production in California comes from four main categories: field crops, vegetables, turf, and flowers. California vegetable seed production accounts for 43.5 percent of the total vegetable seeds produced in the United States. One hundred nineteen farms produced all of the vegetable seed in the state. Also California supplied 37.7 percent of the total United States flower seeds production (Matthews, 2009). Large specialty crop seed production areas are in California and the Pacific Northwest. The semi-arid environment of the Texas High Plains closely mimics that of the Central Valley of California. Central Valley is one of the main locations for seed production in California (Matthews, 2009).

High Tunnel Systems

High tunnels are similar to simple greenhouses covered with clear polyethylene (Wien, 2009). However, these structures differ from greenhouses because they do not contain permanent heating, cooling, or automated ventilation systems. Rolling up the plastic sides allows the wind to circulate air through the high tunnels and the primary source of heat is produced by the sun (Sanchez, Lamont Jr., and Orzolek, 2007).

High tunnels protect crops from extreme environmental conditions, and the Texas Panhandle is known for severe weather ranging from high-speed winds to large hail storms. Several previous studies have examined all of the potential benefits associated with vegetable production using high tunnels. The Texas Panhandle can often experience extreme freezes towards the end of the growing season. Waterer (2003) analyzed the economic benefits of high tunnels for warm-season vegetable crops in Canada where seasonal frosts are also experienced. The objective of the study was to compare yields, crop quality, and production economics of muskmelons, peppers, and tomatoes produced from high tunnel versus low tunnel production practices. Plants within the high tunnels did not receive additional water from rainfall, resulting in a lower weed population. Results indicated that high tunnels allowed the crops to mature earlier, especially the pepper plants. Protection from seasonal frost extended the fall harvest by two weeks on average. The matured peppers were red and these received a premium price of $1.15/kg compared to green at $0.65/kg. Among the three crops in this study, peppers grown in high tunnels were the most economically feasible. The researchers concluded that producers might benefit from raising high-value crops under high tunnels (Waterer, 2003).

A study in South Central Kansas discovered that strawberries had great potential for early season and standard season production (Kadir, Carey, and Ennahli, 2006). An early and later production season may benefit the quality of the crop by avoiding high temperatures and heat stress.

Wallace et al. (2012) compared the yield and quality of spring-planted lettuce from open field and high tunnel production systems. Three experimental field trials were conducted in Knoxville, TN; Lubbock, TX; and Mount Vernon, WA. They found that high tunnels may allow for early lettuce production in southern climate states, and the authors discussed that high tunnels may provide an advantage to producers in places like the Texas High Plains. These structures help protect crops from the high winds and dust common to the area (Wallace et al., 2012).

Another study by Galinato and Miles (2013) examined the economic profitability of growing lettuce and tomatoes in Western Washington. They compared high tunnel and open field production systems. Economic data was collected from focus groups with tomato and lettuce production experience, which researchers used to create enterprise budgets for both production systems. Results indicated for lettuce, even though high tunnels were still profitable, profitability was higher for open field production. However, for tomatoes, the profitability was 62 percent higher for high tunnel production at the lowest expected yield. High tunnels produced higher marketable yields compared to the open field crops (Galinato and Miles, 2013).

Rodriguez et al. (2012) conducted an economic analysis of open field versus high tunnel production of blackberries in northwestern Arkansas. The objective was to estimate the breakeven point to cover the total costs for extending the harvest season of blackberries under open field and high tunnel conditions. One hectare of blackberries was planted for each production system. Total costs of production, for the one hectare, were calculated by using an interactive blackberry enterprise budget. Yield data was represented by actual production data obtained from the Arkansas Agricultural Research and Extension Center. Weekly random yields were generated based on actual yield data, and price was determined from retail data provided by Nielsen Company. A simulation software was used to simulate a random present value of gross revenue using a random yield and price from the data for each production system. The gross revenue was compared to the total cost to determine the breakeven probability. Production results indicated that high tunnels produced greater yields later in the harvest season, and overall total production was greater in high tunnels by year three of the study. However, the authors concluded that the high tunnels did not provide considerable extended season benefits for blackberry production in Arkansas. The simulation results indicated that during some years gross revenue did not offset the total costs of the high tunnel. They speculated that a producer can improve their chance to breakeven by using the structures in additional ways (Rodriguez et al., 2012).

Previous studies discussed the value of the seed industry to specific areas within the United States and the potential profit producers can receive from diversifying their operation. The benefits of high tunnel production systems were also evaluated in previous literature. Although no previous studies have been conducted over the topic of vegetable seed production in the Texas Panhandle, Boychuk (2019) evaluated high-value vegetable production in the Texas Panhandle. This study further expands on Boychuck's study and other aforementioned studies.

Data and Methods

Study Area

The Ogallala Aquifer is the largest underground water reservoir in the United States. The aquifer provides water to eight states in the Great Plains, including Colorado, Kansas, Nebraska, New Mexico, Oklahoma, South Dakota, Texas, and Wyoming. The northernmost 26 counties contained in the Texas Panhandle make up the study area for this project, Figure 1.1. This area specifically includes the following counties: Armstrong, Briscoe, Carson, Castro, Childress, Collingsworth, Dallam, Deaf Smith, Donley, Gray, Hall, Hansford, Hartley, Hutchinson, Lipscomb, Moore, Ochiltree, Oldham, Parmer, Potter, Randall, Roberts, Sherman, Swisher, and Wheeler. This region was chosen as the study area due to the large dependence on the Ogallala Aquifer for irrigated agriculture

Figure 1.1 The study area over the Ogallala Aquifer.

<u>Methodology</u>

Crop enterprise budgets for fresh market tomatoes and jalapeños were created to compare high tunnel to open field production. Enterprise budgets for jalapeño pepper seed and basil seed were developed to determine profit and return on investment as well as breakeven prices. Economic measures were calculated to support the objectives of this study. These measures included revenue, costs, profit, breakeven prices, and return on investment. Due to the variability associated with agricultural enterprises, sensitivity analyses were developed to analyze alternative yields and prices received.

<u>Production Data</u>

Vegetable and vegetable seed production data for this study was primarily based on a field study conducted at the USDA-ARS CPRL/Texas A&M AgriLife Vegetable Production Lab in Bushland, Texas. Tomatoes, jalapeño peppers, and basil each were grown under high tunnel and open field production systems (Gray, 2020).

One high tunnel was planted solely with basil, and two other high tunnels were divided into four zones for pepper and tomato production. Peppers were planted in two zones and tomatoes in the two remaining zones, Figure1.2. Each zone contained three 40-foot by 15-foot rows. The high tunnel footprint was replicated for open field production. The high tunnels used in the field study were 2760 square feet or 0.0634 acres of land. For this study, production activities were divided by 0.0634 to convert quantities to a per acre basis.

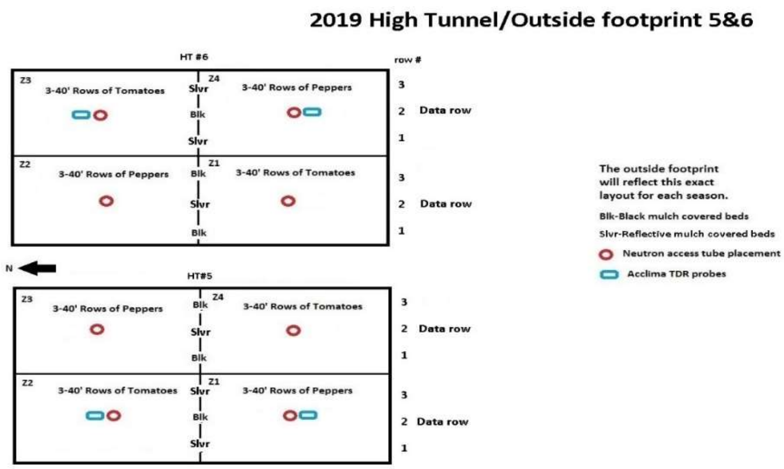

Figure 1.2 Jalapeño pepper and tomato high tunnel and open field plots, 2019
Source: Gray, 2019

Yield

The fresh market vegetable yield was calculated by harvesting a ten-foot section from each zone. Total produce and marketable produce weights were measured in pounds. Each crop was harvested multiple times throughout the season. Weights from each harvest were combined to provide a total annual production yield. Marketable produce weights were used in the enterprise budgets to represent the unblemished high quality produce available to market to the consumer.

For seed production yield, a three plant average was measured from the middle four of six rows in the open field and high tunnel systems. The weights from the data rows were averaged together and divided by three to give a per plant weight in grams. Grams per plant were converted to pounds by dividing by 454. Pounds per plant were multiplied by the number of plants per acre to reach a per acre yield total. Open field seed yield was not available for jalapeño seed production.

Price Data

Price data for this study reflected actual prices received for the fresh vegetables produced during the 2019 field study (Gray, 2020). The produce was sold to a local retailer and was able to be marketed as local. Alternatively, national price data for fresh market produce could be utilized from the USDA Agricultural Marketing Service (2019) and a farm share percentage applied to estimate the wholesale prices producers received (USDA ERS, 2019a; USDA ERS, 2019b). However, it was determined that the local price received for the fresh, marketable produce was the most representative price to use for the purposes of this study.

Wholesale price data for specialty seed crops was not readily available through USDA's databases. This data is limited due to specialty seed crops being a niche market. Many of the commercial vegetable seed companies are owned by larger multinational companies (Welbaum, 2005). The seed typically is grown under a contract between the producer and the seed company (Regional Producers, 2020). Prices producers receive for their commodity is stipulated by the contract, which may be negotiated on a per acre basis rather than per quantity produced. Thus, no seed prices were estimated for the purposes of this study. However, breakeven prices and specific prices that would need to be obtained to reach a certain return on investment were estimated in order to provide price reference points for producers considering vegetable seed production.

Production Costs

Vegetable-specific and field activity inputs were recorded by research staff. Input costs varied by production method and were collected from Texas A&M AgriLife Extension Projected Crop and Livestock Budgets for the Texas High Plains (Boychuk, 2019; Benavidez et al., 2020) and from data collected during the field experiment at Bushland (Gray, 2020). Enterprise activities and costs included applying fertilizer, constructing high tunnels, laying black plastic mulch and drip tape, transplanting jalapeño pepper and basil seedlings, hand-weeding, applying herbicide, and harvesting. For all budgets, interest on credit line was assumed to be one-third of pre-harvest expenses at a rate of 6.25 percent (Boychuk, 2019; Benavidez et al. 2020).

Some inputs for the field study were constant across crops and production systems. Four hundred sixty-nine pounds of 16-16-16 fertilizer were applied evenly across all experiment zones. Fertilizer costs were $0.43 per pound, and application costs were $5.35 per acre (Benavidez et al. 2020; Gray, 2020). Herbicide and insecticide were not used for the 2019 field study. In general, Sevin insecticide is recommended for tomatoes and jalapeños at a rate of 0.17 gallons per acre. Thus, the recommended insecticide was included in the budgets at $87.99 per gallon with an application cost of $5.35 per acre. Herbicides are not approved for fresh market basil (Davis, 1995). For tomatoes and jalapeños, 1.33 pints of Metolachlor and 1.33 pints of Treflan was used for tomato and jalapeño production. Both products were $5.00 per pint with an application rate of $5.35 per acre for each input (Boychuk, 2019; Benavidez et al., 2020).

Drip irrigation lines and black plastic mulch were used in this study. The drip irrigation system required 2.2 rolls of Toro 15-mil drip tape (4,000-foot rolls) with 12-

inch drip emitter spacing for application and 527 drip tape fittings which was estimated to cost $150.00 per roll and $1.60 per fitting, respectively. Black plastic mulch was used for weed management; however, additional manual labor was required to control weeds. One acre requires 2.2 rolls of black plastic mulch at $177.00 per roll. Hand weeding totaled to 90 hours per growing season with an expense of $8.50 per hour (Boychuk, 2019).

Irrigation was applied evenly across the tomato and jalapeño open field experiments. Open field tomatoes and jalapeño peppers were irrigated with 7.66 acre-inches of water over 20 irrigation events. Open field basil production required 8.40 acre-inches. High tunnel production required more irrigation; tomatoes required 10.32 acre-inches, jalapeño peppers used 9.18 acre-inches, and basil was irrigated with 8.93 acre-inches of water. Irrigation events totaled 29, 28, and 24, respectively (Gray, 2020). Irrigation energy had a cost of $3.96 per acre-inch, and labor for irrigation required 0.009 hours per irrigation event with a cost of $13.65 per hour (Boychuk, 2019; Benavidez et al., 2020).

Harvest costs for fresh market produce include harvesting, counting, and sorting the vegetables for market. The custom harvest costs for fresh market tomatoes and jalapeño peppers was $10.45 per cwt (Benavidez et al., 2020). Methods for seed harvesting vary by crop. Seed can be harvested mechanically with a combine from dried basil plants (Putievsky and Galambosi, 1999). The highest quality seed comes from fully ripened fruit. Jalapeños turn a bright red color when ripe. Mechanical seed extractors are used to separate seeds from the pulp and skin of peppers (Crosby, 2020). The majority of the seeds are removed when the machine grinds the fruit; however, seeds surrounded by mucilaginous sheath are treated with hydrochloric acid to release the remaining seeds.

The acid requires only fifteen to thirty minutes to finish extracting seeds (Hawthorn, 1961). Specialized equipment is frequently required, and contracting companies often furnish producers with these implements (Schudel, 1952). The American Seed Trade Association (2011) states that production practices, such as harvesting, can be completed by the seed company, the grower, or shared by the two entities.

Vegetable-Specific Costs

Although a majority of the production costs were consistent across both production systems for all crops there were several species specific costs. Transplant seedlings were used in the 2019 field study for all vegetable crops. All transplants were $0.11 per plant. According to Gray (2020), 17,897 basil, 5,050 tomatoes, and 10,101 jalapeño peppers seedlings were required per acre.

Tomato production requires trellis support to reduce stem breakage and plant diseased that may develop from excess ground moisture. Trellis systems consist of 879 metal posts, 1,757 wood posts, and two rolls of 7000-foot tomato trellis twine. Wood posts and metal posts total in cost of $1,757 and $3,516 per acre (Boychuk, 2019). Trellis twine expenses average $7.00 per roll. Setting posts and twine resulted in 9.7 labor hours per acre at $13.43 per hour (Boychuk, 2019; Benavidez et al., 2020).

Equipment Costs

Machinery labor costs were $13.43 per hour and require 0.98 hours of tractor and self-propelled equipment labor. Other labor hours reflect the additional laborers besides the tractor operator. Other machinery labor totaled 1.79 hours. Fuel used by the machinery totaled 2.19 gallons of diesel fuel at $2.33 per gallon, and gasoline totaled $117.50 per acre. Gasoline totals were calculated by multiplying the annual gallons used by the fuel price and then multiplying by the percentage of annual equipment use (Boychuk, 2019).

High Tunnel Costs

Producers that choose to produce under the high tunnel system will have an initial investment cost that will need to be considered in their decision to produce specialty seed crops. High tunnels are assets with a useful life of 20 years and a 10 percent salvage value (Lewis, 2010). The high tunnels used in the 2019 field study were FarmTek Clear Span 30-foot by 12-foot by 96-foot structures. The starter package building kit requires an initial investment of $7,255 per high tunnel. Additional posts, boards, bolts, screws, concrete, and miscellaneous tools were purchased for the construction of the high tunnels; the additional materials totaled $2,838 per high tunnel. Plastic covers and doors for the structures have a useful life of four years (Sydorovych et al., 2013). Applying the cost of the starter package to an acre area, results in a total investment cost for the high tunnels of $180,266 per acre. Taking into account the life of the high tunnel as well as the estimated salvage value, annual costs for the structure were budgeted to account for the investment for those crops which utilized the production system.

Repair costs for the covers and doors were reported as repair and maintenance costs. Repairs and maintenance were calculated as a percentage of total costs of the equipment (Cornforth, 2020). Fixed costs were represented by equipment depreciation and annualized investment costs. Depreciation was calculated using the straight-line depreciation method. Annual equipment investment costs represented the interest on credit and was calculated by adding the salvage value to the original cost, multiplying the result by the interest rate, and dividing by two. Total interest for the equipment investment is divided by two because this study assumed producers will finance half of the investment cost for the high tunnel structure.

Results

Fresh Market Vegetables

Vegetables grown in the high tunnel systems produced a higher yield compared to the open field systems. Tomatoes and jalapeño peppers produced 333 and 159 cwt per acre of marketable yield in the high tunnels, respectively. Open field tomatoes yielded approximately 190 percent less with a total of 115 cwt per acre. Open field jalapeño peppers yielded 143 cwt per acre, which was a marginal difference compared to the high tunnel marketable yields.

Tomatoes had a budgeted price of $100.00 per cwt, resulting in a gross revenue of $11,500.00 per acre for open field produce and $33,300 per acre for high tunnel production. Jalapeño peppers had an expected price of $65.00 per cwt. Open field peppers grossed $9,295.00 per acre in revenue, and high tunnel production totaled $10,335.00 per acre. The estimated national wholesale farm price for tomatoes was $35.30 per cwt and $23.78 per cwt for jalapeño peppers. These prices would lower the revenue and profit of each vegetable significantly. This indicates that marketing vegetables locally can enhance the overall profitability of fresh vegetable production.

Total variable costs varied due to labor required for production inputs such as transplants, irrigation, and harvest costs. Equipment inputs affected total fixed costs for each crop in each production system. Open field production costs for tomatoes and jalapeño peppers totaled $5,532.93 per acre and $5,603.60 per acre. Total costs for tomatoes and jalapeño peppers produced in high tunnels calculated to $23,215.98 per acre and $21,170.39 per acre, respectively. Both crops in each production system were projected to return a positive profit when produce is marketed locally with the exception of high tunnel jalapeños, Table 1.1.

Table 1.1 Revenue, costs, and total profit per acre for fresh market tomatoes and jalapeño peppers with open field and high tunnel production systems

Commodity	Gross Revenue	Total Variable Costs	Total Fixed Costs	Total Costs	Total Profit
Fresh Tomatoes†	$11,500.00	$4,703.02	$829.90	$5,532.93	$5,967.07
Fresh Tomatoes‡	$33,300.00	$8,077.46	$15,138.52	$23,215.98	$10,084.02
Fresh Jalapeño Peppers†	$9,295.00	$5,405.25	$198.35	$5,603.60	$3,691.40
Fresh Jalapeño Peppers‡	$10,335.00	$6,663.42	$14,506.97	$21,170.39	($10,835.39)

† Vegetables grown in open field system
‡ Vegetables grown in high tunnel system

Seed Production

An increase in yield from open field to high tunnel systems was observed in the basil seed production. Open field yield for basil seed totaled 235 pounds per acre, and the high tunnel system produced 519 pounds per acre. The change in yield was a 121 percent increase from the open field to the high tunnel system. Jalapeño peppers in the high tunnels yielded 446 pounds of seeds per acre. Yield for open field production of jalapeño seeds was not recorded; therefore, there is no comparison between production systems.

Seed production revenue and profit was not calculated due to the limited price data for basil and jalapeño seeds. Total variable costs varied between crops due to irrigation costs, transplant costs, and repair and maintenance of equipment, and fixed costs increased with high tunnel production, Table 1.2. Total variable costs for basil seed grown in open fields was $4,879.04 per acre. Overall open field basil seed expenses totaled $5,077.40 per acre. High tunnel basil seed production costs were higher at $5,962.66 per acre and $20,469.63 per acre for variable and total costs, respectively. High tunnel jalapeño pepper seed production variable costs totaled $6,663.42 per acre, with total expenses of $21,170.39 per acre.

Table 1.2 Costs per acre for basil and jalapeño pepper seed with open field and high tunnel production systems.

Commodity	Total Variable Costs	Total Fixed Costs	Total Costs
Basil Seed†	$4,879.04	$198.35	$5,077.40
Basil Seed‡	$5,962.66	$14,506.97	$20,469.63
Jalapeño Pepper Seed‡	$6,663.42	$14,506.97	$21,170.39

† Vegetables grown in open field system
‡ Vegetables grown in high tunnel system

Economic Measures

Breakeven Prices

A sensitivity analysis of potential production outcomes was conducted for producers to cover variable and total costs for each crop produced in this study. A range of yields was calculated based on percentages of 75, 90, 100, 110, and 125 percent of the expected yield to account for seasonal variations. The resulting breakeven prices indicated the price per unit necessary for producers to cover either variable or total production costs for the season.

Tomatoes in open field production yield required a breakeven price of $40.90 per cwt to cover variable costs and $48.11 per cwt to cover total costs, Table 1.3. At the 125 percent yield level, a breakeven price per cwt of $32.72 and $38.49 was required to cover variable and total costs, respectively. The 75 percent yield level indicated a breakeven price of $54.53 per cwt covered variable costs and $64.15 per cwt covered total costs.

Table 1.3 Breakeven prices to cover variable and total costs for open field tomato production.

		Breakeven price ($/cwt) to cover:	
Yield Percent	**Yield (cwt)**	**Variable Costs**	**Total Costs**
75%	86.25	$54.53	$64.15
90%	103.50	$45.44	$53.46
100%	115.00	$40.90	$48.11
110%	126.50	$37.18	$43.74
125%	143.75	$32.72	$38.49

Tomatoes grown in high tunnel production required lower breakeven prices to cover variable costs as a reflection of higher yields. Increased yields results in higher gross revenue, which outweighs the increase in variable costs of production. The high tunnel produced tomatoes required a breakeven price of $24.26 per cwt to cover variable costs. However, breakeven price to cover total costs increased due to the initial investment costs of a high tunnel outweighing the increased production potential. A price of $69.72 per cwt is required to cover total cost breakeven, Table 1.4.

Table 1.4 Breakeven prices to cover variable and total costs for high tunnel tomato production.

		Breakeven price ($/cwt) to cover:	
Yield Percent	**Yield (cwt)**	**Variable Costs**	**Total Costs**
75%	249.75	$32.34	$92.96
90%	299.70	$26.95	$77.46
100%	333.00	$24.26	$69.72
110%	366.30	$22.05	$63.38
125%	416.25	$19.41	$55.77

A price of $37.80 per cwt and $39.19 per cwt covers the variable and total costs of jalapeño peppers produced in the open field production system, respectively. At the lower yield level of 107.25 cwt per acre, the breakeven prices increased to $50.40 per cwt and $52.25 per cwt to cover variable and total costs, respectively, Table 1.5.

Table 1.5 Breakeven prices to cover variable and total costs for open field jalapeño pepper production.

		Breakeven price ($/cwt) to cover:	
Yield Percent	**Yield (cwt)**	**Variable Costs**	**Total Costs**
75%	107.25	$50.40	$52.25
90%	128.70	$42.00	$43.54
100%	143.00	$37.80	$39.19
110%	157.30	$34.36	$35.62
125%	178.75	$30.24	$31.35

The yield for jalapeño peppers under the high tunnel production system was slightly higher than open field production. However, the increase in revenue was not enough to outweigh the increase in both variable and total costs. Thus, breakeven prices increased compared to open field production, resulting in a price of $41.91 per cwt to cover variable costs and $133.15 per cwt to cover total costs, Table 1.6. An increase in yield by 25 percent resulted in a breakeven price of $33.53 per cwt and $106.52 per cwt to cover variable and total costs, respectively.

Table 1.6 Breakeven prices to cover variable and total costs for high tunnel jalapeño pepper production.

		Breakeven price ($/cwt) to cover:	
Yield Percent	**Yield (cwt)**	**Variable Costs**	**Total Costs**
75%	119.25	$55.88	$177.53
90%	143.10	$46.56	$147.94
100%	159.00	$41.91	$133.15
110%	174.90	$38.10	$121.04
125%	198.75	$33.53	$106.52

Open field basil seed breakeven prices were relatively low compared to the other crops due to fewer overall production inputs and less labor required. The breakeven price to cover variable costs was $20.76 per pound, and to cover total costs a price of $21.61

per pound was required, Table 1.7. The 125 percent level of yield resulted in a price of $16.61 per pound and $17.28 per pound to cover variable and total costs, respectively.

Table 1.7 Breakeven prices to cover variable and total costs for open field basil seed production.

		Breakeven price ($/lb.) to cover:	
Yield Percent	**Yield (lbs.)**	**Variable Costs**	**Total Costs**
75%	176.25	$27.68	$28.81
90%	211.50	$23.07	$24.01
100%	235.00	$20.76	$21.61
110%	258.50	$18.87	$19.64
125%	293.75	$16.61	$17.28

The high tunnel production system increased basil seed yield resulted in a lower breakeven price to cover variable costs. A price of $39.44 per pound is required to cover the total costs of production, Table 1.8. Again, breakeven price for total costs remained higher due to the initial investment of the high tunnel.

Table 1.8 Breakeven prices to cover variable and total costs for high tunnel basil seed production.

		Breakeven price ($/lb.) to cover:	
Yield Percent	**Yield (lbs.)**	**Variable Costs**	**Total Costs**
75%	389.25	$15.32	$52.59
90%	467.10	$12.77	$43.82
100%	519.00	$11.49	$39.44
110%	570.90	$10.44	$35.86
125%	648.75	$9.19	$31.55

Breakeven prices for jalapeño seeds harvested from the high tunnel production system are provided in Table 1.9. At the budgeted yield, a breakeven price of $14.94 per pound and $47.47 per pound would cover the associated variable and total costs, respectively. Breakeven price to cover variable costs would decrease by $2.99 per pound with a yield increase of 25 percent. A 25 percent increase in yield would also decrease the breakeven price to cover total costs by $9.50 per pound.

Table 1.9 Breakeven prices to cover variable and total costs for high tunnel jalapeño pepper seed production.

		Breakeven price ($/lb.) to cover:	
Yield Percent	**Yield (lbs.)**	**Variable Costs**	**Total Costs**
75%	334.50	$19.92	$63.29
90%	401.40	$16.60	$52.74
100%	446.00	$14.94	$47.47
110%	490.60	$13.58	$43.15
125%	557.50	$11.95	$37.97

Return on Investment

Return on investment for fresh market vegetables followed the direction of profit. All of the fresh market vegetables resulted in a positive return on investment with the budgeted amounts used with the exception of high tunnel jalapeño peppers. Jalapeño peppers produced in high tunnels received the lowest return on investment at negative 51 percent. Open field tomatoes had the highest return on investment at 108 percent, Figure 1.3.

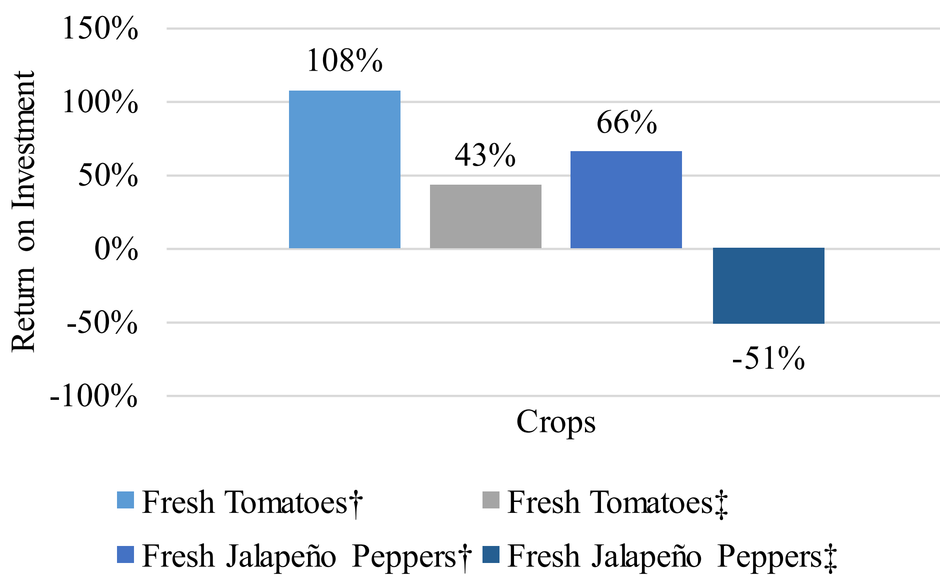

Figure 1.3 Return on investment for fresh market vegetables.
† Vegetables grown in open field system
‡ Vegetables grown in high tunnel system

A sensitivity analysis was conducted to estimate exact prices required to achieve a desired level of return on investment. Prices were calculated at levels of 25 percent, 50 percent, and 75 percent return on investment. A 50 percent return on investment for fresh tomatoes from the open field system, fresh tomatoes from the high tunnel system, fresh jalapeño peppers from the open field system, and fresh jalapeño peppers from the high tunnel system required prices of $72.17, $104.58, $58.78, and $199.72 per cwt, respectively, Figure 1.4.

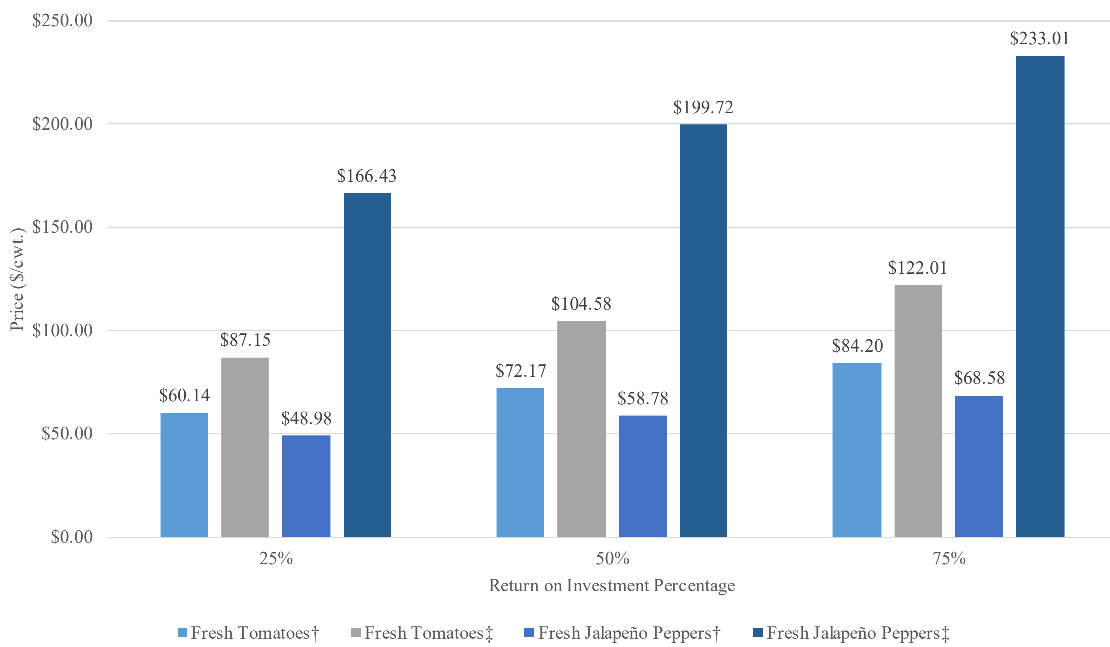

Figure 1.4 Fresh vegetable price per cwt at desired return on investment percentage.
† Vegetables grown in open field system
‡ Vegetables grown in high tunnel system

Due to the limitation of price data total revenue and profit was not determined for seed production. A sensitivity analysis was conducted to estimate prices required to achieve a desired level of return on investment. Prices were calculated at levels of 25 percent, 50 percent, and 75 percent return on investment. A 50 percent return on investment for basil seed from the open field system, basil seed from the high tunnel system, and jalapeño pepper seed from the high tunnel system required prices of $32.41, $59.16, and $71.20 per pound, respectively, Figure 1.5.

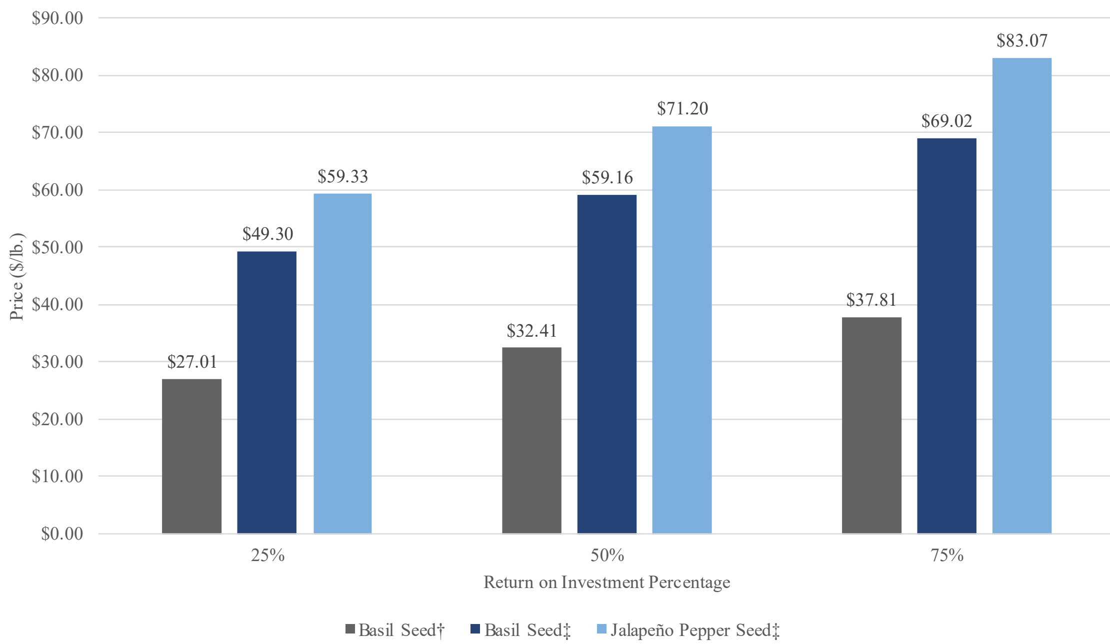

Figure 1.5 Seed price per pound at desired return on investment percentage.
† Vegetables grown in open field system
‡ Vegetables grown in high tunnel system

Summary and Discussion

Producers in the semi-arid Texas Panhandle should consider changes in their production practices as the Ogallala Aquifer depletes. The overall objective of this study was to analyze the economic feasibility of producing high-value fresh vegetables and vegetable seeds. Important economic factors were analyzed in this study to allow producers to make informed, strategic decisions for their existing operations. Fresh market tomatoes and jalapeño peppers and basil seed and jalapeño pepper seed were evaluated with enterprise budgets developed from field trial production data as well as secondary data. Budgets for fresh vegetable crops and basil seed were compared between open field and high tunnel production systems. Vegetable seed production provides producers with an opportunity to diversify their operations and increase profit potential.

Based on the results of this study, fresh market vegetables are a viable alternative to supplement total farm profitability. High tunnel tomatoes had the most promising economic potential with a profit of $10,084.02 per acre. Fresh jalapeño peppers produced under the high tunnel systems are the least feasible with a loss of $10,835.39 per acre. Due to the high initial investment cost of high tunnels, however, open field production results in a higher return on investment for both crops.

Open field basil seed has the potential to increase producers' profitability with the lowest total costs of $5,077.40 per acre. High tunnel jalapeño pepper seed production incurs the highest total cost of the seed production budgets at a total of $21,170.39. Profitability of seed production will vary for each producer due to negotiated contract specifications. This study was limited by the absence of price data for seed production. Seed production is typically produced under contract with commercial seed companies, and the contract stipulates many items concerning production as well as the prices producers will receive. Pepper seed prices vary by variety, but producers have the possibility of receiving $100 to $200 per pound (Crosby, 2020).

There were several other limitations of this study. Seed harvesting costs were not included in the basil seed and jalapeño seed budgets. Harvest methods and costs can be negotiated between the producers and seed companies; therefore, this study assumes the seed company will take responsibility for the harvest costs. Since basil seeds can be harvested with a slight modification to a standard combine, there is the potential to use custom harvest resources and estimate cost similar to traditional field crop custom harvest.

High tunnel production provides numerous benefits. Nonetheless, with agriculture, there are continuously risks to consider. The USDA-ARS CPRL/Texas A&M AgriLife Vegetable Production Lab in Bushland, Texas, planted salvia flowers in high tunnels and open fields during the 2019 field study. Salvia production was not used to create enterprise budgets due to crop failure. The plants experienced heat stress and failed to produce seed. Federal crop insurance programs currently are not available for specialty crop production.

Producers must consider both costs and benefits of producing high-value vegetables and vegetable seeds. The high initial cost of the high tunnels affected the results of this study, and these costs may limit producers' ability to implement the production system into their operation. Current literature provides a range of estimated useful life for high tunnels. The annual costs for the high tunnel structures in this study were estimated with a 20 year useful life. Extending the useful life of the structures would make the investment more economically feasible. In addition, financial assistance from the USDA Natural Resources Conservation Service's (NRCS) Environmental Quality Incentives Program (EQIP) may be available for producers. EQIP is a voluntary conservation program that provides financial resources and planning to help implement improvements. The High Tunnel Initiative is the specific cost-share program available. The goals of the initiative are to extend the growing season, improve plant and soil quality, reduce nutrient and pesticide movement, improve air quality, and reduce energy by providing produce to local consumers. According to Bruce et al. (2017), producers with EQIP funded high tunnels experienced positive outcomes from growing specialty crops. Producers must meet eligibility qualifications and the high tunnels installed must meet the standards and specifications of the NRCS program. The NRCS cost-share rate for high tunnels is $1.39 per square foot. The EQIP funds in Texas are offered through a state priority fund, and this fund caps program contracts at $15,000. However, a producer can apply for multiple contracts (Fishbacher, 2020). One contract through NRCS in Texas would cover one 30-foot by 96-foot structure or roughly eight percent of the total high tunnel costs per acre budgeted in this study.

Further research should consider additional uses for the high tunnels. Using the structures multiple times throughout the year has the potential to increase the economic feasibility. High tunnel production can extend the growing season by protecting crops from potential weather factors, therefore researchers should consider the possibility of double-cropping and allowing an early and late harvest.

References

Almas, L. K., W. A. Colette, and Z. Wu. "Declining Ogallala Aquifer and Texas Panhandle Economy" (p. 20). 2004.

American Seed Trade Association, *Existing U.S. Seed Industry Production Practices that Address Coexistence*. 2011. http://www.amseed.org/pdfs/issues/biotech/asta-coexistence-production-practices.pdf. (April 2020)

Benavidez, J., B. Guerrero, R. Dudensing, D. Jones, and S. Reynolds. *The Impact of AgriBusiness in the High Plains Trade Area*. Amarillo, Texas. 2019. https://amarillo.tamu.edu/files/2019/12/Impact-of-AgriBusiness.pdf. (February 2020)

Benavidez, J., D. Jones, L. Almas, B. Guerrero, and M. Crouch. *Texas Crops and Livestock Budgets, Texas High Plains, Projected for 2020*. College Station, TX. 2020.

Boychuk, M. "Enhancing Producer Profitability with Vegetable Production in the Texas High Plains." M.S. Thesis, West Texas A&M University. 2019. https://wtamu-ir.tdl.org/handle/11310/226. (Accessed July 2019)

Bruce, A., J. Farmer, E. Maynard, and J. Valliant. "Assessing the impact of the EQIP High Tunnel Initiative." *Journal of Agriculture, Food Systems, and Community Development* 7,3 (2017):159. http://search.proquest.com/docview/2057007435/. (Accessed March 2020)

Cornforth, G. Personal Communication, Texas A&M AgriLife Extension Service. March 2020.

Crosby, K. Personal Communication, Texas A&M University Department of

Horticultural Sciences. April 2020.

Davis, J. *North Carolina Basil Production Guide*. 1995. https://content.ces.ncsu.edu/north-carolina-basil-production-guide. (January 2020)

Delouche, J.C., "Environmental Effects on Seed Development and Seed Quality" *Hortscience 15, 6* (1980).

Fess, T. L and V. A. Benedito. *Organic Versus Conventional Cropping Sustainability: A Comparative System Analysis. Sustainability*. (2017).

Fischbacher, T. Personal Communication, USDA Natural Resources Conservation Service. April 2020.

Galinato, S. and C. Miles. "Economic Profitability of Growing Lettuce and Tomato in Western Washington under High Tunnel and Open-field Production Systems" *HortTechnology Hortte* 23,4 (2013).

George, R. A. T. *Vegetable seed production*. CABI. 2009.

Gray, J.D. Personal Communication. Texas A&M AgriLife Research. January 2020.

Hawthorn, L.R.*, Growing Vegetable Seeds for Sale*. U.S. Department of Agriculture Yearbook of Agriculture, 1961.

Kadir, S., E. Carey, and S. Ennahli. "Influence of High Tunnel and Field Conditions on Strawberry Growth and Development." *HortScience HortSci* 41,2 (2006).

Kaiser, C. and M. Ernst. *Chia.* University of Kentucky College of Agriculture, Food, and Environment. 2016.

Khanal, K., S. Henneberry, M. Taylor, R. J. Schatzer, F. M. Epplin, B. W. Roberts, J. Edelson and J. Shrefler. "Organic and Conventional Vegetable Production in Oklahoma." Selected paper presented at the Southern Agricultural Economics

Association Annual Meeting, Dallas, TX. February 2-6, 2008.

Lewis, J.W. Design and Construction of High Tunnels in West Virginia. Sustainable Agriculture Research and Education. 2010. https://www.northeastsare.org/Educational-Resources/SARE-Project-Products/Northeast-SARE-Project-Products/Design-and-Construction-of-a-High-Tunnel-in-West-Virginia. (Accessed February 2020)

Matthews, W.A. *The California Seed Industry: A Measure of Economic Activity and Contribution to California Agriculture*. University of California Agricultural Issues Center (2009).

McDonald, M. B. "Improving Our Understanding of Vegetable and Flower Seed Quality." *Seed Technology* 20,2 (1998):121–124.

McGuire, V. L. *Water-Level and Recoverable Water in Storage Changes, High Plains Aquifer, Predevelopment to 2015 and 2013–15*. U.S. Geological Survey Scientific Investigations Report 2017-5040. Reston, VA. 2017. https://doi.org/10.3133/sir20175040. (Accessed July 2019)

OFRF. *Organic Seed: An Emerging Industry, A Pressing Need*. 18, 4 (2011) 1-28.

Putievsky, E., and B. Galambosi. "Production Systems of Sweet Basil." *Basil* (pp. 47–73). CRC Press. 1999.

Regional Producers. Personal Communication. March 2020.

Rodríguez, H.G., J. Popp, M. Thomsen, H. Friedrich, and C.R. Rom. "Economic Analysis of Investing in Open-field or High Tunnel Primocane-fruiting Blackberry Production in Northwestern Arkansas" *HortTechnology Hortte* 22,2 (2012).

Sanchez, E., W. J. Lamont Jr., and M. Orzolek. *Extending the Garden Season with High Tunnels*. 2007. https://extension.psu.edu/extending-the-garden-season-with-high-tunnels. (Accessed Decmber 2019)

Schudel, H.L., *Vegetable Seed Production in Oregon*. Corvallis, OR: Oregon State College, Agriculture Experiment Station, Station Bulletin No. 512, 1952.

Sydorovych, O., C. L. Rivard, S. O'Connell, C. D. Harlow, M. M. Peet, and F. J. Louws. "Growing Organic Heirloom Tomatoes in the Field and High Tunnels in North Carolina: Comparative Economic Analysis." *HortTechnology Hortte* 23,2 (2013).

Texas A&M AgriLife Research. Extension. "Internal Spreadsheet Workbook for Development and Maintenance of Extension District Crop and Livestock Budgets." Unpublished, Texas A&M AgriLife Extension 2020.

U.S. Department of Agriculture, Agriculture Marketing Service. "Specialty Crops Market News Division National Retail Report-Specialty Crops." 2019. https://www.ams.usda.gov/mnreports/fvwretail.pdf (Accessed March 19, 2020).

U.S. Department of Agriculture, Economic Research Service. "Price Spread from Farm to Consumer – Fresh Tomatoes, Field Grown." 2019. https://www.ers.usda.gov/data-products/price-spreads-from-farm-to-consumer/. (Accessed March 19, 2020).

U.S. Department of Agriculture, Economic Research Service. "Price Spread from Farm to Consumer – Fresh Vegetables Basket." 2019. https://www.ers.usda.gov/data-products/price-spreads-from-farm-to-consumer/. (Accessed March 19, 2020).

U.S. Department of Agriculture, Natural Resources Conservation Service. "High Tunnel System Initiative." 2020.

https://www.nrcs.usda.gov/wps/portal/nrcs/detail/national/programs/financial/eqip/?cid=stelprdb1046250. (Accessed March 2020)

Wallace, R.W., A.L Wszelaki, C.A. Miles, J.S. Cowan, J. Martin, J. Roozen, B Gundersen, and G.A. Inglis. “Lettuce yield and quality when grown in high tunnel and open-field production systems under three diverse climates” HortTechnology 22, 5: (2012) 659-668.

Wallace, R., J Masabni, M. Gu, M. Nesbitt, P. Porter, and M. Palma. *Specialty Crops for High Tunnel Production in Texas*. Texas A&M AgriLife. Ext. Bull. HT-029, 2013.

Waterer, D. “Yield and Economics of High Tunnels for Production of Warm-season Vegetable Crops” *HortTechnology Hortte* 13,2 (2003).

Welbaum, G. *Vegetable Seed Production*. 2005. https://www.hort.vt.edu/Welbaum/seedproduction/currentstate.html.

Wien, H. C. “Microenvironmental Variations within the High Tunnel.” *HortScience Horts* 44,2 (2009).

CHAPTER II: ANALYZING POTENTIAL WATER CONSERVATION STRATEGIES IN THE TEXAS PANHANDLE

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Introduction

The Ogallala Aquifer is the largest underground water reservoir in the United States covering approximately 453,248 square kilometers. The aquifer provides water to South Dakota, Wyoming, Nebraska, Colorado, Kansas, Oklahoma, New Mexico, and Texas. While initially thought to be limitless, it is a finite and depleting groundwater resource (McGuire, 2017). The southern part of the Ogallala Aquifer is the main water source in the Texas Panhandle for agricultural, industrial, and municipal consumption (Panhandle Water Planning Group, 2016).

Agriculture plays a significant role in the economy of the Texas Panhandle. Cash receipts for agricultural production totals approximately $4.8 billion, and agriculture has a regional economic impact of approximately $8.1 billion (Steve Amosson, Guerrero, and Dudensing, 2015). On average 590,089 irrigated hectares were planted across the 21 counties of the Panhandle Water Planning Area (PWPA) from 2016 to 2018. Corn, wheat, and cotton account for the majority of irrigated hectares (USDA 2018). Agricultural production dominates water use in the area and is projected to account for 92 percent of total water use by 2020. Given the declining water availability in the area and current water use rates, seven high demand irrigation counties are expected to encounter supply shortages over the next 50 years (TWDB 2019), Figure 2.1 and Table 2.1.

Table 2.1 Counties projected to have future irrigation shortages in the PWPA (2020-2070).

	Projected Shortage (m^3 per year)					
County	**2020**	**2030**	**2040**	**2050**	**2060**	**2070**
Collingsworth	-8,459,218	-12,489,004	-11,440,544	-11,826,624	-12,007,946	-11,180,279
Dallam	-36,493,794	-143,525,480	-133,161,765	-113,041,210	-91,587,260	-91,587,260
Gray	272,599	272,599	272,599	272,599	-3,314,366	-3,314,366
Hall	-19,359,497	-17,751,037	-14,152,971	-10,215,697	-6,516,485	-8,097,808
Hartley	-104,557,321	-237,772,126	-219,050,339	-196,792,159	-174,427,900	-174,427,900
Moore	-11,357,901	-59,177,525	-60,750,214	-54,101,747	-47,218,918	-47,218,918
Sherman	196,124	196,124	-36,470,357	-47,897,333	-47,127,641	-47,394,073

Source: TWDB (2019)

The state of Texas develops a water plan every five years to evaluate expected regional water demands and supply over the next 50 years (TWDB 2019). The plan identifies areas that may be facing future water shortages and serves to identify and evaluate potential water conservation strategies that could alleviate shortages. To develop a plan that is effective for the varying environments across the state, Texas is divided into 16 water planning areas. Each region has a group of local stakeholders to provide specific insight into regional planning with the overall effort being coordinated by the Texas Water Development Board. This study focuses on efforts by the PWPA.

The Panhandle Water Planning Group (PWPG) identified an agricultural subcommittee (PWPG-AC) to evaluate the accuracy of the regions agricultural water demands and to identify and evaluate the effectiveness of the proposed agricultural water conservation strategies. This group consists of groundwater conservation district managers, research personnel, producers, and commodity organization representatives. The PWPG-AC reviewed previously used strategies plus strategies used in other regions to identify viable strategies suitable for implementing within the Panhandle Region. The

PWPG-AC selected seven water management strategies for the 2020 water plan consisting of: 1) irrigation scheduling, 2) irrigation equipment changes, 3) change in crop type, 4) change in crop variety, 5) conversion to dryland, 6) soil management, and 7) advances in plant breeding. They also included three combination strategies for reducing irrigation demands on withdrawals from the Ogallala Aquifer: 1) irrigation scheduling, irrigation equipment changes, and change in crop type, 2) irrigation scheduling, irrigation equipment changes, and change in crop variety and 3) irrigation scheduling, irrigation equipment changes, change in crop type, and advances in plant breeding for evaluation.

The objective of this analysis is to estimate the potential water savings and implementation costs for each water conservation strategy and identified combinations of strategies. The results should provide pertinent information on the benefits of the alternative irrigation management strategies considered by the planning group and will also be beneficial to local groundwater conservation districts in considering the costs and benefits of implementation of the different options to prolong the practice of irrigated agriculture.

Materials and Methods

<u>Study Area</u>

The study area of this analysis is located in the northernmost part of the state, the Texas Panhandle, and contains 21 counties that make up the PWPA, also known as Region A, as defined by the Texas Water Development Board (2014), Figure 2.1.

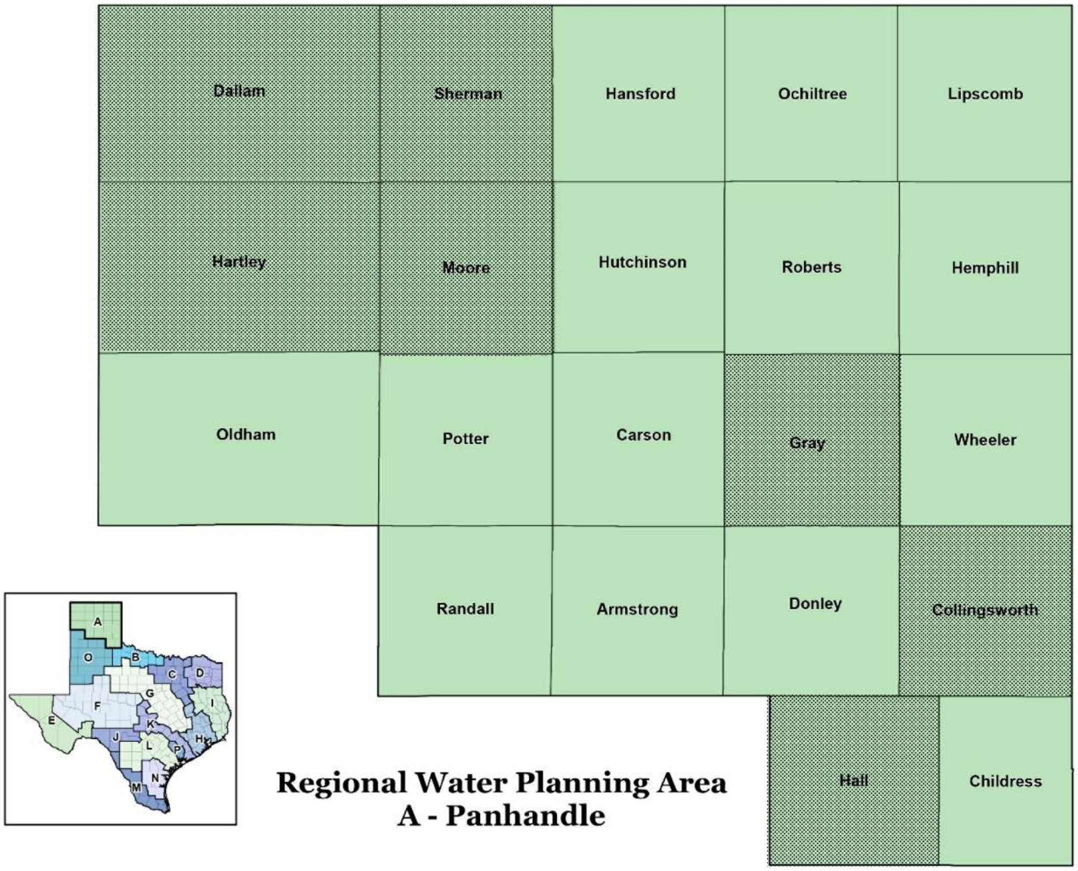

Figure 2.1 Panhandle Water Planning Area (Texas Water Development Board 2019)
Note: Counties with projected deficits are shaded.

<u>Methodology</u>

The year 2018 was selected as the baseline irrigation demand year for evaluating strategies. Current adoption levels for strategies were estimated using secondary data sources and served as baseline rates. In particular, producer surveys conducted as a part of the North Plains Groundwater Conservation District (NPGCD) Master Irrigator Program provided estimated baseline values for irrigation scheduling, irrigation systems, and soil management strategies (NPGCD 2019). All Master Irrigator participants completed the survey and the area farmed or managed by these participants is representative of more than 119,382 irrigated hectares, or 20 percent of the PWPA total irrigated area. The baseline rates were verified and potential future adoption rates from 2020 to 2070 were identified under the guidance of the PWPG-AC, Table 2.2. Since final implementation rates of conservation strategies do not occur until 2070, the water savings, direct cost, and net cost of all strategies were evaluated over a 50-year planning horizon.

Table 2.2 Estimated potential water savings, baseline use, and future adoption percentage of water conservation strategies. (2020-2070)

Water Management Strategy	Annual Water Savings (% of irrigation or m^3/ha/yr.)	Baseline Use 2018	2020 Adoption Goal	2030 Adoption Goal	2040 Adoption Goal	2050 Adoption Goal	2060 Adoption Goal	2070 Adoption Goal
Irrigation Scheduling	10%	65%	70%	75%	80%	85%	90%	95%
Irrigation Equipment Changes	MESA or LESA to LEPA or SDI 384	25%	30%	35%	40%	45%	50%	55%
Change in Crop Type	2,540	0%	5%	10%	15%	20%	25%	30%
Change in Crop Variety	940 (corn) 1,575 (sorghum)	10%	12.5%	15%	17.5%	20%	22.5%	25%
Conversion to Dryland	4,013	0%	0%	1.5%	3%	5%	5%	5%
Soil Management	444	84%	86.5%	89.0%	91.5%	94.0%	95.0%	95.0%
Advances in Plant Breeding	Corn, cotton, and soybean 15% (2020-2030) 30% (2040-2070)	0%	50%	75%	85%	95%	95%	95%
	Wheat and sorghum 12% (2030-2070)	0%	0%	50%	75%	85%	95%	95%

Some of the strategies identified for evaluation were crop-specific, including changes in crop variety, changes in crop type, and advances in plant breeding. Therefore, it was imperative to identify the irrigated crop hectare distribution by county. The region has had a dramatic increase in irrigated cotton hectares and a corresponding increase in cotton specific equipment and processing infrastructure within the last few years. Given these changing conditions, a three-year average (2016 – 2018) of Farm Service Agency (FSA) irrigated hectares was calculated to establish the 2018 baseline hectares by county and by crop (USDA 2016-2018). The three-year average dampened distortions resulting from hectare shifts between crops caused by volatile crop prices while capturing recent crop mix changes in the region. Irrigated hectares and water availability were assumed to remain constant in measuring the water savings of various water conservation strategies.

Implementation costs were defined as the costs that could be borne by producers and the government, associated with implementing a strategy. The savings in pumping cost takes into account variable cost savings from the reduced irrigation. The variable cost of irrigation is assumed to be \$0.08 per m^3 (S. Amosson et al., 2017). All costs were evaluated in 2018 dollars. A more detailed description of the method utilized for each strategy follows.

Water Conservation Strategies

Irrigation Scheduling

Irrigation scheduling allows for the efficient allocation of irrigation water according to crop requirements based on meteorological demands and field conditions. Timely and accurate irrigation scheduling is critical to ensure profitable agricultural production and conservation of water resources. Soil water measurement-based methods, plant stress sensing-based methods, and weather-based methods are the common irrigation scheduling tools. Proper and accurate irrigation scheduling can save up to 508 to 762 m^3/ha of irrigation per year for corn (Almas et al. 2000; Chen et al. 2019; Freese and Nichols, Inc 2006; Marek et al 2005; Marek, Porter, Howell 2005). With an average irrigation application for corn of 5,080 m^3 (Steve Amosson et al., 2011), the savings represents approximately 10 percent of the total. Thus, in this analysis, water savings from this strategy was assumed to be 10 percent of the water applied for each crop. The initial percentage of baseline irrigated hectares utilizing some form of irrigation scheduling was set at 65 percent (NPGCD 2019) reaching an adoption level of 95 percent in 2070. The cost of irrigation scheduling can vary significantly depending on the level of service, equipment costs, and the area served. In general, higher value crops requires a higher investment level. A range of $16.06 to $29.65 per hectare for irrigation scheduling was identified depending on the level of service (Industry Representative Personal Communication 2019). The average cost of $22.86 per hectare annually was utilized for irrigation scheduling.

Irrigation Equipment Changes

Current irrigation methods practiced in the Texas Panhandle include center pivot irrigation (MESA - Mid Elevation Spray Application; LESA - Low Elevation Spray Application; and LEPA - Low Elevation Precision Application) and subsurface drip irrigation (SDI). The average application efficiency of MESA, LESA, LEPA, and SDI is 78, 88, 95, and 97 percent, respectively (Steve Amosson et al., 2011). The water conservation strategy of changing irrigation equipment includes converting MESA and LESA to LEPA or SDI. A combined weighted system efficiency was calculated for the

MESA/LESA and LEPA/SDI conversions, utilizing the above efficiencies, along with the percentage of baseline irrigated hectares in the region that utilized each category of irrigation systems, 75 percent and 25 percent, respectively (NPGCD 2019). The combined weighted system efficiency for MESA/LESA and LEPA/SDI was 86 percent and 95 percent, respectively. The difference in efficiencies was applied to the average water application for all crops to calculate an estimated 384 m^3/ha in water savings. Conversion to LEPA/SDI was expected to reach 55 percent of irrigated hectares by 2070.

Of the producers utilizing a more efficient irrigation system of either LEPA or SDI, 95 percent utilized LEPA (NPGCD 2019). Thus, the cost for implementing this strategy was assumed to be the cost of converting MESA/LESA to LEPA. Many producers choose LEPA because conversion to this system is more economically feasible (Amosson et al. 2011). Currently, the most utilized spacing for drops on center pivots is 0.76 meters. Conversion costs included re-plumbing (fittings and clamps), hoses, heads, weights, and labor. The cost of total replacement of 1.52 meter spacing with 0.76 meter spacing on a 51-hectare system was estimated to be $373.62 per hectare. The cost of converting an existing 51-hectare system with 0.76 meter spacing was estimated to be $108.73 per hectare (Regional Irrigation Manufacturer Personal Communication 2019). Most system conversions (80 percent) (NPGCD 2019) would require total replacement (1.52 meter spacing with 0.76 meter spacing), resulting in an average cost of conversion of $320.64 per hectare.

Change in Crop Type

The use and incorporation of crops with lower water requirements can be viewed as an effective and viable water conservation strategy. Corn, cotton, wheat, and grain sorghum are currently the four major crops in the region and account for about 90 percent of the total irrigated hectares. Corn has one of the highest water requirement of these irrigated crops grown in the Texas High Plains (Howell, 1996). Currently, there is a noticeable trend in corn hectares being replaced with cotton production in the northern Texas Panhandle. Irrigated cotton hectares increased from only 13 percent of total PWPA irrigated hectares in 2016 to 26 percent in 2018 (USDA 2018). Due to these changing conditions and new profitability potential, the conversion of irrigated corn hectares to irrigated cotton was evaluated in this strategy. Actual water use data for corn and cotton during the 2016 to 2018 period indicates the application of 5,232 m^3/ha for corn and 2,515 m^3/ha for cotton (NPGCD Producers Personal Communication 2019). A conservative value of 2,540 m^3/ha was utilized to estimate water savings for this strategy with the implementation of cotton production reaching 30 percent by 2070.

The cost of implementing this water conservation strategy was evaluated in terms of reduced land values as a result of reduced water availability. The cost of adoption was estimated as the difference between the average land value for irrigated cropland with good water availability at $8,402 per hectare and that of irrigated cropland with average water availability at $5,683 per hectare (American Society of Farm Managers and Rural Appraisers, 2018). Therefore, $2,718 per hectare was assumed to be a one-time cost for implementation of this strategy.

Change in Crop Variety

Short season varieties can have a lower seasonal evaporative demand when compared to long (or full) season varieties. Thus, converting from long season to short season varieties of corn and grain sorghum can be a useful water conservation strategy.

However, typically short season varieties result in lower yields that can decrease overall profitability. According to a panel of industry experts (Personal Communication 2019), changing to short-season corn and sorghum from full/mid-season varieties could save 940 m^3/ha and 1,575 m^3/ha, but result in an estimated 18 percent and 32 percent decrease in the yield of corn and sorghum, respectively. It was estimated that 10 percent of both corn and sorghum hectares are currently planted to short-season varieties, which is expected to reach 25 percent by 2070.

The implementation cost was equal to the difference in expected profits between traditional and short season varieties. A partial budget analysis was conducted using the 2018 Texas A&M AgriLife Crop and Livestock Budgets for the region (S. Amosson et al., 2017). The loss in revenue from the reduced yield using a five-year average price for the area versus the savings in seed cost, pumping cost, fertilizer, and harvest expense were evaluated. Results of the partial budgets indicate a net loss to producers of $98.97 per hectare for corn and $110.60 per hectare for grain sorghum for the transition to short season varieties.

Conversion to Dryland

Converting from an irrigated to dryland cropping system may be a viable economic alternative for some producers on marginally irrigated land or as a regional strategy to conserve water resources. The primary dryland crops grown in the area are winter wheat, grain sorghum, and cotton. Conversion programs that provide incentives, identifying crops that perform well under rain fed conditions, and developing higher yielding drought-tolerant varieties will be critical for implementing this strategy. The water saving for this strategy was estimated to be 4,013 m^3/ha, which is the average water use by irrigated crops in the region. It was assumed a maximum of 5 percent total of hectares would be converted to dryland by the end of the time horizon, which was decided by the PWPG-AC.

The cost of implementing this water conservation strategy was evaluated in terms of reduced land values and was estimated as the difference between the average land value across all water availability categories for irrigated cropland at $6,054 per hectare and that of dryland at $2,286 per hectare (American Society of Farm Managers and Rural Appraisers, 2018). Therefore, the implementation cost to retire a hectare of irrigated land was $3,768, assuming the land would be suitable for dryland production. It should be noted that the level of compensation required for this strategy would need to vary considerably depending on the water availability on a specific parcel of land and the value of the dryland in a given portion of the region.

Soil Management

Effective soil management can increase the efficiency of both irrigation and rainfall events by increasing soil infiltration, reducing runoff, reducing evaporative loss, and conserving moisture available within the soil profile. Conservation tillage is defined as tillage practices that minimize soil and water loss by maintaining a surface residue cover of more than 30 percent on the soil surface (Conservation Technology Information Center, 2014). Different tillage practices such as minimum tillage, reduced tillage, no-till; ridge tillage, vertical tillage, and strip tillage are often interchangeably used with the term conservation tillage. In this analysis, the water savings from adopting effective soil management strategy is assumed to be 444 m^3/ha, which is a more conservative estimate than what has been reported (Luedeker 2016). Conservation tillage in some form (minimum till, strip till, or no till) is practiced on 84 percent of the irrigated land in the region (North Plains Groundwater Conservation District, n.d.). It was projected that the implementation of this practice would reach 95 percent by the end of the planning horizon.

The implementation cost of the soil management strategy was estimated as the difference between the cost of conventional tillage and conservation tillage. Results of a recent study indicate a cost savings of $5.07 per hectare for conventional/reduced till compared to no-till operations (Panhandle Water Planning Group, 2016). The difference between practices is due mainly to variable input costs. Epplin et al. (2005) determined that there is a slight increase in costs for smaller farms to convert to no-till. The opposite occurs for larger farms where they receive savings for converting (Luedeker 2016). However, it should be noted that any change in equipment, such as the additional purchase of a strip tiller or no-till planter, and chemical control costs may impede the adoption process. In this analysis, no annualized cost was applied to this strategy which is validated by Epplin et al. (2005).

Advances in Plant Breeding

Biotechnology utilized in plant breeding increases crop productivity and enhances the efficiency of inputs such as irrigation. From a water conservation standpoint, varieties with higher water use efficiency and enhanced drought resistance can lead to substantial water savings (Hao et al. 2019; Zhao et al. 2018). The first wave of drought-resistant varieties for corn, cotton, and soybeans are expected to be released by 2020 and reduce water use by 15 percent followed by the second wave in 2030 that will reduce water use an additional 15 percent compared to current varieties. It is also assumed that drought-resistant varieties of wheat and grain sorghum will be available by 2030 and will reduce the water use by 12 percent.

The panel group of industry and university experts recently reviewed this strategy and verified that all assumptions are still appropriate for inclusion in the 2021 regional water plan (Personal Communication 2019). The adoption rate was projected to be 50 percent in the first decade of market deployment (2020 for corn, soybeans, and cotton; 2030 for wheat and sorghum) and escalate to 95 percent by the end of the planning horizon, assuming new varieties are cost-effective. The implementation cost of this strategy was the additional cost of drought-resistant seed estimated at a dollar for every one percent reduction in water use (Personal Communication 2019).

Combination Strategies

The PWPG-AG committee identified three combinations of the previously mentioned strategies that may be employed specifically in irrigation deficit counties. The combinations of strategies were: 1) change in crop type, irrigation scheduling, and changes in irrigation equipment; 2) changes in crop variety, irrigation scheduling, and changes in irrigation equipment; and 3) change in crop type, advances in plant breeding, irrigation scheduling, and changes in irrigation equipment. When implementing multiple strategies, the impact on potential water savings is not additive. The cumulative water savings from the use of multiple strategies were estimated using a stepwise procedure by first revising water use after implementing the first strategy and then using that revised water use as the base before introducing the second strategy and repeating the process for the third and fourth strategy, where applicable. The interaction between some strategies results in lower water savings from implementing multiple strategies. However, the implementation costs for the strategy combinations are additive in nature.

Results & Discussion

Potential water savings and implementation costs were estimated for each water conservation strategy and three combination strategies. The purpose is to provide information on the potential benefits of alternative irrigation management strategies. The planning group and local groundwater conservation districts may benefit from the following results.

Collingsworth, Dallam, Gray, Hall, Hartley, Moore, and Sherman are counties identified by the PWPA as having irrigation water demands that cannot be met with existing water resources. In Table 2.1, the PWPG projects a range of water deficiency across the Texas Panhandle. Implementing one or more of these strategies could result in a reduction in water demand for these counties and help reduce their expected shortage. A selected conservation strategy or combination strategy should be determined individually for each county based on their needs and water saving goals.

Cumulative water savings and cumulative implementation costs (non-discounted) over the 50 year planning period for each of the water conservation strategies and combinations of strategies are presented in Table 2.3. Results indicate the combination of irrigation scheduling, irrigation equipment changes, change in crop type, and advances in plant breeding generates the largest amount of water savings at 25,139,531 thousand m^3 over the 50-year plan. Advances in plant breeding produced the next largest amount of water savings at 17,717,330 thousand m^3. The cumulative water savings of the remaining strategies in thousand m^3 are as follows in descending order: the combination of irrigation scheduling, irrigation equipment changes, and change in crop type (7,740,661), the combination of irrigation scheduling, irrigation equipment changes, and change in crop variety (4,407,355), change in crop type (4,379,195), conversion to dryland (3,432,350), irrigation scheduling (1,775,353), irrigation equipment change (1,697,519), change in crop variety (983,637), and soil management (944,260).

Table 2.3 Estimated water savings and associated cost with proposed water conservation strategies in the PWPA.

Water Management Strategy	Cumulative Water Savings (WS) (1,000 m^3)	Cumulative Implementation Cost (IC) ($)	IC/WS ($/1,000 m^3)
Irrigation Scheduling	1,775,353	$101,158,515	$56.98
Irrigation Equipment Changes	1,697,519	$47,302,086	$27.87
Change in Crop Type	4,379,195	$156,211,918	$35.67
Change in Crop Variety	983,637	$97,964,884	$99.59
Conversion to Dryland	3,432,350	$111,183,232	$32.39
Soil Management	944,260	-	-
Advances in Plant Breeding	17,717,330	$1,048,090,366	$59.16
Irrigation Scheduling, Irrigation Equipment & Change in Crop Type	7,740,661	$304,672,519	$39.36
Irrigation Scheduling, Irrigation Equipment & Change in Crop Variety	4,407,355	$246,425,484	$55.91
Irrigation Scheduling, Irrigation Equipment, Change in Crop Type & Advances in Plant Breeding	25,139,531	$1,352,762,885	$53.81

Implementation cost can be a critical barrier to the adoption rate of water conservation strategies. It is noted that producers' potential implementation costs may vary considerably. Soil management is the most cost-effective strategy, incurring no annualized costs. The second most cost-effective strategy is irrigation equipment changes. Producers can implement this strategy for an estimated cost of \$27.87 per thousand m^3 of water saved. Implementation costs of the remaining strategies in dollars per thousand m^3 of water saved are as follows in ascending order: conversion to dryland (\$32.39), change in crop type (\$35.67), the combination of irrigation scheduling, irrigation equipment changes, and change in crop type (\$39.36), the combination of irrigation scheduling, irrigation equipment changes, change in crop type, and advances in plant breeding (\$53.81), the combination of irrigation scheduling, irrigation equipment changes, and change in crop variety (\$55.91), irrigation scheduling (\$56.98), advances in plant breeding (\$59.16), and change in crop variety (\$99.59).

Soil management provides the lowest water savings with 944,260 thousand m^3 but is the most cost-effective strategy with no annualized costs. While some individual farms may experience costs associated with the strategy, others may experience cost savings. It should be noted that any change in equipment, such as the additional purchase of a strip tiller or no-till planter, and any additional chemical control costs will likely increase adoption costs. Assistance with the initial equipment investment may be cost-shared with available government programs and overall costs should be evaluated on a farm-level basis.

With the continued depletion of the Ogallala Aquifer, converting to dryland hectares is a possible alternative for producers. Conversion of irrigated hectares to dryland production is estimated to provide 3,432,350 thousand m^3 of water savings. The associated cost would be feasible at $32.39 per thousand m^3 of water saved. Producers could be reluctant to convert hectares because of the opportunity cost of land values. However, programs are available that could provide incentives for conversion and assistance with the strategy adoption rate. Moreover, conversion to dryland is a relatively easy strategy for producers to implement.

Deficit irrigation was not a strategy evaluated in this study. However, a producer may consider reducing irrigation amounts per acre prior to converting previously irrigated land to dryland production. Limiting total irrigation provides water savings while maintaining land values. Future research should consider water savings of the deficit irrigation strategy and the costs associated.

Advances in plant breeding provide significant water savings of at 17,717,330 thousand m^3. Currently, the estimated cost is $59.16 per thousand m^3 of water saved. Strategy assumptions were made with the expected availability of drought-resistant varieties beginning in 2020 and further advancements available in 2030. The availability of new biotechnology to the marketplace is not currently known and thus it may impede or expedite the adoption rate of this strategy.

Three combinations of strategies identified by the PWPG agricultural subcommittee were evaluated. However, it is essential to understand that the implementation of specific strategies can diminish the effectiveness of others if they are also implemented. These combination strategies are not additive in nature and as additional strategies are implemented, an interaction occurs. Interactions between strategies affect the combined water savings.

The combination of irrigation scheduling, irrigation equipment, change in crop type, and advances in plant breeding has significantly higher accumulative water savings than the other strategies evaluated, estimated at 25,139,531 thousand m^3. If the PWPG desires the strategy with the highest water savings, then this combination suffices.

Conclusions

The PWPG, local conservation districts, and producers need to select a water conservation strategy or a combination of strategies to implement a viable water conservation approach for the Texas Panhandle. The strategy(s) selected should be the ones that best align with the water savings goals of the region. Groundwater Conservation Districts in Texas can be instrumental in changing the status quo in order to protect local groundwater resources. The effectiveness of these selections may differ between locations within the region. The regional economic impacts should be a significant determining factor in the selection and implementation of the respective strategies. Maintaining the Ogallala Aquifer for irrigation production in the future is essential, but as Guerrero et al. (2017) concluded, it is vital to consider the regional economic impact and how local businesses and jobs will be affected. Further analysis is needed to determine the impact these evaluated strategies have on the regional economy.

A couple of caveats to this analysis need to be mentioned. First, the associated water savings with these strategies are “potential” water savings. If advances in plant breeding fall short of industry projections, several of the deficit counties may not be able to meet irrigation needs with this strategy. Second, depending on the economics, the improved water-use efficiencies generated from some of these strategies may actually lead to an increasing depletion rate. Finally, changes in irrigation demand, supply, needs, strategy implementation rates, conservation strategies, future crop composition, and the potential interaction between all these factors will impact the effectiveness of conservation strategies.

Many freshwater aquifers around the world are nonrenewable in nature and regions are faced with similar problems surrounding water scarcity. The results of this study may be useful to stakeholders in similar areas with irrigated agriculture that are considering ways to conserve water while keeping agricultural production viable. It is crucial to evaluate and implement strategies to reduce overall water use, not just for the Ogallala Aquifer, but worldwide. Actual implementation of strategies will depend heavily on individual producers, cost sharing programs from respective government entities, and considerations made in the policy planning process. With agriculture being the primary water user in the Texas Panhandle and many other areas worldwide, it is important to continue evaluating potential water conservation strategies to prolong the life of scarce water resources and irrigated agricultural practices so that it is possible to feed our growing population.

References

American Society of Farm Managers and Rural Appraisers (2018) Texas Rural Land Value Trends 2017

Almas L, Bretz F, Amosson S, et al (2000) Water Management Strategies for reducing irrigation demands in Region A. Panhandle Water Planning Project Task 5 Report. Texas A&M University, Agricultural Research and Extension Center, Amarillo, TX, July pp. 31

Amosson S, Almas L, Girase J, et al (2011) Economics of Irrigation Systems B-6113. Amarillo, Texas

Amosson S, Almas L, Guerrero B, et al (2017) Texas Crops and Livestock Budgets, Texas High Plains Projected for 2018

Amosson S, Guerrero B, Dudensing R (2015) The Impact of Agribusiness in the High Plains Trade Area https://agrilifecdn.tamu.edu/amarillo/files/2010/11/2015-Agribusiness-Brochure.pdf

Chen Y, Marek G, Marek T, Gowda P, Xue Q, Moorhead J, Brauer D, Srinivasan R, Heflin K (2019) Multisite evaluation of an improved SWAT irrigation scheduling algorithm for corn (Zea mays L.) production in the US Southern Great Plains. Env Modelling & Software 118: 23-34

Conservation Technology Information Center (2014) Tillage Type Definitions. https://www.ctic.org/resource_display/?id=322

Epplin F, Stock C, Kletke D, Peeper T (2005) Cost of Conventional Tillage and No-till Continuous Wheat Production for Four Farm Sizes. J ASFMRA (American Soc Farm Manag Rural Apprais) 8. doi: 10.22004/ag.econ.190714

Freese and Nichols, Inc (2006) Regional Water Plan for the Panhandle Water Planning Area. Prepared for the Panhandle Water Planning Group, Amarillo, TX. Appendix Q. http://www.panhandlewater.org/2006_reg_plan.html

Guerrero B, Amosson S, Nair S, Marek T (2017) The Importance of Regional Analysis in Evaluating Agricultural Water Conservation Strategies. J Reg Anal Policy 47:188–198

Hao B, Xue Q, Marek T, Jessup K, Hou X, Xu W, Bynum E, Bean B, Colaizzi P, Howell T (2019) Grain yield, evapotranspiration, and water use efficiency of maize hybrids differing in drought tolerance. Irr Sci 37: 25-34

Howell TA (1996) Irrigation Scheduling Research and Its Impact on Water Use. In: Camp CR, Sadler EJ, Yoder RE (eds) Evapotranspiration and Irrigation Scheduling, Proceedings of the International Conference, Nov. 3-6, 1996, San Antonio, TX. American Society of Agricultural Engineers, St. Joseph, MI

Luedeker B (2016) Benefits of conservation tillage discussed at Field Crops Tour. https://soilcrop.tamu.edu/newsletters_bulletins/aggie_agenda/AggieAgendaJuly16.pdf

Marek T, Amosson S, Almas L, et al (2005). Feasibility of Water Management Strategies for the Declining Ogallala Aquifer. ASCE – EWRI World Water and Environmental Resources Congress. Anchorage, AK. May

Marek T, Porter D, Howell T (2005) The Texas High Plains Evapotranspiration Network - An Irrigation Scheduling Technology Transfer Tool. Final report for Contract #2004-358-008, TWDB, Austin, TX pp 16

McGuire VL (2017) Water-level and recoverable water in storage changes, High Plains Aquifer, predevelopment to 2015 and 2013–15. Reston, VA

North Plains Groundwater Conservation District (2019) The Master Irrigator Program. http://northplainsgcd.org/conservationprograms/communityedu/master-irrigator/

Panhandle Water Planning Group (2016) Panhandle Regional Water Plan. Amarillo, Texas

Texas Water Development Board (2014) Regional Water Planning Area A - Panhandle. http://www.twdb.texas.gov/mapping/doc/maps/rwpg/RWPA_A_8x11.pdf Accessed 1 Sep 2019

Texas Water Development Board (2019) 2021 Regional and 2022 State Water Plan Projections Data. http://www.twdb.texas.gov/waterplanning/data/projections/index.asp

USDA (2018) Farm Service Agency Crop Acreage Data 2016-2018. https://www.fsa.usda.gov/news-room/efoia/electronic-reading-room/frequently-requested-information/crop-acreage-data/index Accessed October 2018

Zhao J, Xue Q, Jessup K, Hao B, Hou X, Marek T, Xu W, Evett S, O’Shaughnessy S, Brauer D (2018) Yield and water use of drought-tolerant maize hybrids in a semiarid environment. Field Crops Research 216: 1-9

CHAPTER III: PRODUCERS' ATTITUDES, USAGE, AND CONSERVATION OF GROUNDWATER IN THE TEXAS HIGH PLAINS

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Introduction

The Ogallala Aquifer covers approximately 175,000 square miles and provides water to South Dakota, Wyoming, Nebraska, Colorado, Kansas, Oklahoma, New Mexico, and Texas. This makes it the largest underground water reservoir in the United States (McGuire, 2017). Agricultural producers rely heavily on the Ogallala Aquifer as the main source of water for irrigation in the Texas High Plains.

Given the decline in water availability agricultural producers are faced with making changes in their production practices. Understanding producers' current operation activities can help policy makers and water conservation districts with future plans. However, there is limited data from agricultural producers representing the entire region concerning water conservation practices and perceptions.

Understanding factors that influence concerns for water availability in the future and motivate water conservation efforts can be helpful for policy makers and programs designed for managing groundwater utilization (Shepler et al., 2019). Groundwater districts follow rules provided by state and federal agencies and act as a liaison between these agencies and the residents of the districts. Currently, the water conservation districts issue water well permits, collect groundwater information, perform water quality analyses and provide a number of well system tests and other services. Water conservation districts also help identify future concerns and solutions to water shortages. They help provide producers with resource management programs.

The survey population consists of agriculture producers from the top 20 Texas Panhandle counties as well as counties within the greater Texas High Plains region. The study area ranges from the northernmost border of Texas to the southernmost border of

Lynn County. Survey respondents are located within the High Plains Groundwater, Hemphill County Underground Water Conservation, North Plains Groundwater Conservation, and Panhandle Groundwater Conservation districts.

The objective of this study was to evaluate the use of water on irrigated cropland, determine what new conservation technologies are being utilized and the associated implementation rates, identify factors producers believe are responsible for groundwater decline, and recognize perceived changes in groundwater levels overtime.

Review of Previous Literature

Past research indicated that a solid understanding of producers' perception and attitudes can aid in developing research to adequately address producers' concerns (Adrian et al., 2005). Adrian et al. (2005) conducted a study to demonstrate the impact of perception and producers' attitudes on their decision to adopt precision agriculture technologies. Surveys from 85 Alabama producers were used to estimate willingness to adopt new technologies. The authors concluded attitude of confidence directly affected the intention to adopt the tools. Higher confidence, larger farm sizes, and more education led to the implementation of more precision agriculture technologies (Adrian et al., 2005).

Understanding what producers will forgo for sustainability is increasingly important. Chouinard et al. (2008) evaluated what motivates producers facing conservation decisions. A model was created to estimate producers' willingness to pay for stewardship. Data was collected using a survey of 29 producers in Washington State. It was concluded that some producers were willing to forgo some profit to adopt new conservation practices (Chouinard et al., 2008).

In a recent study, researchers evaluated factors correlated with groundwater values (Shepler et al., 2019). A survey was deployed to over 1,000 users of groundwater in the Republican River Basin of Colorado. The survey assessed 275 producers' current groundwater use and attitude towards potential groundwater management strategies. Questions regarding the participant's demographics, farm management practices, groundwater use, and attitudes related to groundwater conservation were asked, and the survey had a response rate of 22.8 percent. A payment-card contingent valuation question provided a range of values for the respondent to select, and provided the minimum and maximum value of groundwater. This style of question was used to provide ease to respondents. Well capacity data was determined by a hydraulic conductivity test and saturated thickness at the well location. An empirical model was estimated to determine producers' willingness to pay to maintain groundwater availability, and two Probit models were created to estimate the probability of adopting specific practices and factors that influence the support of conservation efforts. The authors concluded that producers who exclusively rent land and older producers were less likely to participate in private conservation efforts and less likely to support conservation initiatives (Shepler et al., 2019).

Once it is determined what water conservation practices producers were implementing, researchers must discover the rate of technology adoption. North Plains Groundwater Conservation District's (NPGCD) surveyed graduates of the Master Irrigator Program in 2019. This program is designed to inform irrigated crop producers on the latest water management techniques and conservation strategies to maximize net returns per acre-inch applied, and the objective of the survey was to establish a baseline of the current adoption rate of irrigation strategies discussed in the program. Results indicated that the majority of the producers are using LESA irrigation systems. Irrigation scheduling, remote pivot tracking, and flow meters were some of the most common technologies used by the survey population. Crop residue management and in-season fertilizer management were the most common tillage practices used (North Plains Groundwater Conservation District, 2019).

Previous studies discussed the producers' willingness to pay for sustained water availability and the conservation practices and technologies used to accomplish conservation efforts. Shepler et al. (2019), was especially useful in designing the survey instrument for the present study. The following study expands on previous literature by evaluating an area with limited data. The data collected from this study will be beneficial to future studies within the region.

Data and Methods

Data analyzed in this study were produced from a survey of regional agricultural producers. Information was collected in regards to the producers' demographics, management practices, and producers' attitudes towards water scarcity.

The Institutional Review Board (IRB) at West Texas A&M University reviewed the survey prior to distribution. Participation for this study was completely voluntary, and no personally identifying information was asked or reported.

Qualtrics online survey software was used to develop and deploy the instrument. A recruitment letter and an anonymous survey link was provided via email from the area groundwater districts and Texas A&M AgriLife Extension. Raw data was downloaded from the online software and survey responses declining participation were removed from the dataset. Due to limited responses, all partial survey responses were analyzed. Questions were displayed to participants based on answers to previous question. Therefore not all participants were required to evaluate each question. For example, producers that indicated having only dryland production were not required to answer questions in regards to irrigation methods. Observations or frequencies were recorded for each question.

The survey consisted of 30 questions. The responses were anonymous, and respondents were only required to answer the consent statement. The topics included: demographics, acreage, irrigation methods, groundwater wells, management practices, and attitude towards water conservation.

Participants willing to complete the survey received the first set of questions upon their consent. Those not willing to participate were thanked for their time and prompted to exit the survey. Respondents were free to exit the survey at any time. Display logic was used to display subsequent questions.

Surveys were downloaded from the online software into Microsoft Excel and data were analyzed using descriptive statistics. The descriptive statistics included means, medians, standard deviations, minimums, maximums, and frequencies.

Results

Survey respondents were asked to list up to three counties where they currently farm in the Texas High Plains. Sixteen survey respondents had farmland located in 17 counties, with eight respondents farming in more than one county, Figure 3.1. The county with the highest frequency of the respondents was Ochiltree County, with four respondents. Of the sixteen respondents that provided demographic information, 94.8

percent were male. The average age of the participants was 56 years old, and the ages ranged from 30 years to 69 years old. Survey participants were asked to select their level of education. The majority of participants have a bachelor's degree, Table 3.1.

Figure 3.1 Location of respondents' farmland.

Table 3.1 Age, gender, and education level of survey respondents (n=16)

Age	Mean	Std. Dev.	Min	Max		
	56	10	30	69		
Gender	Male	Female				
Frequency	15	1				
%	93.8	6.3				
Education level	Some high school	Some college	Technical degree	Associate's degree	Bachelor's degree	Graduate degree
Frequency	1	3	1	1	7	3
%	6.3	18.8	6.3	6.3	43.8	18.8

On average, participants' families have been farming the area for 75 years. The production years of these families ranged from 34 years to 110 years. Respondents were asked if they expected their family members to continue farming the area once they retired and the majority responded yes, Table 3.2.

Table 3.2 Years which survey respondent's families have been farming the area and expectation to continue farming in the area (n=16)

Family Farm Years	Mean	Std. Dev.	Min	Max
	75	25	34	110
Family Successor	Yes	No	Unsure	
Frequency	9	4	3	
%	56.3	25.0	18.8	

On average, 66 percent of total household income was from farming. However, some respondents recorded as little as five percent to as high as 100 percent of total household income resulting from farming. Of farm income generated, respondents were also asked to provide the percentage of gross sales that were derived from irrigated farmland. Totals ranged from 15 percent to 100 percent with an average of 64 percent, Table 3.3.

Table 3.3 Percent of total household income from farming and gross farm sales from irritation

% household income from farming	Mean	Std. Dev.	Min	Max
	66	29	5	100
% farm sales from irrigated farming	Mean	Std. Dev.	Min	Max
	64	29	15	100

The average dryland acres farmed was 2,174 acres, while the range was five acres to 7,500 acres. Irrigated acres averaged 1,192 acres per respondent, with a recorded a range from five acres to 3,500 acres, Table 3.4.

Table 3.4 Total number of dryland and irrigated crop acres farmed by survey respondents, 2019

	Observations	Mean	Median	Std. Dev.	Min	Max
Dryland Acres	18	2,174	1,335	2,327	5	7,500
Irrigated Acres	14	1,192	900	901	5	3,000

Of the dryland and irrigated acreage farmed by respondents, they were asked to denote which crops were planted and harvested during the year of 2019. Respondents indicated the number of dryland acres planted to traditional field crops or list other dryland crops they planted that year. Nine respondents planted an average of 1,411 acres of dryland cotton. Wheat had the most acres planted to dryland with an average of 1,987 acres per respondent, Table 3.5. Of the planted acres, six participants harvested an average of 1,418 acres of dryland cotton. The highest number of dryland acres harvested was wheat. The remaining harvested dryland acres by crop are reported in Table 3.6.

Table 3.5 Planted dryland acres by crop

Commodity	Observations	Mean	Median	Std. Dev.	Min.	Max.
Corn Grain	2	150	150	-	150	150
Wheat	7	1,987	1,200	2,545	57	7,500
Cotton	9	1,411	600	1,612	200	5,000
Sorghum Grain	5	910	700	641	350	2,000
Other - Hay Grazer	1	100	100	-	100	100
Other - CRP Grass	1	300	300	-	300	300
Other - Rye	1	1,100	1,100	-	1,100	1,100

Table 3.6 Harvested dryland acres by crop

Commodity	Observations	Mean	Median	Std. Dev.	Min	Max
Corn Grain	2	150	150	-	150	150
Wheat	4	2,358	1,038	3,330	57	7,300
Cotton	6	1,418	850	1,849	50	5,000
Sorghum Grain	4	963	750	727	350	2,000
Other - Rye	1	200	200	-	200	200

Irrigated acres planted to traditional field crops or list other irrigated crops planted in 2019 were also collected. The number of respondents with irrigated acres increased for grain corn and cotton. Respondents also planted corn for silage. Planted acreage totals decreased for all crops, excluding grain corn and corn silage. Irrigated wheat had the highest average of planted acres at 1,062 acres per respondent, and irrigated grain sorghum had the least amount of acres planted, Table 3.7. Most respondents who recorded planting irrigated acres also recorded harvesting the listed crop, Table 3.8.

Table 3.7 Planted irrigated acres by crop

Commodity	Observations	Mean	Median	Std. Dev.	Min	Max
Corn Grain	6	408	375	180	190	710
Corn Silage	2	500	500	424	200	800
Wheat	5	1,062	710	867	300	2,500
Cotton	10	688	700	555	62	1,800
Sorghum Grain	1	130	130	-	130	130
Other - Pearl Millet	1	300	300	-	300	300

Table 3.8 Harvested irrigated acres by crop

Commodity	Observations	Mean	Median	Std. Dev.	Min	Max
Corn Grain	6	408	375	180	190	710
Corn Silage	2	500	500	424	200	800
Wheat	4	1,178	955	955	300	2,500
Cotton	10	546	370	542	62	1,800
Sorghum Grain	1	130	130	-	130	130
Other - Pearl Millet	1	300	300	-	300	300

Participants were asked to indicate the number of acres irrigated with center pivot irrigation, subsurface drip irrigation, and furrow irrigation. Respondents averaged 1,189 acres of center pivot irrigation, 357 acres of subsurface drip irrigation, and 160 acres of furrow irrigation, Table 3.9. The maximum acres recorded was 3,000 acres under center pivot irrigation. The smallest amount of irrigation was 120 acres allocated to furrow irrigation.

Table 3.9 Acres irrigated by irrigation system.

Irrigation Method	Observations	Mean	Median	Std. Dev.	Min	Max
Center Pivot Irrigation	13	1,189	930	861	300	3,000
Subsurface Drip Irrigation (SDI)	3	357	440	180	150	480
Furrow Irrigation	2	160	160	57	120	200

Several methods of center pivot irrigation are available to producers, and respondents were asked to detail which method they used on their acreage. Low Elevation Spray Application (LESA) averaged the highest acres, but more respondents noted using the Low Elevation Precision Application method, Table 3.10. A few respondents also used Mid-Elevation Spray Application on their center pivots.

Table 3.10 Acres irrigated by center pivot methods

Center Pivot Method	Observations	Mean	Median	Std. Dev.	Min	Max
Mid-Elevation Spray Application (MESA)	2	210	210	127	120	300
Low Energy Spray Application (LESA)	4	1,230	1,210	206	1,000	1,500
Low Energy Precision Application (LEPA)	10	1,027	690	808	400	3,000
Mobile Drip Irrigation (MDI)	0	0	0	0	0	0

The number of water wells operated by respondents based on pumping capacity was recorded. Wells pumping less than 100 gallons per minute (gpm) were operated by 10 participates and averaged 18 wells per response. Wells with a gpm of between 100 and

250 ranged from three to 130 wells and averaged 25 wells per response. The remaining well sizes are indicated in Table 3.11.

Table 3.11 Number of wells operated by survey respondents

Gallons Per Minute (GPM)	Observations	Mean	Median	Std. Dev.	Min	Max
Less than 100	10	18	9	27	2	91
Between 100 & 250	10	25	11	38	3	130
Between 250 & 400	5	2	2	1	1	3
Between 400 & 600	3	3	2	2	2	5
More than 600	2	3	3	3	1	5

In reference to pumping capacity of their groundwater wells, participants recorded how it had changed over the last 10 years. They were asked to select the option that best represented their wells. Fifteen respondents completed this question. Forty percent experienced somewhat of a decrease in pumping capacity. 33.3 percent selected that their well pumping capacity has decreased greatly, and the remaining respondents said their pumping capacity remained stable, Table 3.12. No respondents experienced an increase in their well pumping capacity.

Table 3.12 Change in groundwater well pumping capacity over the last 10 years

	Frequency	%
Decreased Greatly	5	33.3
Decreased Somewhat	6	40.0
Remained Stable	4	26.7
Increased	0	0

Yearly respondents' well depth to groundwater changes. Five respondents indicated the wells change one to two feet per year. Four responses specified a change of less than one foot per year. A change of two to three feet per year and a change in three to five feet per year both had three responses each, Table 3.13. No respondents recorded a change greater than five feet per year.

Table 3.13 Yearly change in depth to groundwater on wells operated by survey respondents

	Frequency	%
Less than 1 foot per year	4	26.7
1-2 feet per year	5	33.3
2-3 feet per year	3	20.0
3-5 feet per year	3	20.0
5-10 feet per year	0	0
More than 10 feet per year	0	0

Several questions regarding management practices were included. Participants were asked to indicate which of the following irrigation management practices they currently use: remote well management, variable rate irrigation, variable frequency drives, irrigation scheduling, remote pivot tracking, soil moisture sensors, delayed planting dates, flow meters, drones, or other practices. Eleven participants indicated they use multiple irrigation management practices. Remote pivot tracking and irrigation scheduling were used by most respondents, followed by flow meters, Figure 3.2. No respondents currently include drones in their irrigation management.

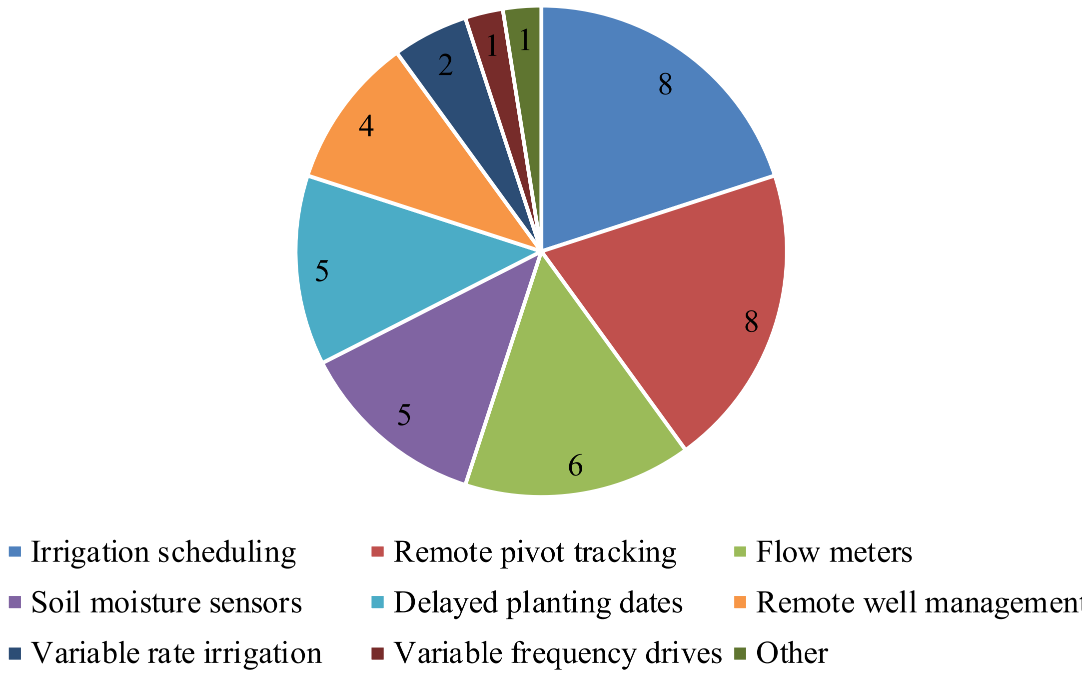

Figure 3.2 Number of survey respondents by irrigation management methods

Respondents indicated which of the following tillage practices they used: conventional tillage, conservation tillage, strip till, no till, or crop residue management during 2019. Twelve responded using multiple tillage practices throughout the year. Ten respondents used no till, nine used crop residue management, eight used conservation tillage, seven used conventional tillage, and five respondents used strip till, Figure 3.3.

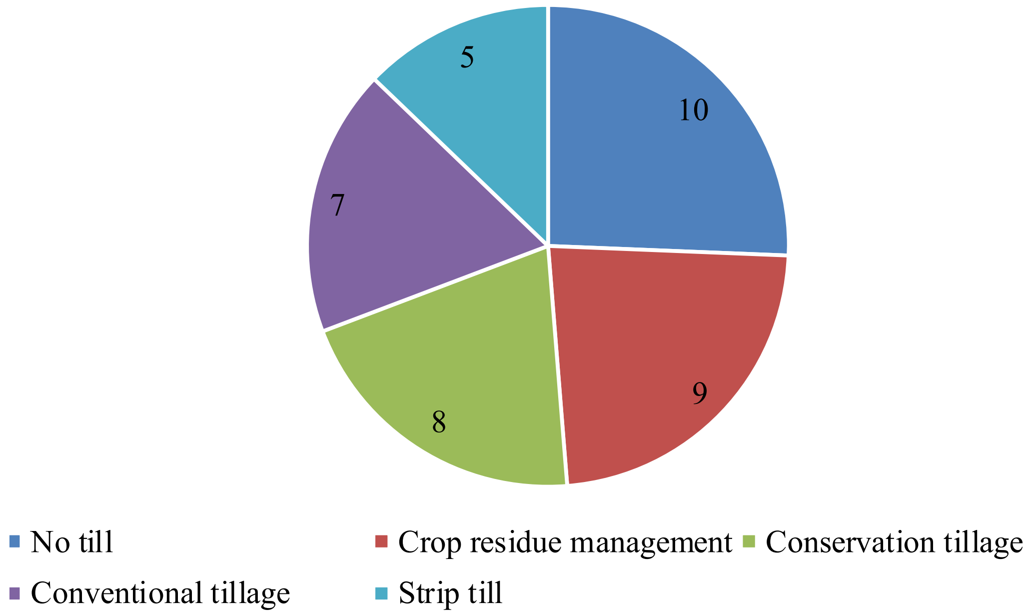

Figure 3.3 Number of survey respondents by tillage practice

Respondents have changed their current production practices in response to reduced water availability. Multiple participants have introduced several production practices to their operation. Changing their crop mix to crops that required less water is the most common with 12 responses. Ten respondents are converting previously irrigated acres to dryland acres and limiting the total amount of water applied per acre. Only two respondents noted they had not made any changes to their operation with the decline of water, Figure 3.4.

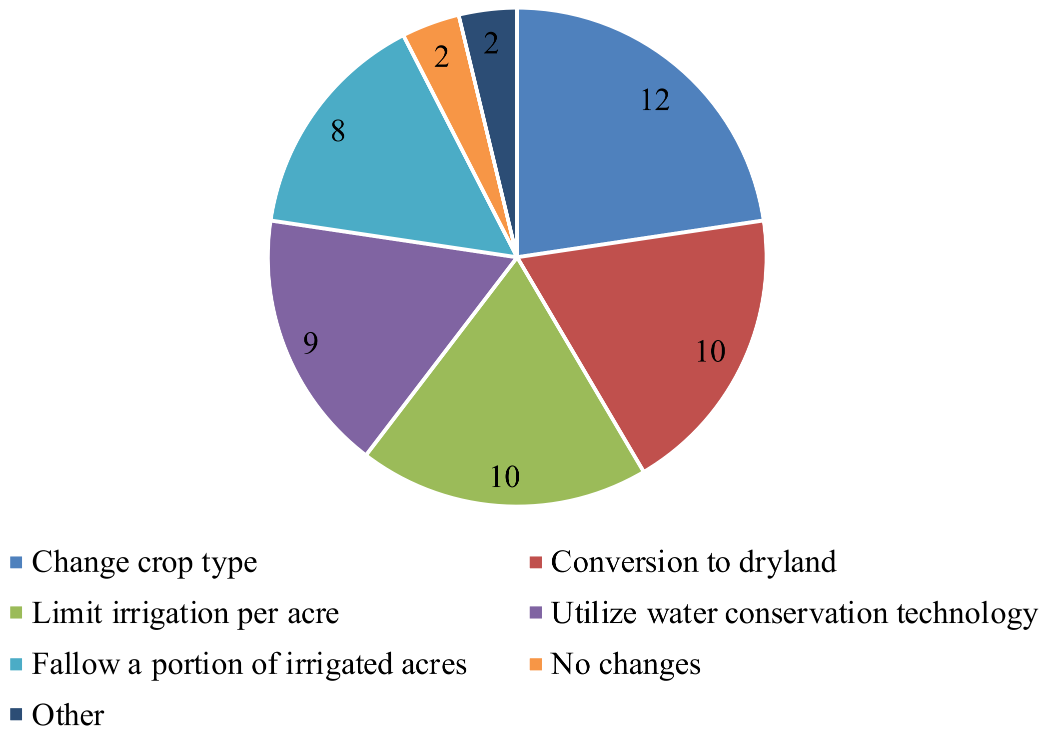

Figure 3.4 Number of survey respondents who implemented production practices due to reduced water availability

If faced with a 25 percent decline in water, participants indicated they would first fallow a portion of irrigated acres. Converting irrigated acres to dryland production would be the second management decision implemented. Changing crop type and implementing no change were evenly ranked third by participants. How participants ranked the remaining practices is indicated in Figure 3.5.

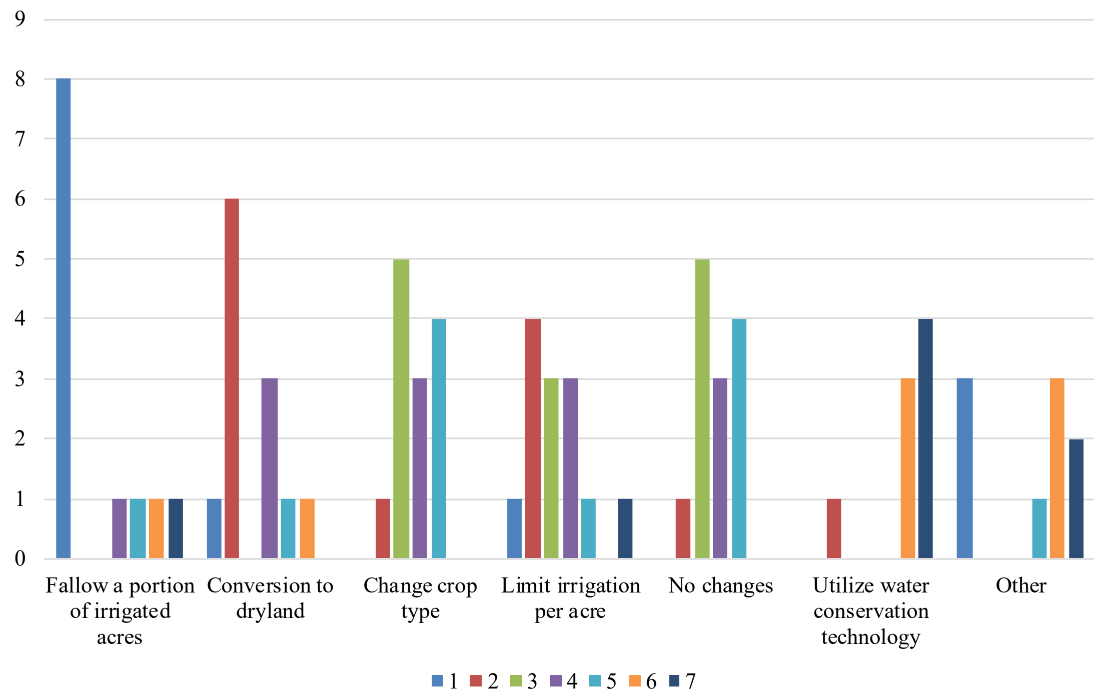

Figure 3.5 Implementation of production practices ranked by survey respondents

Frequency of irrigation prior to planting was also included. Of the responses analyzed, no one irrigated prior to planting every year. Approximately 54 percent of the respondents irrigate some years prior to planting, 31 percent irrigate most years, and only 15 percent indicate they never use pre planting irrigation, Table 3.14.

Table 3.14 Number of survey respondents that irrigate prior to planting

	Frequency	%
Most years	4	30.8
Some years	7	53.8
Never	2	15.4
Every year	0	0

Attitudes toward water usage and conservation was the final area of the survey. Respondents were asked to rank what they believe to be the most responsible for the decline of groundwater over the last 10 years. Personal groundwater use was ranked as the first and second reason by four respondents. The remaining factors' rankings are reported in Figure 3.6.

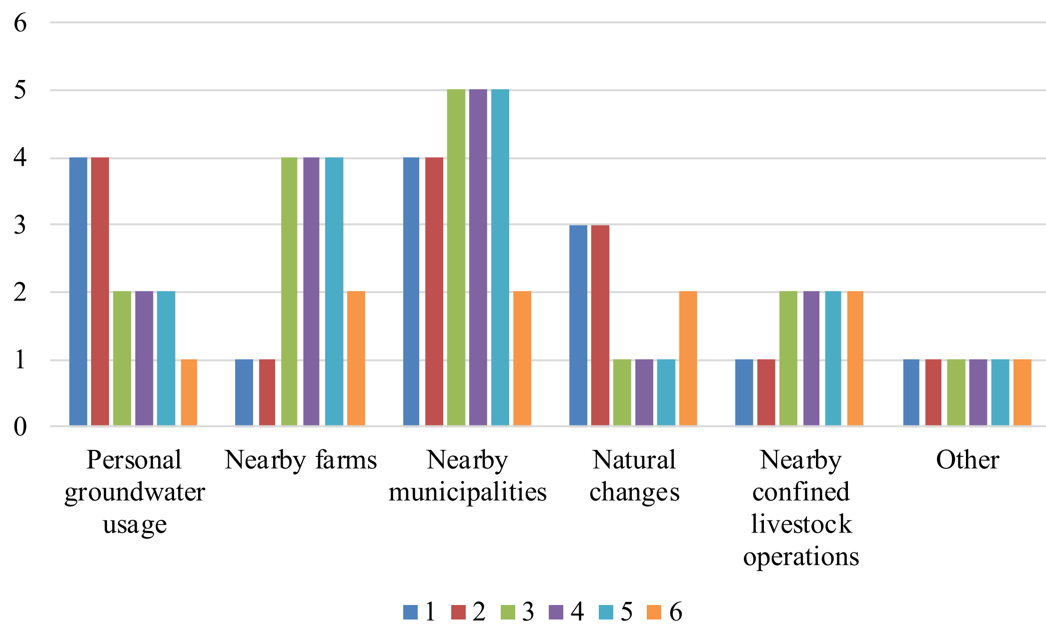

Figure 3.6 Factors responsible for groundwater declines over the last 10 years

The level of concern participants had regarding the availability of future groundwater in their area was recorded. Seventy-one percent of the responses were very concerned. The remaining respondents were moderately or slightly concerned, Table 3.15. All participants expressed concern.

Table 3.15 Level of concern for long-term availability of groundwater

	Frequency	%
Very concerned	10	71.3
Moderately concerned	2	14.3
Slightly concerned	2	14.3
Not concerned	0	0

When asked if they would be willing to decrease the economic returns of their operation in order to increase the amount of groundwater available in the future. Approximately 43 percent of respondents indicated they "might or might not" be willing.

Another 35.7 percent of respondents said they would “probably” be willing, and 28.6 percent responded with a “definite yes”. Only 7.1 percent responded probably not, and no respondents were definitely against trading economic returns for water longevity, Table 3.16.

Table 3.16 Willingness to decrease economic returns in exchange for an increase in future groundwater availability

	Frequency	%
Definitely yes	4	28.6
Probably yes	5	35.7
Might or might not	6	42.9
Probably not	1	7.1
Definitely not	0	0

Survey participants were asked how supportive they are of a groundwater conservation district’s efforts to conserve water. The majority (69%) responded “very supportive” of the efforts, Table 3.17. None of the respondents oppose the efforts of the districts.

Table 3.17 Support level for water conservation efforts

	Frequency	%
Very supportive	11	68.8
Somewhat supportive	2	12.5
Neutral	3	18.8
Somewhat opposed	0	0
Very opposed	0	0

Summary and Discussion

Three key areas were evaluated in this study: demographics, management practices, and producers’ attitudes towards water conservation. The small number of respondents limited this study. However, the results indicated that producers are including new management practices to their operation, and they are concerned about the future availability of the groundwater. Producers are supportive of current conservation efforts from the districts to preserve groundwater according to the results.

Reassessing the structure of the survey instrument will benefit the study by increasing the number of respondents. It has been shown that the length of a survey affects participants' willingness to participate and the number of completed questionnaires (Galesic and Bosnjak, 2009). Limiting the survey to 10 minutes would help reduce the time producers need to complete the survey. The survey had an average completion time of 145 minutes. This was due to participants starting the survey one day and completing it the next day. Reducing the survey time would keep participants interested and increase the number of completions.

Sectioning this survey into three sections focused primary on the objective of the study would decrease response times. Section one should collect demographic information, section two would inquire about management practices, and section three would requests respondents' attitudes towards water conservation.

An additional suggestion would be to add additional logic to the survey questions in Qualtrics. The current survey asks respondents to provide their overall dryland and irrigated acres and then planted and harvested acreage by crop. Including logic that does not allow respondents to enter totals above their overall acres would help eliminate human error. That survey question could also be simplified by having participants select the crop the majority of their acres are planted to instead of requiring participants to fill in exact acreage amounts.

A more accurate assessment of the region should be considered to model the future groundwater resources in the area. A better understanding of producers' attitudes and perceptions towards scarcity can assist policy makers and management districts in the development to better reach sustainability.

References

Adrian, A.M., S.H. Norwood, and P.L. Mask. 2005. "Producers' perceptions and attitudes toward precision agriculture technologies." *Computers and Electronics in Agriculture* 48 (3): 256-71. https://doi.org/10.1016/j.compag.2005.04.004.

Chouinard, H.H, T. Paterson, P.R. Wandschneider, and A.M. Ohler. "Will Farmers Trade Profits for Stewardship? Heterogeneous Motivations for Farm Practice Selection." *Land Economics* 84 (1): 66-82. https://www-jstor-org.databases.wtamu.edu/stable/27647806.

Galesic, M. and M. Bosnjak. 2009. "Effects of Questionnaire Length on Participation and Indicators of Response Quality in a Web Survey." Public Opinion Quarterly 73 (2): 349-60. https://www-jstor-org.databases.wtamu.edu/stable/25548084.

McGuire, V.L. "Water-Level and Recoverable Water in Storage Changes, High Plains Aquifer, Predevelopment to 2015 and 2013-15" U.S. Geological Survey Scientific Investigations Report 2017-5040. https://doi.org/10.3133/sir20175040.

North Plains Groundwater Conservation District. 2019. "The Master Irrigator Program." http://northplainsgcd.org/conservationprograms/communityedu/master-irrigator/

Shepler, R., J.F. Suter, D.T. Manning, and C. Goemans. 2019. "Private Actions and Preference for Coordinated Groundwater Conservation in Colorado's Republican River Basin." *Journal of the American Water Resources Association* 55 (6): 657-69. https://doi-org.databases.wtamu.edu/10.1111/1752-1688.12741.