When High-Water-Use Neighbors Move In: Farming Pecans in Valencia County, New Mexico

Tylee M. Griego

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When High-Water-Use Neighbors Move In:
Farming Pecans in Valencia County, New Mexico

by

Tylee M. Griego

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A Professional Project Submitted in Partial Fulfillment of the Requirements for the
Degree of
Master of Water Resources
Hydroscience Concentration
Water Resources Program
The University of New Mexico
Albuquerque, New Mexico
May 2022
Acknowledgements

This research was funded in part by the South-Central Climate Adaptation Science Center (SC CASC) and by the University of New Mexico (UNM). I am very grateful to SC CASC and UNM for their support, and for John Fleck’s assistance securing funding and employment. I am additionally appreciative of the Utton Center’s support for a portion of this project. I would like to especially thank my committee including John Fleck for his time and efforts providing me with invaluable assistance in completing this project, as well as providing encouragement and useful suggestions. John was very patient with me and indispensable as we went through many iterations of this paper. I would also like to thank the other members of my committee, Robert “Bob” Berrens and Adrian Olgesby, for their time, efforts, information, support, and other help in completing this project. Adrian Olgesby was instrumental at starting me down the path of stacking water rights and in supplying some papers of interest to get me started. Bob Berrens is to thank for helping me title this project as well as helping ensure I paid attention to consistency in adjustments and notations for inflation. A thank you is also deserved Talisa Barancik who shared data with me concerning the counties she was studying for comparison to Valencia County; Talisa was my companion in delving into Census of Agriculture data and trying to put it into a usable form. I would also like to thank Laura Crossey, one of my mentors, for her help, encouragement, and the suggestion that I apply to the Water Resources Program at UNM, a program that turned out to be just perfect for me. Also, I would like to thank Ron Goens for his kind assistance in providing water data for Whitfield Wildlife Area in Valencia County. Thank you to J. Phillip King in providing me with the EBID stacking policy, which was no longer available online. I would like to thank my family, cats, and dog for their help and support; I could not have completed this project without their assistance and cooperation. Sarah was of special assistance especially when important files went missing. Thank you, to my family, for understanding when I was too busy working on my project to give you the attention I wanted to; thank you all for your patience. Additionally, I would like to thank my mother, Doreen, and friend Axel who both provided unexpected support and encouragement at a time when I needed it most.
Abstract

Valencia County, comprised of a collection of farming communities in the Middle Rio Grande of central New Mexico, is undergoing a fundamental change in its irrigated agriculture. Historically, over recent decades, it has had many smaller-sized farms, or “hobby farms”, with fewer larger commercial enterprises, and with alfalfa as its dominant crop. But in recent years, it has seen a significant expansion of acreage devoted to pecan orchards – a higher value commercial crop that also is substantially higher in water use. Some of these orchards have been planted on land not previously irrigated. The Rio Grande flows through the county and is the primary source of irrigation water. All the water flowing in the Rio Grande is already allocated. Agricultural, municipal, industrial, and environmental water uses are competing for the use of a scarce resource. Climate change, in particular a lengthened growing season, appears to be one of the drivers of the expansion of pecans acreage. But climate change also is decreasing flows in the Rio Grande, and therefore the available water to meet Valencia County’s competing needs. The objective of this investigation is to identify the main water policy implications of farming high-water-use crops, such as pecans, in Valencia County, as well as the viability for the county of using techniques such as water rights ‘stacking’, as has been used elsewhere, to try to reduce stress on the hydrologic system.

Keywords: Agricultural water use, agriculture, Middle Rio Grande, pecan evapotranspiration, pecan water use, pecans, stacked water rights, stacking, Valencia County, water management, water policy, water rights stacking, water use
# Farming Pecans in Valencia County, New Mexico

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<td>AE</td>
<td>Application Efficiency</td>
</tr>
<tr>
<td>AF</td>
<td>Acre-Feet</td>
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<tr>
<td>AF/YR</td>
<td>Acre-Feet Per Year</td>
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<tr>
<td>AOI</td>
<td>Area of Interest</td>
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<tr>
<td>AWRM</td>
<td>Active Water Resource Management</td>
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<tr>
<td>BEMP</td>
<td>Bosque Ecosystem Monitoring Program</td>
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<tr>
<td>BOR</td>
<td>United States Bureau of Reclamation</td>
</tr>
<tr>
<td>CDL</td>
<td>Cropland Data Layer</td>
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<tr>
<td>CIR</td>
<td>Consumptive Irrigation Requirement</td>
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<tr>
<td>cm</td>
<td>Centimeter</td>
</tr>
<tr>
<td>CR</td>
<td>Cash Receipts</td>
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<td>EBID</td>
<td>Elephant Butte Irrigation District</td>
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<td>EPCWID</td>
<td>El Paso County Water Improvement District</td>
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<tr>
<td>ET</td>
<td>Evapotranspiration</td>
</tr>
<tr>
<td>FDR</td>
<td>Farm Delivery Requirement</td>
</tr>
<tr>
<td>ft</td>
<td>Foot/Feet</td>
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<tr>
<td>GIS</td>
<td>Geographic Information System</td>
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<td>ha</td>
<td>hectare</td>
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<tr>
<td>in</td>
<td>Inch</td>
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<tr>
<td>IWUE</td>
<td>Irrigation Water Use Efficiency</td>
</tr>
<tr>
<td>KAF</td>
<td>Thousand Acre-Feet</td>
</tr>
<tr>
<td>Kc</td>
<td>Crop Coefficient</td>
</tr>
<tr>
<td>km</td>
<td>Kilometers</td>
</tr>
<tr>
<td>Ky</td>
<td>Constant Slope Coefficient</td>
</tr>
<tr>
<td>LRG</td>
<td>Lower Rio Grande</td>
</tr>
<tr>
<td>LRGV</td>
<td>Lower Rio Grande Valley</td>
</tr>
<tr>
<td>m</td>
<td>Meters</td>
</tr>
<tr>
<td>mm</td>
<td>Millimeters</td>
</tr>
<tr>
<td>MAPD</td>
<td>Mean Absolute Performance Difference</td>
</tr>
<tr>
<td>MRCOG</td>
<td>Mid-Region Council of Governments</td>
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<tr>
<td>Acronym</td>
<td>Full Form</td>
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<td>-----------</td>
<td>----------------------------------------</td>
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<tr>
<td>MRG</td>
<td>Middle Rio Grande</td>
</tr>
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<td>MRGCD</td>
<td>Middle Rio Grande Conservancy District</td>
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<td>MRGV</td>
<td>Middle Rio Grande Valley</td>
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<tr>
<td>NASS</td>
<td>National Agricultural Statistics Service</td>
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<td>NHD</td>
<td>National Hydrology Dataset</td>
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<td>NMPG</td>
<td>New Mexico Pecan Growers</td>
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<td>NM OSE</td>
<td>New Mexico Office of the State Engineer</td>
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<tr>
<td>NM SEO</td>
<td>New Mexico State Engineer Office</td>
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<tr>
<td>NMSU</td>
<td>New Mexico State University</td>
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<td>NRCS</td>
<td>National Resources Conservation Service</td>
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<tr>
<td>OSE</td>
<td>New Mexico Office of the State Engineer</td>
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<tr>
<td>PDSI</td>
<td>Palmer Drought Severity Index</td>
</tr>
<tr>
<td>PHDI</td>
<td>Palmer Hydrologic Drought Index</td>
</tr>
<tr>
<td>POD</td>
<td>Point of Diversion</td>
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<tr>
<td>REEM</td>
<td>Regional Evapotranspiration Estimator</td>
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<tr>
<td>SES</td>
<td>Social-Ecological System</td>
</tr>
<tr>
<td>SKL Model</td>
<td>Stephens Keyes Larson Numerical Groundwater Flow Model</td>
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<tr>
<td>SPI</td>
<td>Standardized Precipitation Index</td>
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<tr>
<td>SPI24</td>
<td>24-Month Standardized Precipitation Index</td>
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<tr>
<td>SRGDCFA</td>
<td>Southern Rio Grande Diversified Crop Farmers Association</td>
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<tr>
<td>SSURGO</td>
<td>Soil Survey Geographic Database</td>
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<tr>
<td>SWUA</td>
<td>Surface Water User’s Agreement</td>
</tr>
<tr>
<td>TIA</td>
<td>Total irrigable acreage</td>
</tr>
<tr>
<td>USCD</td>
<td>United States Climate Data</td>
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<tr>
<td>USDA</td>
<td>United States Department of Agriculture</td>
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<tr>
<td>USDA-NASS</td>
<td>United States Department of Agriculture-National Agricultural Statistics Service</td>
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<tr>
<td>USGS</td>
<td>United States Geological Survey</td>
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<tr>
<td>VIF</td>
<td>Variance Inflation Factor</td>
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<td>WRRS</td>
<td>Water Rights Reporting System</td>
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<tr>
<td>VSWCD</td>
<td>Valencia Soil and Water Conservation District</td>
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WUE Water Use Efficiency
Introduction

There is a long history of agriculture in Valencia County including farming fruits, vegetables, and nuts, as well as livestock and many dairy farms. Agriculture is closely entwined with the local culture; farming has been a way of life in Valencia County, New Mexico for hundreds of years (Clark, 1987). Agricultural pursuits began with the indigenous Native American communities, which have lived on the land for time immemorial. Farming continued and evolved as the Spanish and other Europeans settled the land that would one day become New Mexico (Clark, 1987). Valencia County receives very little rain, so irrigation is very important to agriculture in the county. The indigenous peoples were able to farm by the judicious use of water flowing in the Rio Grande (Clark, 1987). Acequias, or ditches, that carry water from the Rio Grande to the agricultural lands, are still used by many farmers today. Figure 1 is a view of the Rio Grande with a cottonwood stretching out over the river. We can see in this picture the river level is quite low and water is flowing slowly enough that a pool of stagnant water has formed at the bank providing a mini ecosystem for local wildlife including tadpoles.

Valencia County is an unusual farming community in that there are relatively few large-sized farms, but many smaller-sized farms (USDA-NASS, 1989, 1994, 1999, 2004, 2009, 2014, 2019). However, in more recent years, there is a change towards increasing farm size as well as a change in crops grown (USDA-
NASS, 1989, 1994, 1999, 2004, 2009, 2014, 2019). In particular, pecans are being grown in Valencia County to a much greater degree than previously has been seen (USDA-NASS, 1989, 1994, 1999, 2004, 2009, 2014, 2019). In part this is because upon reaching full maturity, pecan trees can average $3,750 per acre profit, but can generate a profit of up to $5,000 per acre, adjusted into constant 2019 dollars (Adams, 2019, September 23), compared to $200-300 per acre for alfalfa, in constant 2019 dollars, while both crops have similar equipment costs (Adams, 2019, September 23). This makes the change to pecans appealing to some farmers within Valencia County.¹

However, pecans are a high-water-use crop (Skaggs et al., 2008; Ibraimo et al., 2016) and some of the land on which they are being grown has not previously been used for agriculture (Davis, 2006, April 10). Along with the agricultural water needs of the county, municipal and industrial needs are continuing to increase as well. Climate change is putting pressure on the scarce water resources as well by raising air temperatures (Bean, 2019; Chavarria & Gutzler, 2018) and increasing the frequency and severity of droughts (Cayan et al., 2010; Jones & Gutzler, 2016; Plassin et al., 2021; Seager et al., 2013). At the same time, flows in the Rio Grande are decreasing (Cayan et al., 2010; Jones & Gutzler, 2016; Plassin et al., 2021; Seager et al., 2013).

This leads us to wonder, with the effects of climate change and the other demands on water supplies what are the water policy implications of farming pecans in an arid to semi-arid region? Are there any ways to make pecan farming more sustainable despite climate change? How would a change to larger commercial agricultural enterprises such as pecan orchards affect Valencia County and its water resources, when Valencia County has historically had predominantly “hobby,” subsistence, or custom and culture farms?

Establishing a commercially-focused, high-consummptive-water-use crop, such as pecans, on land previously not used for crops will cause the demand for water to increase, thereby increasing the demand for surface water for irrigation. Ultimately, irrigators will increasingly turn more to groundwater sources for irrigation of their crops during times of drought and/or with the other effects of climate change causing decreased surface water availability from the Rio Grande. This increased demand for water for higher-dollar-value, yet higher-water-demand

¹ All dollar values presented in the paper are in inflation adjusted, constant 2019 dollars, unless specifically stated otherwise.
crops, will exacerbate New Mexico’s water shortages unless policy tools and innovative water management techniques are pursued.

The objective of this investigation is to identify the main water policy implications of farming high-water-use crops, such as pecans, in Valencia County, New Mexico, as well as the viability for the county of using techniques such as water rights ‘stacking’, as has been used in the Elephant Butte Irrigation District (EBID), to try to reduce stress on the hydrologic system.

**Background & Literature Review**

![Figure 2: Valencia County, New Mexico is highlighted in magenta (Created Spring 2020 for “Irrigation Adaptation to Climate Change in the Middle Rio Grande Valley of New Mexico and Colorado: Middle Rio Grande” which was the early name of this professional project).](image)

**Location**

Valencia County is located approximately 30 miles to the south of the City of Albuquerque (in Bernalillo County), New Mexico, USA. The county of Socorro lies to the south of Valencia County, Torrance County is to the east, and Cibola County is to the west. Cibola County was part of Valencia County until 1981 when Cibola County was established. With the creation of Cibola County, Valencia County lost just over 80% of its former size, making it one of the smallest counties in New Mexico at approximately 1,068 square miles (Encyclopaedia Britannica, n.d.; Ferguson, n.d.). Figure 2, above, shows Valencia County’s location highlighted in magenta.
Valencia County was established, originally, as part of Mexico in 1844. It was confirmed in 1852 when the area became part of the Territory of New Mexico and continued as New Mexico gained statehood in 1912. The Village of Los Lunas, at an elevation of 4,856 feet, is the county seat as well as one of the three municipalities in Valencia County, along with Belen and the Village of Bosque Farms. There are also a number of smaller, unincorporated areas in the county. Additionally, the Pueblo of Isleta\(^2\) lies at the north end of the county with parts of it extending into Bernalillo County as well as Torrance County. Also, part of the Laguna Pueblo\(^3\) lies within Valencia County in the northwest corner (as shown in Figure 3, above) (Encyclopaedia Britannic, n.d.; Ferguson, n.d.).

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\(^2\) The native name of the tribe at the pueblo at Isleta is Shiewhibak (NMI, 2020, July 11).
\(^3\) The native name of the tribe at Laguna is Kawaik, the largest Keresan-speaking pueblo (Weiser-Alexander, 2021, November).
Over time, Valencia County’s farm sizes have changed as shown below in figure 4. 


Figure 4, above, shows a general decrease in medium sized farms by acres irrigated (shown in yellow). Medium sized farms are farms with irrigated acreage of 180 to 999 acres. Figure 4 also shows a general increase in large sized farms (shown in orange) by acres irrigated (farms with irrigated acreage of 1,000 or more acres). Small sized farms with irrigated acreage of 1 to 179 acres are shown in green, showing a slight increase in small sized farms. The number of large farms is increasing while the number of medium farms is decreasing.

In 1987, Valencia County’s farms were mostly small farms of 1-179 acres irrigated acres (around 60%). Medium-sized farms of 180-999 acres accounted for nearly 34% of irrigated acreage in farms in the county. In 1987, large-sized farms of 1,000 acres or more accounted for 7% of irrigated acreage in farms in Valencia County (USDA-NASS, 1989).

By 2017, small-sized farms in Valencia County accounted for just under 57% of irrigated acreage in farms. It is interesting to note that medium-sized farms accounted for just over 18% of irrigated acreage in farms in the county. The largest increase (an 18% increase), however, was
found in large-sized farms which went from 7% in 1987 to 25% of irrigated acreage in farms in Valencia County by 2017 (USDA NASS, 2019).

It should be noted that there may be a slight underestimation in the percentage of medium sized farms (180-999 acres) since out of 20 farms, “D” values of irrigated acreage were reported for the two farms that were 500-999 irrigated acres in size, and close to 2200 acres of irrigated agricultural land was reported for farms from 180-499 irrigated acres in size. “D” values are given in the Census of Agriculture when to report the acreage would result in individual farms becoming identifiable, potentially exposing private information.

Valencia County receives only 9.77 inches of precipitation annually (USCD, 2019) with the majority falling as snow in the winter or rain during the monsoon season. Due to the arid to semi-arid conditions in Valencia County, precipitation must be supplemented by irrigation in order to be successful agriculturally. The main source of irrigation in the county is surface water flowing from the Rio Grande into ditches, acequias, and arroyos with very little agricultural reliance on groundwater compared to other counties in New Mexico like Socorro County or even more so Doña Ana County, for example, a county where groundwater use for irrigated agriculture is significantly greater than the diversions of surface water used for irrigated agriculture (USDA-NASS 1989, 1994, 1999, 2004, 2009, 2014, 2019; NM SEO, 1992, July; 1997, September; NM OSE, 2003, February; 2008, June; 2013, October; 2019, May).
In 1990, Valencia County used 37% of the MRG’s total surface water withdrawals for irrigated agriculture while Socorro used 29%, Bernalillo 21%, and Sandoval 14% of the MRG’s total surface water withdrawals for agriculture (NM SEO, 1992, July). In 1990, as seen in Figure 5, above, Valencia County was responsible for withdrawing approximately 131,730 AF of surface water for irrigated agriculture while Socorro County withdrew approximately 103,360 AF, Bernalillo withdrew approximately 73,730 AF, and Sandoval withdrew approximately 49,510 AF (NM SEO, 1992, July; 1997, September; NM OSE, 2003, February; 2008, June; 2013, October; 2019, May). By 2015, Valencia County increased its proportion of the surface water used for agriculture from 37% of the MRG’s surface water withdrawals for irrigated agriculture to 46% of the MRG’s total, using approximately 134,060 AF of surface water in 2015.
In 2015, Socorro’s portion of surface water withdrawn for irrigated agriculture increased to 30% of the MRG totals, however, the amount withdrawn decreased to approximately 86,750 AF (NM OSE, 2019, May). In 2015, Bernalillo’s proportion of surface water withdrawn for irrigated agriculture decreased to 12% of the MRG’s total surface water withdrawals for irrigated agriculture, using approximately 36,650 AF of water (NM OSE, 2019, May). Sandoval withdrew the least amount of surface water for irrigated agriculture withdrawing approximately 35,900 AF which is 12% of the MRG’s total surface water withdrawals for irrigated agriculture (NM OSE, 2019, May).

Figure 6: Groundwater withdrawals for irrigated agriculture in the Middle Rio Grande. Graph Data Source: NM SEO (1992, July; 1997, September); NM OSE (2003, February; 2008, June; 2013, October; 2019, May).

Graph Data Source: NM SEO (1992, July; 1997, September); NM OSE (2003, February; 2008, June; 2013, October; 2019, May).
Figure 6, above, shows the groundwater withdrawals for irrigated agriculture in the MRG between 1990-2015 (NM SEO, 1992, July; 1997, September; NM OSE, 2003, February; 2008, June; 2013, October; 2019, May). In 1990, Socorro withdrew 69% of the MRG’s groundwater for irrigated agriculture while Valencia withdrew 20%, Bernalillo 9%, and Sandoval 2% (NM SEO, 1992, July). The amount of groundwater Valencia County withdrew for irrigated agriculture in 1990 was approximately 9,090 AF while Socorro withdrew approximately 30,960 AF, Bernalillo withdrew approximately 4,040 AF, and Sandoval withdrew approximately 685 AF (NM SEO, 1992, July). By 2015, Socorro withdrew 70% of the MRG’s total groundwater for irrigated agriculture (approximately 27,280 AF) while Valencia withdrew 22% of the MRG’s total groundwater for irrigated agriculture (approximately 8,450 AF) (NM OSE, 2019, May). In 2015, Bernalillo’s groundwater withdrawals for irrigated agriculture represented 7% of the MRG’s totals (approximately 2,540 AF) and Sandoval’s groundwater withdrawals for irrigated agriculture represented just 1% of the MRG’s totals (approximately 570 AF) (NM OSE, 2019, May).

As the climate changes, many farmers are changing their cropping patterns. Hay, mainly alfalfa, continues to account for the majority of harvested acreage in the MRG. However, over the last three decades, there has been a slight shift away from growing lower dollar value (per unit of water) crops like alfalfa, and a shift away from crops like vegetables in the MRG. Although acreage in vegetables has increased in Valencia County since 1987, overall, in the MRG, acreage devoted to vegetables has decreased. During this timeframe, acreage devoted to orchards in the MRG has increased substantially. The growth in orchards is predominantly a growth in acreage devoted to growing pecan trees (USDA-NASS, 1989, 1994, 1999, 2004, 2009, 2014, 2019). Of the counties of the MRG, Valencia County had a significant increase in acreage devoted to pecans: 7 acres in 1987 to over 400 acres by 2017 (USDA-NASS, 1989, 1994, 1999, 2004, 2009, 2014, 2019). One farmer with pecan orchards in Valencia County states their pecan trees are on approximately 400 acres, although ultimately 850 acres are planned (Adams, 2019, September 23). That Valencia County farmer, as of 2019, had a total of 22,000 trees (Adams, 2019, September 23). The county, previously, has consisted mostly of smaller, “hobby” farms with some medium sized farms, and few larger commercial farming ventures. With climate change, will the pecan trees flourish further northward than they have previously? One local newspaper noted, “Pecan production has been expanding northward and eastward across New
Mexico” (Hedden, 2019, October 15). Thus far, Belen has been the farthest north that pecans have been commercially grown in New Mexico and so far, it seems to be a success for the farmer, with more acres of pecan trees planned.

New Mexico is considered a good place to grow pecans. When comparing nutmeat percentage, New Mexico’s pecans produce “more meat per nut” (Hedden, 2019, October 15). New Mexico’s pecans are 50-55% nutmeat while Georgia’s pecans contain 40% nutmeat (Hedden, 2019, October 15). The pecan industry in New Mexico has less variability and uncertainty, generally, than states where pecans grow native and are managed very little. For instance, the practice of pruning pecan trees so as to limit their canopy and prevent overgrowth can affect production significantly, allowing for more pecan production in New Mexico each year and “for more consistent marketing for buyers to come to New Mexico for the nut” (Hedden, 2019, October 15).

At the same time, flows in the Rio Grande have been decreasing, making less water available in the arid to semi-arid southwest and droughts are becoming more frequent and severe (Cayan et al, 2010; Jones & Gutzler, 2016; Plassin et al, 2021; Seager et al, 2013). The waters of the Rio Grande are fully appropriated in the MRG basin. This means that all the water flowing in the Rio Grande is put to beneficial use for agricultural, municipal, and/or industrial needs, or to meet instream flow requirements for wildlife and compact obligations to Texas and Mexico.

Climate change is also driving up average global temperatures, and this trend is seen in New Mexico as well. Beene (2019) cautions, “Temperatures are expected to rise by up to 5.5º F by 2070, with the most pronounced impacts manifest as summer heatwaves and longer stretches between annual freezes, which will be detrimental to the yield and productivity of regional crops like established fruit and nut trees” (italics added). Further, Chavarria and Gutzler (2018) note that “winter and spring season temperatures in the [Rio Grande] basin have increased significantly”. Increased temperatures cause potential evapotranspiration (ET) to increase as well; this means the crops grown will require more water than under lower temperatures.

New Mexico has experienced prolonged periods of drought, and climate change is expected to exacerbate this, causing more frequent, more severe, and longer droughts (Cayan et al., 2010; Jones & Gutzler, 2016; Plassin et al., 2021; Seager et al., 2013). Models predict that there will be decreased availability of water in the southwest (Chavarria & Gutzler, 2018). Observations show trends that are decreasing in snow depth and snow extent in the western U.S.
because of warmer temperatures (Chavarria & Gutzler, 2018; Mote et al., 2018). With warmer springs comes the observed shift to “earlier spring streamflow” (Chavarria & Gutzler, 2018). Chavarria and Gutzler (2018) observe the data show that streamflow in the Rio Grande has been reduced somewhat in the “April-July snowmelt runoff season”, and that there is a 25% decrease in the “April 1 snow water equivalent” (SWE), showing that less precipitation is falling as snow and it is falling as rain instead (Chavarria & Gutzler, 2018). This means that less water is available at the start of the growing season being released as the snow melts because there is less snow available, and that snow is melting earlier – a bit earlier than it is needed. Previously, the snow has been an important ‘bank’ where New Mexico keeps its water until it is needed at the start of the growing season. Chavarria and Gutzler (2018) state that the climate in the southwest “is changing in ways that are projected to have significant impacts on water availability and water management in the Rio Grande Basin”. Plassin et al. (2021) state the southwest has “faced severe and persistent drought” with the time period between 2000-2018 being the “driest 19-year period since the late 1500s and the second driest since 800 CE” (Plassin et al., 2021; see also Williams et al., 2020).

One Valencia County farmer sought Middle Rio Grande Conservancy District (MRGCD) water to irrigate “former sandhills near Belen”, New Mexico (Davis, 2006, April 10). The purpose was to grow pecan trees on a “120-acre patch of former sandhills” in Valencia County as part of an approximately “800-acre farm complex” (Davis, 2006, April 10). With this pecan orchard’s success with the new acreage being irrigated in the county, a potential shift in areas where pecan trees are shown to thrive, and the shift from growing vegetables in the MRG, generally considered to have a lower consumptive water requirement, to growing pecans with their higher consumptive water requirement, we would expect that more demands will be placed on the county’s hydrologic system

In 2021, the MRGCD asked farmers not to farm if they didn’t need to (MRGCD, 2021, June 23). Then, in the MRGCD’s 2022 Irrigation Season Outlook (2022, January 18), the MRGCD states that due to weather and climactic conditions this winter including the effects of La Niña that “for the 2022 irrigation season, the MRGCD will have little water storage available, and will have to depend on natural inflows for irrigation deliveries in 2022” (MRGCD, 2022, January 18). The MRGCD is further “warning all irrigators to expect significant changes to irrigation delivery”, stating also that lowest priority water users should not expect to receive
water for the 2022 irrigation season, and they urge irrigators to use “caution when making farming plans this year”, bearing in mind the limited water supply for all irrigators (MRGCD, 2022, January 18).

During the years between 1987-2017, the population of Valencia County has continued to increase as well, going from just over 40,500 people in 1987 to just below 76,000 people in 2017 as shown in Figure 7, reproduced below (USCB, n.d.). Industrial needs have also grown in recent years with the placement of a Facebook data center, bottling plant proposed, Amazon fulfillment warehouse proposed, and other industries with their water requirements. This puts added pressure on an already strained water supply.

*Figure 7: Valencia County population, 1987-2017. Graph Source: U.S. Census Bureau (n.d.), Resident Population of Valencia County.*

This leads us to ask how can we make pecan farming viable in Valencia County given all the demands on a fully allocated water system?

**Agriculture**

This section discusses pecan trends both in the United States and more locally in New Mexico, pecan climactic requirements, varieties of pecan trees grown in New Mexico and northern Texas, as well as which varieties might successfully be grown in Valencia County, and
lastly this section discusses the water requirements of pecan trees/orchards and estimating evapotranspiration (ET). For farmers to have successful pecan orchards in Valencia County, the above-mentioned parameters are of key importance. This information can help us determine whether pecan orchards are a viable endeavor in Valencia County.

**Pecan Trends**

This section includes background about pecan trees and trends in the United States as well as New Mexico. This section helps us understand the demand for pecans in the United States.

- Pecan trees are not native to New Mexico and require ample irrigation to supplement scant rainfall in this arid to semi-arid area.
- Pecans are an alternate bearing tree with a year of lower pecan production followed by a year of higher pecan production on alternating years.
- Pecans have many health benefits and demand has increased due in part to the export of pecans.
- In 2016, the United States was the world’s largest producer of pecans.
- Between 1987-2017 national pecan acreage increased by 22.1%.
- In 2019, major pecan production in the United States occurred in New Mexico, Georgia, Arizona, Texas, and Oklahoma.
  - New Mexico accounted for 36.3% of pecan production.
  - Georgia accounted for 28.0% of pecan production.
  - Arizona accounted for 15.9% of pecan production.
- Between 1987-2017, New Mexico’s pecan acreage increased by 126.5%, rising from ~22,000 acres to ~51,000 acres.
- In New Mexico, most pecans are grown in the southern portion of the state, especially in the Elephant Butte Irrigation District (EBID).

The pecan tree (*Carya illinoinensis*), although not native to New Mexico, is native to the southern United States (Skaggs et al., 2008). The pecan’s native range closely follows the Mississippi River and its tributaries, as well as the rivers and tributaries of central and eastern Texas (Skaggs et al., 2008; Sparks, 2005). The pecan tree is an alternate-bearing tree with a year of more plentiful pecan production followed by a year of low or no pecan production (Nesbitt et al., 2013; Skaggs et al., 2008; Sparks, 2005).
As of 2016, the United States had become the “world’s largest pecan-producing country” (Thomas et al., n.d.) and as of 2020, the United States ranked as the “second largest producer of tree nuts worldwide (Asci & Devados, 2021). In the United States, consumption of pecans is rising with the advent of educational campaigns highlighting research which confirms the health benefits of pecans (Nesbitt et al., 2013). Pecans contain many helpful vitamins, contain high amounts of antioxidants, and pecans have been proven to help correct blood cholesterol levels (Nesbitt et al., 2013).

In New Mexico, all pecan nut production is from improved varieties rather than native varieties (Skaggs et al., 2008). Pecans are becoming a major agricultural crop in many states with major pecan production occurring in Georgia, New Mexico, Texas, Arizona (Skaggs et al., 2008; Asci & Devados, 2021; USDA, 2020a), and Oklahoma (Asci & Devados, 2021; USDA, 2020a). Learning how to work with New Mexico’s “unique southwestern soil and climate conditions” has enabled growers to achieve “high pecan yields and quality” (Thomas et al., n.d.). As of 2019, New Mexico produced 36.3% of the nation’s pecans, Georgia ranked second with 28.0% of the nation’s pecan production, and Arizona ranked third at 15.9% of national pecan production (USDA-NASS, 2020a).

Pecans are often grown in arid or ‘water scarce’ regions (Ibraimo et al., 2016; Wang et al., 2007) as these more arid regions offer some benefits. One benefit, Ibraimo et al. (2016) point out, is the reduced occurrence of pecan scab in arid climates (Ibraimo et al., 2016). Further, fungal diseases are of very little concern in dry climates (Thompson & Conner, 2012). Also, in dry climates, there is enough heat for a crop to mature fully (Ibraimo et al., 2016).

Pecans are a growing major agricultural crop throughout New Mexico. The Elephant Butte Irrigation District (EBID) in New Mexico has over 11,000 hectare or approximately 27,180 acres of pecans which use one-third of annual water diversions in the area (Skaggs et al., 2008). New Mexico’s pecan production previously has been limited to the southern areas of the state. This is because “desirable commercial varieties require a longer growing season” (Herrera, September 2005). The southern part of the state has historically had more favorable growing conditions for pecans.

**Pecan Climatic Requirements**

This section discusses the climactic requirements of pecan trees. This information is important for Valencia County pecan farmers in order to assess the viability of various varieties of pecan trees for use in the county.

- Pecans require between 171-233 frost-free days for the nuts to reach maturity, depending on the variety of pecan tree.
- Early fall freezes as well as late spring frosts can be damaging to pecan trees.
- However, pecan trees need a sufficient amount of “chill” in the winter to produce well the next season.

Pecan production is limited to southern states because pecan trees, depending on the variety, require between 205-233 frost-free days in order for the nuts to reach maturity (Thomas et al., n.d.), except a few varieties require just 171-189 frost-free days (Herrera, 2005, September). Pecan crops are sensitive to early fall freezes and late spring frosts which can cause damage (Nesbitt et al., 2013). Researchers at Texas A&M caution that freezing weather can damage young pecan trees. They recommend avoiding planting young pecan trees in “frost pockets” (or areas of low-lying topography), where there is an increased potential to injury from the cold (Nesbitt et al., 2013). While more mature trees have thick bark making it much less likely for frost damage to occur to the tree, fall freezes can injure maturing nuts (Nesbitt et al., 2013). Texas A&M researchers recommended planting early-harvest varieties where a shorter growing season and early fall freezes are an issue (Nesbitt et al., 2013). Researchers at NMSU observe that the “selection of early-maturing varieties is of major importance because nuts of many varieties, even in southern New Mexico, fail to mature properly in some years because of short growing seasons” (Herrera, 2005, September). Thompson & Conner (2012) comment that even southeastern New Mexico has an issue with shorter growing season and assert, “early
freezes can be a problem” (Thompson & Conner, 2012). The high light intensity in New Mexico tends to help offset the shorter growing season (Herrera, 2005, September). With New Mexico’s warm temperatures and low mean relative humidity, pollination can require more “special attention” (Herrera, 2005, September). Researchers at NMSU recommend planting more than one variety of pecan tree in orchards to “help ensure adequate fruit set and nut production” (Herrera, 2005, September).

It is interesting to note that an adequate amount of cold is also necessary for healthy and productive pecan orchards. Ibraimo et al. (2016) observed, “Bud break uniformity...depends solely on the accumulation of sufficient chill in winter”. They report “accelerated canopy development” in localities that have experienced an adequately “chilling” winter (Ibraimo et al., 2016). The implications of this need for a sufficient amount of chill in the winter while localities are experiencing the effects of climate change are that as temperatures continue to rise globally, places where pecan trees used to thrive may become too warm for the trees to flourish. A local newspaper noted that pecan growers in New Mexico are expanding northward and eastward with pecans being grown “as far north as Belen or Capitan” (Hedden, 2019, October 15).

For Las Cruces, New Mexico, for pecan trees in the early pollen shedding group (e.g., Mesilla, Peruque, San Saba Improved, and Western) the period of pollen shedding begins in late April and lasts until the first week or two of May while pollen receptivity begins around May 5th and lasts until May 10th-13th (dates of average flowering characteristics are from 1962-1964) (Herrera, 2005, September). The late pollen shedding group (e.g., Ideal (Bradley), Burkett, Rincon, and Wichita) begin their period of pollen shedding around May 4th or 5th and last through May 10th-15th and the period of pollen receptivity begins in late April and lasts anywhere from May 5th to May 10th, depending on the variety (Herrera, 2005, September). This offset makes it important to choose a couple of types of varieties to make sure some trees are receptive to pollen while others are shedding pollen. The average number of days from flowering to harvest in Las Cruces, New Mexico between 1960-1964 of select pecan varieties ranged from 171 days at the least (Peruque) to 189 days at the most (Western) (Herrera, 2005, September). The length of the growing season in the area dictates which trees may be successfully grown.

Over the years, Valencia County pecan farmers have found that orchard management strategies that work in southeastern New Mexico, Texas, or Georgia don’t always work in Valencia County (Adams, 2019, September 23). Pecan farmers have learned various adaptations
for Valencia County like “when to turn the sprinklers on to protect the trees from freezes”, helping to extend the growing season (Adams, 2019, September 23).

**Pecan Types**

This section examines pecan varieties used in North Texas, southern New Mexico, and those varieties used in Valencia County, as well as varieties that might be viable for use in Valencia County. This information can help pecan farmers decide which pecan tree varieties in which to invest in the county.

- Early maturing pecan trees should be chosen due to the potential of damage from early freezes in more central and northern areas like Valencia County.
- Pecan tree varieties found to die or be damaged in late or early freezes in Valencia County: Ideal/Bradley.
- Pecan tree varieties found to pollinate too late in Valencia County: Lakota.
- Pecan tree varieties that may be successful in Valencia County include: Western Schley or Western, Kanza, Wichita, Sullivan, Pawnee, Colby, Giles, Major, Peruque, or Posey.

Since not much data exists for pecan growing in central and northern New Mexico regions, we can look at North Texas data for comparison. Researchers at Texas A&M found that in North Texas the growing season is shorter than at other more southern locations; thus, early maturing pecan trees should be chosen so that nuts are not damaged by early fall freezes (Nesbitt et al., 2013; Herrera, 2005, September). Types of pecan trees grown in North Texas include: Caddo, Lipan (a relatively new variety being tested with trial plantings), Mandan (another relatively new variety being tested with trial plantings), Osage, Pawnee, Kanza, and Lakota (Nesbitt et al., 2013).

While there are many pecan varieties grown in New Mexico, researchers at NMSU concluded that important commercial varieties for New Mexico include ‘Western Schley’ (‘Western’), ‘Wichita’, and ‘Ideal’ (‘Bradley’) (Herrera, 2005, September). Cold hardy varieties tried in Valencia County include ‘Pawnee’, ‘Lakota’, ‘Western Schley’, ‘Bradley’, and ‘Kanza’ which is a newer variety (Adams, 2019, September 23). Early freezes as well as late freezes complicate growing in Valencia County. A local farmer has found issues with trees dying in late or early freezes (like the ‘Ideal’/‘Bradley’) or issues with trees pollinating too late (like the ‘Lakota’) (Adams, 2019, September 23). The Valencia County farmer is hoping that the
newer Kanza and the Western Schley will be able to live, “pollinate at the proper time”, and thrive in Valencia County (Adams, 2019, September 23).

**Possible Varieties for Valencia County**

The ‘Western Schley’ or ‘Western’ is appealing for growing in Valencia County because it is a vigorous tree that starts bearing at an early age and is less affected by heat stress or water stress than other pecan trees (Herrera, 2005, September; Thompson & Conner, 2012). The average number of days from flowering to harvest was determined to be 189 days (Herrera, 2005, September). The ‘Western Schley’ has relatively late maturing nuts but is able to produce relatively high yields (Thompson & Conner, 2012). One Valencia County farmer feels this will be a successful variety in Valencia County and has planted a number of this type of pecan tree (Adams, 2019, September 23). This farmer is also trying the newer ‘Kanza’ for which there is limited data currently for New Mexico.

The ‘Wichita’ is attractive to growers because it matures early in the fall (about a week before the ‘Western Schley’), the variety begins bearing at an early age, and is quite productive and capable of producing high yields (Herrera, 2005, September; Thomas & Conner, 2012). However, the ‘Wichita’ is more susceptible to moisture stress than the ‘Western Schley’ (Herrera, 2005, September; Byford, 2005; Thompson & Conner, 2012) and ‘Wichita’ pecan trees become dormant later in the season than some other varieties, making low fall temperatures a concern especially in young trees (Herrera, 2005, September). Low fall temperatures could be an issue in Valencia County.

Another option for Valencia County is the ‘Sullivan’, a variety released by NMSU in 1983, that averages 175 days from flowering to harvest (Herrera, 2005, September). Herrera (2005, September) notes that the ‘Sullivan’ could be successful in northern New Mexico due to its shorter growing season, making it a good candidate for Valencia County. Additionally, the ‘Pawnee’ matures quite early and is very tolerant to winter freezes (Herrera, 2005, September) making it a good option for Valencia County. Further, varieties that are grown predominantly in northern states may find success in northern parts of New Mexico (like the ‘Colby’, ‘Giles’, ‘Major’, ‘Peruque’, or ‘Posey’) (Herrera, 2005, September). The ‘Peruque’ is appealing because the average days from flowering to harvest are 171 days, making it one of the fastest maturing pecan varieties suitable for the area (Herrera, 2005, September).
Water Requirements & Estimating ET

This section provides an overview of the data provided from studies performed on water requirements and estimated ET (see Appendix C for a more detailed literature review). The key points to note are:

- Pecans have a high water requirement and soil moisture needs to be adequate for trees to thrive.
- Pecan orchards’ consumptive water use is high compared to other crops. Irrigation is necessary in Valencia County to meet pecan orchards’ water needs.
  - Pecan ET, which we can equate to the trees’ consumptive use, is 0.9 AF to 4.9 AF per acre per year.
  - The irrigation requirement (or amount of water to be diverted for irrigation) for pecan orchards is 4.3 AF to 8.2 AF per acre per year.
  - ET and irrigation requirements of pecan trees are highly variable depending on several factors including soil type, stage of nut and/or foliage development, age of tree, and irrigation and management practices.
- Nut size and kernel development are dependent on sufficient irrigation and soil moisture.
- Pecan orchards consume more water in June and July when temperatures are high, foliage is fully developed, and nuts are growing.
- Acreage with pecan orchards cannot be fallowed like many other crops; insufficient water one year can have effects that last multiple years. Pecan orchards require adequate water every year.

Numerous studies have documented the high consumptive water requirement of pecan trees (Andales et al., 2006; Ibraimo et al., 2016; Kallestad et al., 2006; Miyamoto, 1983; Samani et al., 2011; Sammis et al., 2004) including the “large quantities of soil moisture” needed in order to thrive (Kallestad et al., 2006; Sparks, 2002; Wolstenholme, 1979). In pecan trees, the nut size as well as kernel development are especially tied to the available soil moisture (Herrera & Sammis, 2002; Skagggs et al., 2008; Sparks, n.d.). Canopy development is also tied to available water (Samani et al., 2011).

Pecan trees have often been referred to as a ‘thirsty tree’ (Skagggs et al., 2008) with large amounts of water being consumed by mature trees (Ibraimo et al., 2016). Researchers at Texas
A&M concluded that while orchards receiving less than 2.9 feet (88.9 cm) of rainfall a year have fewer disease issues, at least 4.6 feet (139.7 cm) of rainfall per acre per year are required for pecan orchards to have “good tree growth and crop production” (Nesbitt et al., 2013). Sammis et al. (2004) concluded pecan diversionary and consumptive water use is high when compared to other irrigated crops (see also Kallestad et al., 2006; Miyamoto, 1983), resulting in pecan orchards requiring “more irrigation water to maximize yield than any other crop grown in the Southwest US” (Sammis et al., 2004). Irrigation is a significant factor affecting the pecan yield produced (Kallestad et al., 2006; see also Garrot et al., 1993). This high water requirement of pecan trees necessitates irrigation systems to supply the deficit in the Southwest, and Valencia County is no exception.

The annual ET in pecan orchards ranges from 0.9 to 4.9 AF per acre per year (27.5 to 147.9 cm per acre per year) depending on the age of the tree, the tree’s canopy, tree spacing, ground cover surrounding the tree, stage of nut development and/or foliage development, soil type, and irrigation and management practices (Miyamoto, 1983; Worthington et al., 1987; Miyamoto, 1995; Sorenson, 1997; Frias-Ramirez, 2002; Sammis et al., 2004; Reveles, 2005; Skaggs et al., 2008; Samani et al., 2011; Ahadi et al., 2013; Ibraimo, 2016). This is the orchard’s consumptive pecan tree use. The irrigation requirement for pecan orchards was found to be 131 to 250 cm annually per acre or 4.3 to 8.2 AF per acre per year in southern New Mexico (Miyamoto, 1983; Sammis et al., 2004, Kallestad et al., 2006). The irrigation requirement could be equated to the amount of water that would need to be diverted. During the peak water use for the season, the irrigation amount for a mature orchard was calculated by Miyamoto (1995) as high as 13,000 gallons per acre per day or 0.04 AF per day (Miyamoto, 1995). The irrigation amount increases during certain times of the growing season and during times of higher than usual temperatures or droughts. Pecan orchards cannot be fallowed, unlike many other crops commonly grown in Valencia County. Because pecan orchards need ample water every year and regularly to prevent the tree from becoming unhealthy, less productive, or from dying, the amount of water given pecan orchards cannot be decreased during times of drought without severe consequence but must remain consistent with the needs of the tree (Goldhamer, 2003, September 9; Herrera & Sammis, 2002). A pecan orchard’s water needs can vary significantly throughout the growing season since in a well-managed orchard, “pecan trees may have more than one cycle of shoot growth in a single season” (Ibraimo et al., 2016). Researchers note the
importance of “maintaining non-moisture stress conditions” in pecan orchards, not only throughout the season, but particularly in August and September during the “nut-filling stage” in an attempt to “maximize yield, quality and economic return” (Sammis et al., 2004). In fact, Sammis et al. (2004) observe, “WUE [water use efficiency] and nut quality decrease when trees are water stressed during the nut-filling stage” (see also Herrera, 2001). Conversely, alfalfa is very drought and heat tolerant. If alfalfa is not given enough water, the yield and quality may be affected, or the plant may go dormant until adequate water is restored (Fleck, 2016).

Additionally, alfalfa fields can be fallowed during times of drought without affecting the productivity of the crop during the next growing season. However, pecan orchards can be severely affected when moisture is not adequate even causing “permanent wilting” of the tree (Herrera & Sammis, 2002).

See Appendix B for commonly used terms in agricultural irrigation. One commonly used term is “consumptive water use”. The consumptive water use of a pecan orchard can be defined as the loss of water through evapotranspiration (ET) (Miyamoto et al., 1995). Consumptive use can be considered “the basis for estimating irrigation water needs” as well as scheduling irrigation (Miyamoto et al., 1995). When developing and operating an irrigation system for a pecan orchard, maximizing “irrigation application efficiency” (IAE or AE) is the goal (Sammis et al., 2004). This paper will later examine previous research done in an attempt to quantify the consumptive use of pecans in New Mexico (or sometimes nearby Texas) or their evapotranspiration (ET) (see Appendix C). AE is discussed below.

Irrigation is prevalent in the western United States where more than 90% of the water is consumed by irrigated agriculture (Skaggs et al., 2008). Pecans trees account for one-third of the EBID’s irrigated farmland (Skaggs et al., 2008) and by 2010 accounted for 46% of irrigation water in the LRGV of New Mexico (Skaggs et al., 2008). Researchers at Texas A&M and New Mexico State University assert that pecan orchards “consume one-third of the annual diversions” in the EBID (Skaggs et al., 2008). Further, in the EBID, pecan trees account for a “large portion of the regions consumptive use of limited ground[water]” supplies (Skaggs et al., 2008).

During the hottest times of the growing season, pecan orchards consume more water. During June and July when temperatures are higher, foliage is well developed, and the tree is growing pecan nuts, the water consumption is much more than at the start of the growing season (Herrera & Sammis, 2002). Researchers at Texas A&M concluded that flood irrigated mature
pecan trees require one or two inches of water per acre per week be applied to the orchard (Nesbitt et al., 2013). If well water is used, they further determined that the well must be able to produce 10 gallons of water per minute per acre of pecan trees (Nesbitt et al., 2013). Herrera and Sammis (2002) note that “watering pecan trees should entail more than just applying water to orchards every 14 to 21 days”. In a pecan orchard, the goal is to use or consume water in an efficient manner while meeting the needs of the trees and reducing deep percolation as well as reducing runoff and potential pollution (Herrera & Sammis, 2002). Knowing how often to appropriately apply water is more complex than just the number of days since the last watering, but also the soil type and the soil’s ability to hold water are important (Herrera & Sammis, 2002).

Much of the EBID is irrigated using deficit irrigation practices (irrigating a crop below its full water requirement or its ET) (Fereres & Soriano, 2007), using traditional basin or basin-furrow methods (in which there is no runoff from the end of the field), and “on-farm efficiency” (the crop’s consumptive use relative to the farm’s water delivery) or AE is often quite high. Deficit irrigation practices, although allowing the crop to become somewhat water stressed, increases AE’s (Fereres & Soriano, 2007). Al-Jamal et al. (1997) found on-farm efficiencies that ranged from 70-76% for fields of chile peppers, while onions’ on-farm efficiencies were higher at around 80%, and alfalfa’s on-farm efficiency was around 97% (Skaggs, et al., 2008). Deras (1999) found on-farm efficiencies for pecans to range from 79-98% while alfalfa’s on-farm efficiencies ranged from 87-98%, cotton 88-87%, corn 89-97%, and for chile peppers it was found to range from 83-94% (Skaggs et al., 2008). Samani and Al-Kattheeri (2001) found on-farm efficiencies or AE for basin and basin-furrow irrigation methods to be as high as 95% for pecans (Skaggs et al., 2008).

Al-Jamal et al. (2001) describes on-farm application efficiencies or AE for flood-irrigated pecan orchards in the Las Cruces Mesilla valley as high as 89% (Al-Jamal et al., 2001; Sammis et al., 2004; Kallestad et al., 2006). The on-farm application efficiencies or AE for other crops using flood irrigation ranged from 50-73% (Sammis et al., 2004; Oster et al., 1986; Chimonides, 1995; Zalidis et al., 1997).

**Economics**

This section discusses the economic considerations of pecan orchards including pecan production, pecan farm size and cost considerations, the costs of establishing a pecan orchard, annual operating expenses, and the benefits, returns, and market considerations of pecans. This
section also discusses the price elasticity of pecans, government subsidies and tax exemptions, as well as an outline of the agricultural economics of Valencia County. These topics are all important to understanding the economics of pecan farming, particularly in Valencia County.

**Pecan Production**

This section discusses trends in pecan production. Of note:

- Nut production in the United States is increasing, in part due to the export market.
- Pecan production in the United States is also increasing, in part due to the export market.
- The value of production of pecans is increasing in the United States.
- Traditionally grown crops are being replaced, in the United States, often by nut orchards.

Pecans have been being promoted as “nutritious and healthy snacks by government programs, marketing boards, and trade associations” (Asci & Devados, 2021). Overall, nut production is increasing, in part because of the export market (Asci & Devados, 2021). As a result of the export market, pecan production has increased as well. However, the domestic utilization and consumption of pecans has remained largely the same since the per capita utilization of pecans in the United States has remained around 0.5 pounds with only a slight increase (Asci & Devados, 2021; USDA, 2020a). This is illustrated in the graphs below created with data from Asci and Devados (2021) and the USDA (2020a). Figure 8, below, shows the value of pecan production in the United States between 1987-2017, in thousands of dollars, adjusted for inflation into constant 2019 dollars. The value of pecan production, shown in yellow, can be seen increasing. It is interesting to note that since the year 2000, pecan exports have exceeded pecan imports to the United States (Asci & Devados, 2021; USDA 2020a).
Figure 8: Value of Pecan Production in the United States, 1987-2017, adjusted into constant 2019 dollars. (Data Source: Asci & Devados, 2021; USDA, 2020a).

Data Source: Asci & Devados (2021); USDA (2020a), adjusted for inflation into constant 2019 dollars.

Figure 9, below, shows the utilized production of pecans in the United States between 1980-2020. Pecan production is shown in yellow and is increasing between the years 1980-2020.
Figure 9: Utilized Production of Pecans in the United States, 1980-2020. (Data Source: Asci & Devados, 2021; USDA 2020a).

Data Source: Asci & Devados (2021); USDA (2020a)

Figure 10, below, shows the per capita use of major tree nuts in the United States between 1980-2020. Again, pecans are shown in yellow, and the per capita utilization of pecans is variable with a slight increase between 1980-2020.
There is some evidence to suggest that with the growth of domestic and international consumer demand for tree nuts produced in the United States, traditionally grown crops are being replaced in the United States with nut orchards (Asci & Devados, 2021; Goldhamer & Fereres, 2017). Although tree nuts have many nutritional benefits, increased tree nut production has been a contentious issue due to the “consumptive use of water in production” of tree nuts (Asci & Devados, 2021; Fulton et al., 2019).

**Pecan Farm Size and Cost Considerations**

This section discusses some of the costs associated with pecan orchards, and the reported farm sizes that avoid higher equipment costs per acre. This information is important for farmers in Valencia County to minimize their expenses while maximizing their profits.

- Pecan and other tree nut farming is labor intensive and requires numerous pieces of equipment such as tractors, shakers, harvesters, and other equipment.
- Researchers at Texas A&M determined pecan orchards should be at least 50 acres in size to avoid increased equipment costs per acre.
A Valencia County farmer stated they felt a pecan orchard must be at least 400 acres in size to justify the investment.

The Census of Agriculture includes orchards of 20 or greater trees (USDA-NASS, 2009). However, when considering what size pecan orchard to start, factors to consider include water availability, quality and cost, cash flow, and equipment costs (Nesbitt et al., 2013). The researchers at Texas A&M note that “hobby orchards” of one or two acres, could be harvested by hand, potentially. However, larger-sized pecan orchards will need equipment such as “tractors, shakers, harvesters, and air-blast tree sprayers” (Nesbitt et al., 2013). Even though most pecan orchards of size are mechanically harvested, researchers note, “tree nut farming is still considered a labor-intensive endeavor” (Asci & Devados, 2021; Martin, 2018). The researchers point out that the commercial equipment costs the same whether the equipment is being used for 10 acres of pecan trees or 200 acres of pecan trees (Nesbitt et al., 2013); consequently, in order to avoid higher equipment costs per acre the researchers at Texas A&M concluded that pecan orchards should be of at least 50 acres (Nesbitt et al., 2013).

Researchers at Texas A&M have determined that pecan orchards of less than 50 acres have “increased per acre equipment costs” (Nesbitt et al., 2013). If a pecan orchard is too large or too small, it may not be as successful or as profitable. There are fixed costs which must be recaptured, as well as the costs to establish the orchard (Nesbitt et al., 2013). Additionally, trees will need to be watered for years before the orchard will become profitable (CACL, 2012). Nesbitt et al. (2013) noted that pecan orchards can be financially rewarding “when market prices are favorable and crop failures are avoided”.

A Valencia County farmer noted, “there is a lot of equipment to invest in for pecans and you need at least 400 acres to justify all of the equipment purchases” including the equipment mentioned previously like shakers, as well as transfer trailers in which to ship the pecans (Adams, 2019, September 23). This pecan farmer feels that 400 acres is necessary to justify the cost of the investment.

**Costs of Establishment**

This section discusses some of the costs associated with establishment of a pecan orchard including the time it takes to break even on the investment. The upfront costs for a pecan orchard are quite high. This information is important so that farmers in Valencia County can make educated decisions when considering pecan farming.
- Levelled farmland with water rights, in 2019, was $20,000-25,000 per acre in New Mexico, depending on the seniority of the water right, and not accounting for the indirect costs.

- The average investment for starting a pecan orchard is $14,070 per acre in constant 2019 dollars.

- Pecan trees require an average of 10 years until maturity; 10 years to break even on the investment, but 10-12 years until the pecan orchard is profitable.

Pecan orchards have been described as being a long-lasting, but expensive investment (Herrera, 2005, September). Pecan orchards have significant upfront costs (Hwang & Bin, 2019; Nesbitt et al., 2013) including costs for the land, the water delivery system, possibly a well, equipment, and other needs such as fencing to keep the wildlife out (Nesbitt et al., 2013). The cost, in 2019, of a piece of levelled farmland with water rights in New Mexico was $20,000-25,000 per acre, depending on the seniority of the water right, besides other costs (including equipment depreciation) (Adams, 2019, September 23).

Pecan trees’ average time to maturity is 10 years (Hwang & Bin, 2019). Pecan trees produce very little for at least the first seven to 10 years making it important to have the cash flow to pay for the upfront costs and other costs until the pecan orchard becomes fully established and begins bearing enough nuts (Nesbitt et al., 2013; see also Adams, 2019, September 23). Further, Hwang and Bin (2019) note in their study that “due to the relatively high upfront costs of producing pecans, farmers may reduce their water use for other crops in favor of pecan orchards” during times of drought, noting this “has the effect of increasing the overall cost of pecan production.”

A Valencia County pecan orchard owner asserts, “on average it takes until year 10 for a pecan stand to break even and you begin to make money after year 12” (Adams, 2019, September 23). Further they claim, “Pecans really start producing in their seventh year and reach full production in year 12” (Adams, 2019, September 23). The president of the New Mexico Pecan Growers similarly stated, “Pecan trees take about 10 years to produce, and 12 years to turn a decent profit” (Hedden, 2019, October 15). Table 1 (CACL, 2012), reproduced below, lists several crops including pecans and the investment dollars per acre and lead-time until the venture produces income, as well as other notes. All dollar values in the Table 1, below, were adjusted for inflation into constant 2019 dollars. Table 1, below, calculates that the investment in pecans is
approximately $14,070 per acre, adjusted for inflation into constant 2019 dollars. It takes 7 years before there is an ‘acceptable yield’ with maximum production occurring by years 10-12 with a maximum production of around 2000 pounds of nuts per acre. Pecans are considered profitable from year 10 and the table states that the operator can expect to break even at year 15 (CACL, 2012). It should be noted that these calculations include water costs yearly for a pecan orchard of $1.77 per acre in constant 2019 dollars (CACL, 2012).

Table 1: Crops, Investment (dollars per acre), Lead Time until Income-Producing (years) and other notes about pecans and several other crop, adjusted for inflation into constant 2019 dollars (Reproduced from CACL, 2012, as adjusted for inflation into constant 2019 dollars).

<table>
<thead>
<tr>
<th>Crop</th>
<th>Investment, $/Acre</th>
<th>Lead Time until Income-producing, Years</th>
<th>Comments</th>
</tr>
</thead>
<tbody>
<tr>
<td>Pecans</td>
<td>14,070</td>
<td>7-12</td>
<td>Initial investment = cumulative losses from years 1 to 7 assuming a nut price of $2.05/lb. (there is some yield from year 3). Acceptable yield from year 7, maximum production by years 10-12, around 2,000 lbs./acre/year. Profitable from year 10. Break even at year 15. Flood irrigated.</td>
</tr>
<tr>
<td>Chile</td>
<td>1,055-1,175</td>
<td>1</td>
<td>Costs for one year prior to harvesting.</td>
</tr>
<tr>
<td>Onions</td>
<td>1,640-2,345</td>
<td>1</td>
<td>Costs for one year prior to harvesting.</td>
</tr>
<tr>
<td>Wine Grapes</td>
<td>14,065-17,590</td>
<td>3-5</td>
<td>8,205-14,070/acre initial set up, but some costs allowed until year 3 before the first suitable grapes are produced.</td>
</tr>
<tr>
<td>Wine</td>
<td>12,895-15,245</td>
<td>1-5 in addition to vineyard lead time as above</td>
<td>Lead time depends on the type of wine produced. Some wines are ready to sell year 1 but good reds need 3-5 years to produce. Break even 10 years.</td>
</tr>
<tr>
<td>Lavender Oil</td>
<td>5,860-9,380</td>
<td>2-3</td>
<td>Full production from year 3, plant life approx. 10 years. Assumes 50+ acre farms.</td>
</tr>
</tbody>
</table>

All dollar values in table are adjusted for inflation into constant 2019 dollars.

Source: CACL (2012), adjusted into constant 2019 dollars.
Annual Operating Expenses

This section discusses the annual operating expenses of pecan orchards as well as the cost of deficit irrigation. It is important for Valencia County pecan farmers to understand the annual costs involved and the potential yield costs of insufficient water.

- Producing pecan orchards’ annual operating expenses are approximately $660-$680 per acre, in constant 2019 dollars.
- Water costs can include pumping costs of groundwater when surface water supplies are low.
- The practice of deficit irrigation has a cost in terms of the yield of pecans produced. In 2002, the yield cost of deficit irrigation resulted in a pecan crop that could have been over 36% larger if adequate irrigation water was applied. The value of lost production was approximately $20 million for the year 2002 (adjusted for inflation into constant 2019 dollars) as a result of deficit irrigation.

Researchers at Texas A&M found that a producing orchard has annual operating expenses of about $660-$680 per acre, adjusted into constant 2019 dollars (Nesbitt et al., 2013). Most farmers in the areas examined primarily rely on surface water for orchard irrigation. When surface water supplies are low, farmers turn to groundwater to supplement the surface water for irrigation. Generally, the pumping costs associated with groundwater being used for agricultural irrigation increase the costs of groundwater use over surface water use (Hwang & Bin, 2019).

Skaggs et al. (2008) estimated the “cost” of deficit irrigation in terms of the pecan trees’ total yield and found the “yield cost” of the 228 orchards analyzed as a result of deficit irrigation was 5931 metric tons (Skaggs et al., 2008). Relative to the year’s pecan production, Skaggs et al. (2008) report that “the state’s pecan crop would have been more than 36% larger if the yield potential had been reached” that year (2002) (Skaggs et al., 2008). The value of lost production due to deficit irrigation was approximately $20 million, adjusted for inflation into constant 2019 dollars, for the year 2002 (Skaggs et al., 2008).

Benefits, Returns, & Market Considerations

This section discusses the financial benefits and returns of pecan orchards as well as market considerations. It is important for Valencia County pecan farmers and other interested parties to understand the benefits associated with pecans as well as the variability in the pecan market.
• Well-managed pecan orchards on good sites can produce 1,000 to 2,000 pounds of pecans per acre per year.

• Pecan market prices typically decline from October to January, as the season progresses.
  o New Mexico harvests later than the southeastern U.S. pecan growers making it important for New Mexico growers to maximize production.

• Moisture levels impact cash receipts from pecans.
  o Gains on cash receipts from moderate to extreme wet conditions are estimated to be as high as +16% equating to approximately +$13.8 million (adjusted for inflation into constant 2019 dollars) during ‘wet’ conditions.
  o Losses on cash receipts from moderate to severe drought conditions are estimated to be as high as -30% equating to approximately -$65.5 million (adjusted for inflation into constant 2019 dollars) during ‘dry’ or ‘drought’ conditions.

• Pecan production decreases in New Mexico under conditions of moderate to extreme drought.

• Farmers are often willing to accept water costs that are higher – during times of water shortage – in order to maintain the health of the pecan trees.

• In Valencia County, pecans average a profit of $3,750 per acre up to $5,000 per acre, in constant 2019 dollars.

• Pecans’ annual gross revenue in New Mexico, in constant 2019 dollars, is $1,172 per AF of irrigation water consumed.

• The gross value of irrigated crop production of pecans per volume of irrigation water consumed is $1,128 per AF of irrigation water consumed while alfalfa’s is just $244 per AF of irrigation water consumed, in constant 2019 dollars.

• Pecan orchards can expect a net operating loss through year 9 with very minimal profits in year 10. Pecan orchards can expect years 11-20 to have a net operating profit of between approximately $2,500 per acre to $3,020 per acre (adjusted for inflation into constant 2019 dollars) with a yield of 2,000 pounds per acre expected.

Researchers at Texas A&M assert that “well-managed orchards” located on good sites are able to produce from 1,000 to 2,000 pounds of pecans per acre per year (Nesbitt et al., 2013).
Asci & Devados (2021) observe, “pecans have also shown noticeable growth in both crop values and utilized production quantities since 2000”. However, pecan harvesting can mean a rush to get the pecans to market quickly. Nesbitt et al. (2013) note, “Pecan market prices traditionally become more volatile and may decline as the season progresses from October to January” which makes it advisable to harvest the pecans quickly and get the crop to market early in the season. Because harvesting in New Mexico occurs “later than that of the southeast, cultivators must be able to maximize production to make up for the lower prices received” (Thompson & Conner, 2012).

Hwang and Bin (2019) estimated “effects of changes in climatic conditions on local pecan production, price, and cash receipts in New Mexico” between the period of 1964 to 2014. The study uses a model that “builds on the existing framework for estimating the effects of changes in climactic conditions on agricultural output” including the effects on cash receipts and effects on crop demand (Hwang & Bin, 2019). The study used a local crop demand model with a local crop supply model to “obtain the effects on demand and supply jointly and derive the impact on cash receipts” (Hwang & Bin, 2019). Hwang and Bin (2019) further used the Palmer Drought Severity Index (PDSI) as well as the 24-month Standardized Precipitation Index (SPI24) to supply the climactic information. The study models local supply, local demand, and market demand in a “joint a system of equations using variables for local price, market price, and local production” (Hwang & Bin, 2019). Local production is included to “capture the effects from changes in climactic conditions” (Hwang & Bin, 2019). Additionally, market price was included as a factor to “capture the competitive market structure of pecans” (Hwang & Bin, 2019).

The study’s findings were consistent with previously performed studies in that the effects of “moisture deficits” were found to be more significant and “pronounced” as compared to periods with higher moisture level conditions (Hwang & Bin, 2019). The study notes, “the gains from moderate to extreme wet conditions on cash receipts are estimated to be as high as +16% while the losses from moderate to severe droughts are as much as -30%” (Hwang & Bin, 2019). By applying the estimates to the cash receipts during years when New Mexico was experiencing a wet spell and a drought, respectively, this translated into values of the estimated effects, respectively, of +$13.8 million (adjusted for inflation to constant 2019 dollars) and -$65.5 million (adjusted for inflation in constant 2019 dollars) (Hwang & Bin, 2019). The study observes, “previous studies have found measures of meteorological or climatological events to
be useful predictors of crop yields” (Hwang & Bin, 2019; see also Offutt et al., 1987; Black & Thompson, 1978). Researchers have found it helpful to include variables that measure climatic conditions in order to improve the accuracy of models of agricultural output (Hwang & Bin, 2019; see also Dixon et al., 1994; Sparks, 1996, 1997; Mendelsohn & De Dhar, 2003).

The analysis performed in this study showed a “near one-to-one relationship” between the price of pecans in New Mexico and the price of pecans of the U.S. as a whole. The study notes that “the link between “NM” price and “NM” production is less pronounced, which is indicative of pecans being traded in a competitive market setting” (Hwang & Bin, 2019). The study concludes from this, “cash receipts would generally increase or decrease as production increases or decreases” (Hwang & Bin, 2019). New Mexico’s cash receipts for pecans are tied directly to pecan production. The study, additionally, found that “production may not always increase” during years with wet conditions, or if it does increases, the increase will be rather small (Hwang & Bin, 2019). However, the results show that production decreases under “moderate-to-extreme drought conditions” (Hwang & Bin, 2019).

Hwang & Bin (2019) estimated the percent change in cash receipts, price, and local production in both a year with “very wet” conditions (1992) and a year when New Mexico was experiencing severe drought conditions (2013) using data from monthly values of the Palmer Hydrologic Drought Index (PHDI) and of the 24-month Standardized Precipitation Index (SPI24) (Hwang & Bin, 2019). The study reports that “estimates for PHDI show that moderate-to-extreme wet conditions may increase the production [of pecans] by 17%, decrease the price by 0.73%, and increase the cash receipts by 16%” as compared to conditions that are normal-to-mild (Hwang & Bin, 2019). In times of “moderate-to extreme drought”, the study notes, “the PHDI model shows production may decrease by 26%, price may increase by 1.4%, and cash receipts may decrease by 25%”. However, when SPI24 values are examined for “moderate-to-extreme wet conditions”, the production, price, and cash receipts do not show as significant a change with a potential production increase of 14%, price decrease of 0.61%, and cash receipts may increase by 13.6% (Hwang & Bin, 2019). Yet, during times of moderate-to-extreme droughts, the SPI24 model indicates that “production may decrease by 31%, price may increase by 1.7%, and cash receipts may decrease by 30%” when compared to conditions that are normal-to-mild (Hwang & Bin, 2019).
The study concludes that given the importance of the implications of extended periods of
droughts or, alternatively, “very wet” years, accurate impact assessments are important for the
agricultural industry and local water authorities as well as government agencies in order to
develop useful strategies for arid regions where water resources are becoming scarcer (Hwang &
Bin, 2019). The study asserts, “Farmers often choose to incur higher water costs to maintain the
health of pecan orchards during water shortages” since the detrimental effects of pecan orchards
becoming water stressed may last for many years (Hwang & Bin, 2019). Being able to better predict farmers’ behavior during droughts, as well as the ideal behavior, can help make future
economic models of pecan production more accurate and useful.

A pecan orchard owner in Valencia County observed, “pecans average a $3750/acre net
when reaching full maturity and production” but continues stating pecans “can net up to
$5000/acre” (Adams, 2019, September 23). The farmer contrasted this with alfalfa which
generates a profit of approximately $200-300/acre with both types of farms having a high cost in
equipment depreciation (Adams, 2019, September 23). The pecan farmer asserts, “The gross
profit per acre is much higher for pecans [than for alfalfa]…as much as 11 times higher gross
profits” (Adams, 2019, September 23).

The annual gross revenue in dollars per AF of irrigation water consumed of pecans is
approximately $1,170 per AF of irrigation water consumed for the state of New Mexico (CACL,
2012). Table 2, below, reproduced from CACL (2012), shows major crops that are grown in
Catron, Grant, Hidalgo, and Luna Counties. The year shown is 2010 except where otherwise
stated. The last column is the gross value of the crop production per the volume of irrigation
water that is consumed and is given in dollars per AF adjusted into constant 2019 dollars. All
dollar values in Table 2 are adjusted into constant 2019 dollars. In Table 2, below, we can see that
alfalfa hay, the predominant crop, has a value of $244 per AF of irrigation water consumed while
pecans’ value is $1,128 per AF of irrigation water consumed, in constant 2019 dollars. This is
quite a significant difference between alfalfa’s gross value per volume of irrigation water used
and pecan’s gross value. We can see why pecans are appealing to grow with such a high gross
value of crop production given the irrigation water used.
Table 2: Major crops grown in Catron, Grant, Hidalgo, and Luna Counties (in 2010 except where otherwise stated) (Reproduced from CACL, 2012, as adjusted for inflation into constant 2019 dollars). The last column is Gross Value of Crop Production per Volume of Irrigation Water Consumed (in dollars per acre-foot). Reproduced from CACL (2012), as adjusted for inflation into constant 2019 dollars.

<table>
<thead>
<tr>
<th>Crop</th>
<th>Irrigated Harvested Acre</th>
<th>Production Amount</th>
<th>Unit of Production</th>
<th>Statewide Gross Value/Unit of Production</th>
<th>Gross Value of Crop Production ($/acre/yr.)</th>
<th>Irrigation Water Consumption (AF/yr.)</th>
<th>Gross Value of Crop Production/Volume Irrigation Water Consumed ($/AF)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Alfalfa Hay</td>
<td>7,500</td>
<td>49,000</td>
<td>Ton</td>
<td>159</td>
<td>9,134,472</td>
<td>5</td>
<td>37,500</td>
</tr>
<tr>
<td>Corn Silage</td>
<td>3,400</td>
<td>109,000</td>
<td>Ton</td>
<td>35</td>
<td>4,472,855</td>
<td>3</td>
<td>10,200</td>
</tr>
<tr>
<td>Upland Cotton</td>
<td>3,100</td>
<td>4,100,000</td>
<td>Lbs.</td>
<td>0.927</td>
<td>4,456,089</td>
<td>3</td>
<td>9,300</td>
</tr>
<tr>
<td>Pecans (2)</td>
<td>1,000</td>
<td>1,700,000</td>
<td>Lbs.</td>
<td>2.83</td>
<td>5,640,604</td>
<td>5</td>
<td>5,000</td>
</tr>
<tr>
<td>Chle</td>
<td>3,700</td>
<td>30,000</td>
<td>Ton</td>
<td>625</td>
<td>21,983,231</td>
<td>3</td>
<td>11,100</td>
</tr>
<tr>
<td>Onions (3)</td>
<td>2,600</td>
<td>1,354,000</td>
<td>Cwt.</td>
<td>27.4</td>
<td>43,497,017</td>
<td>3</td>
<td>7,800</td>
</tr>
<tr>
<td>Wine Grapes (4)</td>
<td>700</td>
<td>2,800</td>
<td>Ton</td>
<td>950</td>
<td>3,118,688</td>
<td>2</td>
<td>1,400</td>
</tr>
<tr>
<td>Wine</td>
<td>700</td>
<td>2,800</td>
<td>Ton</td>
<td>950</td>
<td>27,000,000</td>
<td>45,222</td>
<td>1,400</td>
</tr>
</tbody>
</table>

1. Based on state-wide average prices; county/county prices not available.
2. Figures are for Luna County only; acreage inferred from nut production and is based on 2007 Census.
3. Figures are for District 70 in total.
4. U.S. average $669/ton in 2010 but NM believed to be more like $1,134/ton. Yield is about 4 tons/acre. Other crops may be grown, but acreages are not disclosed.
   *For some crops there are big year/year changes, e.g., onion prices increased by 40%, potatoes by 50%, and pecans by 60% between 2009 and 2010, so all figures can only be taken as indicative.*

**Source:** CACL (2012), adjusted for inflation into constant 2019 dollars.

It is interesting to note that corn silage’s gross value of irrigated crop production per volume of irrigation water consumed is $439 per AF, as adjusted into 2019 dollars (CACL, 2012).

CACL (2012) data reports that pecan orchards can expect a net operating loss through year 9. For year 10, CACL (2012) report a farmer can expect a net operating profit of only approximately $360 (adjusted for inflation into constant 2019 dollars) based on a yield of 1,500 pounds per acre. However, years 11 through 20 show an expected net operating profit of approximately $2,500 to $3,020 per acre (adjusted for inflation into constant 2019 dollars) with an expected yield of 2,000 pounds per acre (CACL, 2012). Other sources estimate the generated profit as high as $5,000 per acre upon full maturity (Adams, 2019, September 23).

**Price Elasticity & Other Considerations**

This section discusses economic price elasticity. It is important to understand how the market responds to changes – how those changes affect the demand for pecans.

- Pecans have the lowest expenditure elasticity compared to tree nuts.
• If expenditures for tree nuts in the United States decreased overall, pecans would be the least negatively impacted of the tree nuts.

• The localities where tree nuts are grown may change for economic reasons such as:
  o Government regulations
  o Immigration policies and labor regulations.

• Export markets can be affected by trade issues and policies such as tariffs.

• The demand for tree nuts such as pecans is expected to continue growing.

In economic considerations, price “elasticity” is of importance. In general terms, elasticity is the ratio of the percentage change in a dependent variable over an independent variable, which is a unit-less measure or responsiveness in proportional terms. Price elasticity represents the percentage change in the quantity demanded of a given good (e.g., particular tree nut) with respect to its own price (own price elasticity); this is expected to be negative, with a downward sloping demand curve. If the price change in percentage terms is for an alternative good, this is referred to as a cross price elasticity, which indicates a substitute (complement) relationship if positively (negatively) signed. Thus, elasticity measures the responsiveness in percentage terms, such as in the case of consumer demand for tree nuts in the United States to changes in either a given price or expenditures on food - “the effect of a change in tree nut price or its expenditure on quantity demanded of that tree nut” (Asci & Devados, 2021). Notably, hazelnuts have been shown to have the highest “expenditure elasticity” at 2.71 (Asci & Devados, 2021). Ranked according to expenditure elasticity, hazelnuts rank highest followed by pistachios, almonds, walnuts, and, finally, pecans (Asci & Devados, 2021). In fact, Asci & Devados (2021) report the expenditure elasticity for pecans at 0.53 (see Table 3, below). This means that if expenditures for tree nuts in the United States decreased overall, quantity demanded of hazelnuts would be the most negatively impacted while pecans would be the least negatively impacted (Asci & Devados, 2021). Table 3, below, reproduced from Asci & Devados (2021), shows the estimated price and expenditure elasticities of demand for major tree nuts from 1996-2018. The own price elasticity for pecans is negative (-0.08) and relatively inelastic (or unresponsive), but not statistically significantly different from zero. Hazelnuts are shown to be a significant substitute for pecans.

<table>
<thead>
<tr>
<th></th>
<th>Almond</th>
<th>Pistachio</th>
<th>Walnut</th>
<th>Pecan</th>
<th>Hazelnut</th>
</tr>
</thead>
<tbody>
<tr>
<td>Almond</td>
<td>-0.12</td>
<td>0.04</td>
<td>0.10*</td>
<td>-0.07</td>
<td>0.06*</td>
</tr>
<tr>
<td></td>
<td>(0.12)</td>
<td>(0.08)</td>
<td>(0.06)</td>
<td>(0.09)</td>
<td>(0.03)</td>
</tr>
<tr>
<td>Pistachio</td>
<td>0.19</td>
<td>-0.33</td>
<td>-0.07</td>
<td>0.41</td>
<td>-0.20</td>
</tr>
<tr>
<td></td>
<td>(0.40)</td>
<td>(0.43)</td>
<td>(0.22)</td>
<td>(0.26)</td>
<td>(0.16)</td>
</tr>
<tr>
<td>Walnut</td>
<td>0.22*</td>
<td>-0.03</td>
<td>-0.16</td>
<td>-0.03</td>
<td>0.00</td>
</tr>
<tr>
<td></td>
<td>(0.12)</td>
<td>(0.09)</td>
<td>(0.10)</td>
<td>(0.12)</td>
<td>(0.05)</td>
</tr>
<tr>
<td>Pecan</td>
<td>-0.09</td>
<td>0.10</td>
<td>-0.02</td>
<td>-0.08</td>
<td>0.09*</td>
</tr>
<tr>
<td></td>
<td>(0.11)</td>
<td>(0.06)</td>
<td>(0.07)</td>
<td>(0.15)</td>
<td>(0.03)</td>
</tr>
<tr>
<td>Hazelnut</td>
<td>1.03*</td>
<td>-0.71</td>
<td>-0.03</td>
<td>1.25*</td>
<td>-1.29</td>
</tr>
<tr>
<td></td>
<td>(0.57)</td>
<td>(0.56)</td>
<td>(0.39)</td>
<td>(0.43)</td>
<td>(1.02)</td>
</tr>
</tbody>
</table>

Notes: Asterisks (*) denote the elasticities are statistically significant at 10% level. Numbers in parenthesis are approximate standard errors. Elasticities are calculated at mean values of data. Expenditure elasticities are computed conditional on total tree nut expenditures. Price elasticities are the so-called “Slutsky” variation.

Source: Asci & Devados (2021).

Figure 11, below, reproduced from Asci & Devados (2021), shows the “simulated effects” of changes of expenditures on the quantity demanded for 2018. In Figure 13, pecans are shown in yellow, and the least responsive of the set.

Figure 11: Simulated Effects of Expenditure Changes on Quantity Demanded, 2018 Prices and Quantities (Reproduced from Asci & Devados, 2021).

Source: Calculated by authors using the expenditure elasticity estimates.

Source: Asci & Devados (2021).
Tree nuts, including pecans, have high protein content and high fiber content, as well as other important nutrients; thus, tree nuts are seen as a healthy food to consume, further encouraging consumers to purchase tree nuts (Asci & Devados, 2021). However, the localities where tree nuts are grown may change for economic reasons other than those caused by climate change. Asci & Devados (2021) assert, “The U.S. tree nut industry is prone to showing negative long-term response to changes in government regulations and trade policies. Therefore, tree nut operations may shift out of states with high regulations and costs into states with fewer regulations and other bureaucratic restrictions on water and labor”. Since pecan trees and their harvesting are so labor intensive, the researchers note, “stricter immigration policies and labor regulations would increase labor costs for tree nut farming by 22% or more” (Asci & Devados, 2021; Martin, 2017; Richard, 2018). Additionally, the United States tree nut industry is highly reliant on export markets, which make tree nut crops “susceptible to international trade issues” such as tariffs on the tree nuts (Asci & Devados, 2021). Since 2018, countries including China, India, and Turkey have placed “retaliatory tariffs” on tree nuts from the United States (Asci & Devados, 2021). Thus, climate change may not be the only driver for changes to the locations where pecans and other tree nuts are grown or how many pounds of nuts are sold.

Researchers observe that the “nut farming industry is expected to continue growing over the next five years”, and further assert that “consumer demand and government programs targeting consumption of tree nuts will likely continue this growth” (Asci & Devados, 2021).

**Government Subsidies & Tax Exemptions**

This section discusses a few of the different government subsidies, programs, and tax exemptions available to pecan orchard owners. It is important for Valencia County farmers considering growing pecans to understand these subsidies and tax exemptions.

- The government has promoted the benefits of tree nuts such as pecans, including through programs and bills encouraging people to consume more nuts and fresh produce.
- Commercial pecan orchards can claim agricultural land tax exemptions, but this can be of limited assistance.
- Pecan orchards in disaster areas are eligible to receive some government benefits.

While pecans and other tree nuts offer health benefits, Asci & Devados (2021) contend, “The main driver of changes in favorable consumer preferences for nuts is the promotion of tree
nuts’ dietary benefits by marketing boards, trade associations, and government programs” (italics added). Government programs include the government nutrition assistance programs as well as the 2014 Farm Bill and 2018 Farm Bill, which “encourage consumers to consume more fresh produce and nuts and to prepare healthier meals to meet the Dietary Guidelines for Americans (Asci & Devados, 2021; USDHHS and USDA, 2015).

Nesbitt et al. (2013) observe that commercial pecan orchards are able to claim agricultural land tax exemptions, but “since 1986, there are few tax advantages for pecans, and profits need to be determined on a true cash basis”.

However, the USDA’s Tree assistance program seeks to help commercial orchards in disaster areas (as declared by the Secretary of Agriculture) by providing subsidies “to help them replant trees they lose or to prune and save trees damaged because of the disaster” (TFCS, 2018, March 22). With this program, if the losses exceed 15% of the orchards’ total trees, then farmers are eligible to receive subsidies wherein which “taxpayers will cover 65% of replacement costs or 50% of efforts at salvaging trees” (TFCS, 2018, March 22). In 2018, Section 731 of Division A expanded the USDA Tree Assistance program for pecan growers. For the calendar year of 2017, pecan orchards with 7.5% loss (but less than 15%) could receive subsidies with payments totaling up to $15 million (TFCS, 2018, March 22).

Valencia County Agricultural Economics

This section discusses the agricultural economics of Valencia County including crop sales, net cash farm income, and government subsidies. It is important to understand the trends within the county over the last 30 years because farming within the county can be a very complex endeavor including economically. The key points:

- Crop sales have varied between 1987-2017.
- Though formerly positive, net cash farm income has been negative in both of the most recent years reported by the Census of Agriculture, 2012 and 2017.
- Government assistance to farms has varied significantly between 1987-2017, peaking in 2012 with $717,000 of government assistance going to Valencia County farmers, adjusted for inflation into constant 2019 dollars.
- The difficulties in making a profit farming in Valencia County have led some to consider growing a higher-dollar-value crop such as pecans.


In 2012 and 2017, the net cash farm income for Valencia County was negative. From Figure 12, above, we can see that making money at farming in Valencia County has become more difficult in the more recent decade than in the previous decades. We can see why higher-dollar-value crops might be desirable.

Given the financial difficulties with farming in the county, government assistance is provided to some farms. Figure 13, below, shows government assistance to farms in Valencia County between 1987-2017.

We can see from Figure 13, above, that government assistance varies significantly between years with the lowest amount of government assistance provided in 1987 of $15,000 (as adjusted for inflation into constant 2019 dollars). Government assistance peaks in 2012 at $717,000 and by 2017 drop down to $56,000 (as adjusted for inflation into constant 2019 dollars) (USDA NASS 1989, 1994, 1999, 2004, 2009, 2014, 2019).

For comparison, Figure 14, below, shows crop sales compared to government assistance to farms between 1987-2017 in thousands of dollars (USDA-NASS, 1989, 1994, 1999, 2004, 2009, 2014, 2019). Crop sales are shown in green while government payments are shown in red.


As we can see in Figure 14, above, government payments are not necessarily commensurate with crop sales. For instance, in 2012, government payments peaked at $717,000 while crop sales also peaked at $14,872,000 (both values were adjusted for inflation into constant 2019 dollars). We might expect to find more government payments in years when crop sales are decreased; however, this does not appear to be the case. There must be other factors driving government payments to farmers besides crop sales.

Research Methods

U.S. Bureau of Labor Statistics

The U.S. Bureau of Labor Statistics inflation calculator from the U.S. Department of Labor found at https://www.bls.gov/data/inflation_calculator.htm (USDL, n.d.) was used to convert dollar amounts into equivalent dollar amounts so that direct comparisons could be made between the different years examined excluding inflation. Dollar amounts from publicly
available data including USDA-NASS Census of Agriculture publications were converted from the values given for the year reported into December of 2019 dollar values for consistency.

**USDA-NASS Publications**

USDA-NASS publications were reviewed including QuickStats and the Census of Agriculture (USDA-NASS, 1989, 1994, 1999, 2004, 2009, 2014, 2019). The Census of Agriculture is published every five years and is available in PDF form. Census of Agriculture publications were reviewed for every five-year period beginning with 1987 and going through the Census of Agriculture for 2017. National trends, state, and county data were examined. Pertinent data was transcribed from the available PDF files into Microsoft Excel for further analysis of the data and to create graphs. When there was a difference between reported values between two different years of Census of Agriculture publication data, the most recently published values were considered the most up-to-date information available.

National and State data was reviewed as it was relevant to pecans including orchard size, quantity of pecans/utilized pecan production, and ranks of states for utilized pecan production. County data collected includes main crop types by acreage utilized, harvested acreage, irrigated acreage, farm size, and pertinent economic information including net cash farm income and government payments. Economic information was adjusted for inflation using the Bureau of Labor Statistics inflation calculator.

The data from USDA-NASS publications for Valencia County includes farms whose acreage is not given if to provide the acreage amount would enable the farm to be identified individually and private data about the farm’s production and economic activities would be disclosed by disclosing the acreage value. In the USDA-NASS publications these farms are given values of “D”.

**USGS**

Available surface water data were acquired from the USGS for Valencia County at [https://waterdata.usgs.gov/nwis/sw](https://waterdata.usgs.gov/nwis/sw) (USGS, 2020). Data were downloaded as .csv files and imported into Microsoft Excel for further analysis. Data were acquired for the Rio Grande gauge at Albuquerque (site number 8330000) for the years 1987-2017 and for the gauge at San Felipe (site number 8319000) for the same time range. These data were imported into Microsoft Excel for further analysis and the creation of graphs of streamflow.
Office of the State Engineer

Technical papers and releases from the Office of the State Engineer are published every 5 years and contain water use data including amounts of surface water as well as groundwater that are diverted for agricultural irrigation (NM SEO, 1992, July; 1997, September; NM OSE, 2003, February; 2008, June; 2013, October; 2019, May). The amounts of surface water diverted for irrigated agriculture and of groundwater for irrigated agriculture were examined in PDF form for the years 1990-2015 and the data was transcribed into Excel for further analysis. Graphs were created from the data.

Additionally, point of diversion (POD) online maps were accessed through the NM OSE’s website at [https://gis.ose.state.nm.us/gisapps/ose_pod_locations/](https://gis.ose.state.nm.us/gisapps/ose_pod_locations/) to identify wells used for agricultural purposes within Valencia County (NM OSE, n.d.). CropScape (USDA-NASS, 2021) was cross referenced with the OSE’s POD online map to find locations of interest (e.g., where pecans are being grown) and if there is a corresponding well for groundwater irrigation at that location. CropScape’s assessment that the land was growing pecans was confirmed visually wherever feasible.

CropScape


The USDA-NASS CropScape platform was used to obtain a map of the county with the crops grown color-coded. It was also used to obtain data on land use including crop type grown.

The spatial resolution of the data CropScape used was 30 m (USDA-NASS, 2021).

The USDA-NASS CropScape web service was accessed at [http://nassgeodata.gmu.edu/CropScape/](http://nassgeodata.gmu.edu/CropScape/) (USDA-NASS, 2021). Using CropScape, Valencia County was selected as the area of interest (AOI). CDL data for the AOI were exported as .csv files. Data including maps of Valencia County land use was accessed using CropScape. The year 2010 was selected, and the year 2020, for further analysis. Further years were examined as necessary. The .csv files were imported into Microsoft Excel and further analysis was undertaken including creating pie charts.
The CropScape web site notes, “There will be differences between CropScape and official NASS estimates when comparing acreage statistics at the state, district, and county levels. Statistics generated by CropScape are dependent on pixel counting and multiplying by the area estimates. Counting pixels and multiplying by the area of each pixel will result in biased area estimates and should be considered raw numbers needing bias correction. Official crop acreage estimates at the state and county level are available at QuickStats” (USDA-NASS, 2021). See Appendix D for CDL codes to analyze for Valencia County.

Using Microsoft Excel pie charts were constructed for 2010 and 2020, respectively. The pie chart of the overview of land use in the county groups land use as listed in Appendix D.

For land use (excluding shrubland) pie graphs for 2010 and 2020, respectively, the same categories as enumerated in Appendix D were used; however, the shrubland category was excluded.

For agricultural land use pie graphs for 2010 and 2020, respectively, the CDL codes were grouped as listed in Appendix D.

To specifically look at pecans the CDL code for pecans was used, as shown in Appendix D.

**Open ET**

Data available on Open ET, available at [https://explore.etdata.org](https://explore.etdata.org) (OpenET, 2022), was explored to examine the approximate consumptive water use of pecan fields in Valencia County. The earliest year available was 2016, and the most recent year available was 2021. Those two years, respectively, were examined for consumptive water use of local pecan orchards. Three pecan orchards were chosen, one orchard of over 100 acres, one orchard of between 50-99 acres, and one orchard of under 50 acres.

OpenET is a collaboration of a number of agencies, universities, and researchers including NASA, the Desert Research Institute (DRI), the Environmental Defense Fund (EDF), the USDA, the USGS, the University of Nebraska, the University of Idaho, the University of Wisconsin, the University of Maryland, California State University Monterey Bay, the University of Montana, Google Earth Engine, and web development from Habitat Seven. OpenET is an online platform which is for “mapping evapotranspiration (ET) at the scale of individual fields” (OpenET, 2022). This is to help those interested have a better understanding of ET and thus consumptive use. OpenET offers estimates of the total ET from a land surface such as a field.
These estimates are based on satellite data, and use “data from multiple satellite-driven models” (OpenET 2022, February 1). These models use data from Landsat satellites (OpenET 2022, February 1).

**xmACIS2**

XmACIS2 (2022, March 7), found at [https://xmacis.rcc-acis.org/](https://xmacis.rcc-acis.org/), was used to examine the frost-free period in Valencia County from the Los Lunas 3 SSW recording station. This was done by selecting “first” and “last” frost dates for the Los Lunas 3 SSW recording station. The result was obtained in comma-delimited format which was ultimately imported into Microsoft Excel for further analysis. The length of time between the first and last frosts was used to construct a graph of the frost-free period in Valencia County. Excel was instructed to ignore empty cells since there were missing data for a few years scattered throughout the data. Then a linear trendline was plotted to visualize the trend more easily.

**Literature Review**

Economic information regarding the costs of pecan (and other) farming was acquired from peer reviewed journal articles as well as from the NMSU agricultural extension website and the Texas A&M agricultural extension website. Much of the data available is specific to southeastern New Mexico where the bulk of the pecans in New Mexico are grown.

A review was done of literature to determine what other counties are doing to meet their agricultural needs as well as to determine if other counties’ techniques could be used or are already being used in Valencia County to meet its agricultural water needs. Literature reviewed included peer-reviewed journal articles, newspaper articles, and legal proceedings that were applicable.

**Results**

**USGS**

Figure 15, below, represents the mean river discharge in cubic feet per second (CFS) at the USGS gage (USGS, 2020) on the Rio Grande at San Felipe. While we can see that discharge varies quite a bit from year to year, overall, we can see that at no point since 1987 has discharged reached the level of approximately 2,500 CFS, last seen in 1987. By 2017, the discharge of the river was under 1,600 CFS. A simple linear trendline shows a general downward trend of decreasing discharge over time in the Rio Grande at San Felipe gage.

Data Source: USGS (2020)

Figure 16, below, shows the mean discharge in CFS in the Rio Grande at Albuquerque gage between 1987-2017 constructed with data from the USGS on streamflow (USGS, 2020). During this timeframe, the discharge has been highly variable. The greatest mean discharge in the Rio Grande at Albuquerque (between 1987-2017) was in 1987 at just over 2,200 CFS. By 2017, the discharge of the river was just over 1,300 CFS for the year. A simple linear trendline shows the flows in the Rio Grande at Albuquerque gage are decreasing with time.
Office of the State Engineer

The OSE POD or point of diversion well locations were examined for Valencia County (NM OSE, n.d.). The location of the POD/irrigation well that was chosen is known to be a pecan orchard. This was confirmed both by CropScape and visual inspection as a pecan orchard. This pecan orchard has the right to divert 3.00 AF at present from the well (NM OSE, n.d.).

The OSE water use reports are discussed above for Valencia County. However, Doña Ana County was examined since this is the state’s largest pecan-producing county. In 1990, surface water used for irrigated agriculture amounted to 368,042 AF for the year while the groundwater withdrawn for irrigated agriculture was 104,989 AF (NM SEO, 1992, July). By 2015, surface water use dropped to 136,235 AF; however, groundwater use rose to 197,214 AF for the year, far exceeding their surface water diversions (NM OSE, 2019, May). In Doña Ana County, they have
come to rely far more heavily on groundwater than we have seen in some other counties like Valencia County. In 2015, Valencia County diverted 134,059 AF of surface water and just 8,452 AF of groundwater for the year (NM OSE, 2019, May). It is interesting to note that Doña Ana County is made up of predominantly large-sized, commercial farms (USDA-NASS, 1989, 1994, 1999, 2004, 2009, 2014, 2019).

**CropScape**


Figure 17, below, taken from the USDA-NASS CropScape website (USDA-NASS, 2021), shows the wide variety of crops that are grown in Valencia County, particularly in strips along either side of the Rio Grande. Pecans are shown in brown on this map; however, the brown of the pecan orchards is very hard to find in this map, appearing to be smaller, discrete parcels of pecan trees. Alfalfa is shown in pink in the Figure 17, below, and we see alfalfa peppering the agricultural lands in abundance.
Figure 17: USDA-NASS CropScape graphic of Valencia County agriculture in 2010 (USDA-NASS, 2021).


Figure 18, below, created from the data found on CropScape (USDA-NASS 2021), shows that in 2010 nearly 85% of Valencia County’s acreage devoted to agriculture was growing alfalfa, while acreage growing pecans accounted for just over 2% of Valencia County’s agricultural acreage. USDA-NASS QuickStats does not have data on Valencia County pecan acreage for the year 2010 – making it hard to compare the data sets. However, for the year 2012, CropScape lists alfalfa acreage at 2,133.2 acres (USDA-NASS, 2021) while the Census of Agriculture lists alfalfa acreage at 16,195 acres (USDA-NASS, 1989, 1994, 1999, 2004, 2009, 2014, 2019); this is a large discrepancy between the two data sets.
Figure 18: 2010 Valencia County Agriculture. Data Source: USDA-NASS CropScape (2021).

Data Source: USDA-NASS (2021)

Figure 19, below, shows Valencia County agriculture for the year 2020 which was obtained from CropScape (USDA-NASS, 2021). The gray areas seen are developed areas, and we can see that the developed areas are greater in acreage in 2020 than in 2010. Pecans are shown in brown on the map and can be seen on the far southwestern side on the Rio Grande along the agricultural lands that are found near the Rio Grande. Alfalfa is again shown in pink and features prominently in the agricultural areas along the Rio Grande.
Figure 19: USDA-NASS CropScape graphic of Valencia County agriculture in 2020 (USDA-NASS, 2021).


Figure 20, below, shows 2020 Valencia County agriculture and was created with data from CropScape (USDA-NASS, 2021). In the below figure, alfalfa (shown in green) accounts for 76.7% of the county’s agriculture. Pecans (shown in pink) account for 7.0% of agricultural acreage in 2020. CropScape estimated 9,160.7 acres of alfalfa in 2020 and 840.9 acres of pecan trees (USDA-NASS, 2021). USDA-NASS QuickStats does not provide data for Valencia County pecan tree acreage for the year 2020 because to do so would allow individual farming operations to be identified, potentially exposing sensitive data.
To compare pecan tree acreage values, we can look at the year 2017 with CropScape and in the Census of Agriculture publications. In 2017, CropScape estimated 5,613.5 acres of alfalfa and 81.8 acres of pecan trees (USDA-NASS, 2021). However, the Census of Agriculture reports 9,809 acres of alfalfa for 2017 and between 400 and 462 acres of pecans; a more precise number of acres of pecan trees is not available due to values being withheld by the Census of Agriculture so as not to expose private information concerning individual farms (USDA-NASS, 2019).

Clearly, in the Valencia County area of New Mexico, CropScape is not as accurate as we would hope. CropScape seems to work fairly well with large parcels of land growing only one crop, but with smaller parcels of land, there seems to be more uncertainty in crop identification. Valencia County has comparatively smaller parcels of land, sometimes with numerous crops grown on the parcel, and this makes CropScape far less accurate for the county at this time.

**OpenET**

OpenET was used to examine the ET in Valencia County pecan orchards for the years 2016-2021. OpenET showed that one large pecan orchard showed an ET or consumptive use 2.4 AF per acre for the year 2016. In 2021, the same orchard had an ET of 3.2 AF per acre for the
year (Open ET, 2022). Another pecan orchard had similar amounts of ET in 2016 at 2.3 AF per acre for the year, and in 2021, the same orchard had an ET of 3.3 AF per acre for the year (OpenET, 2022). A third pecan orchard had an ET in 2016 of 2.0 AF per acre for the year, and an ET in 2021 of 3.0 AF per acre for the year (OpenET, 2022). ET increases as the trees mature, and we can see this increase in the ET values. The ET of the trees also increases with increasing temperatures due to climate change. The consumptive use of these orchards is increasing yearly.

**xmACIS2**

XmACIS2, found at https://xmacis.rcc-acis.org/ (2022, March 7), was used to examine the frost-free period in Valencia County from the Los Lunas 3 SSW recording station. Figure 21, below, shows the change in the frost-free season over time. For the period available, 1959-2021, a simple linear trendline shows an upward trend in the frost-free days or an overall increase in the length of the frost-free season in Valencia County. This lends support to the idea that pecans may become successful further north than southern New Mexico.

*Figure 21: Length of Frost-Free Season in Valencia County, New Mexico – Los Lunas Station: 1959-2017 (Data Source: xmACIS2, 2022, March 7).*

Data Source: xmACIS2 (2022, March 7).
Literature Review

“Stacking” of water rights is allowed under New Mexico law (NMSA §72-5-28, 1978; Winchester & Hadjigeorgalis, 2009, Winter). Stacking of water rights or “stacked water rights” is a process by which more water rights are added to a parcel of land without the parcel’s acreage increasing (EBID, 2012; Winchester & Hadjigeorgalis, 2009, Winter). The Elephant Butte Irrigation District (EBID) is one location that uses stacking of water rights as a management technique. Under the EBID policy, irrigators are allowed to purchase additional water rights for use on their lands and the water rights can be stacked up to double the original water rights (EBID, 2012; Winchester & Hadjigeorgalis, 2009, Winter). In the EBID, the farm delivery requirement (FDR) is 4.5 AF per acre per year (1371.6 mm) with a consumptive irrigation requirement (CIR) of 4.0 AF per acre per year (1219.2 mm), and those values are for all crops. In the EBID, up to 5.5 AF per acre per year (1676.4 mm) FDR may be able to be claimed if “historically higher water use” can be proven (Ahadi et al., 2013). The acreage of the existing EBID land must be two acres or more (EBID, 2012). Water rights can be stacked only on land considered eligible with EBID water rights already (EBID, 2012). Additionally, the water must be put to beneficial use (EBID, 2012). The Board of Directors in the EBID must approve water rights stacking applications and the policy states, “transferred rights are subject to all EBID rules, conditions, assessments, and policies” (EBID, 2012). However, the EBID is not the only place within New Mexico where stacking water rights is allowed.

The Animas Basin and the Roswell Basin both have provisions for “stacked” irrigation rights (NM OSE, 2005, February; 2016, July) along with mentions made of stacking water rights for the Pecos River in the Roswell Basin (NM ISC, 2020, May) and in the Mimbres River Basin in southwestern New Mexico (Reno-Trujillo et al., 2013, April). In the Animas Basin, stacked water rights are defined as “irrigation rights on an acre of land that exceed the amount of water per irrigated acre associated with the average basin-wide CIR” or consumptive irrigation requirement (CIR) (NM OSE, 2016, July). For the Animas underground water basin, the FDR is 3.0 AF per acre per year and the CIR is 2.10 AF per acre per year. In the directions from the New Mexico Office of the State Engineer (NM OSE), for applications to change the purpose or use of stacked irrigation rights, diversions are “limited to the CIR times the irrigated acreage of the original water right placed to beneficial use” (NM OSE, 2016, July). Where water rights are stacked, when applying to change the place of use, diversions are “limited to the combined
diversion amount” in the Animas Basin (NM OSE, 2016, July). Reno-Trujillo et al. (2013, April) make mention of “stacking” water rights in the Mimbres River Basin (see Mimbres Valley Irrigation Co. v. Salopek et al., 1993, January) leading us to conclude that stacking of irrigation rights is done in that region as well.

In the Roswell Basin to stack irrigation water rights:

- There must be a valid reason for stacking the right (NM OSE, 2005, February).
- The stacking cannot “constitute a waste of water” (NM OSE, 2005, February).
- The stacking cannot be “contrary to the conservation of water within the state or detrimental to the public welfare” (NM OSE, 2005, February).
- The OSE “may establish a new duty for the irrigated lands based on the existing duty and the stacked water”. The example given is “if 100 AF/year of water are requested to be stacked on 100 acres of land with an existing duty of 3.0 AF/year, the OSE may permit the stacking of water rights at the move-to lands with a duty of 4.0 AF/year” (NM OSE, 2005, February).
- Once permitted, a stacked water right becomes “appurtenant to the land upon which it has been stacked” (NM OSE, 2005, February).
- Stacked rights may be severed from the land if the owner applies to sever the stacked right and provides an explanation of why the stacked water rights are no longer needed on the land (NM OSE, 2005, February).
- Land from which water rights have been severed will be “subject to deed restrictions to ensure that no new water development or use, including the drilling of domestic wells…occurs on the land without transfer of valid, existing water rights…and recorded and provided to the State Engineer” (NM ISC, 2020, May).
- Water rights can be stacked for a temporary period of time or permanently. Stacking water rights temporarily is a common practice often used “at the end of a five-year accounting period to prevent or offset an over diversion” (NM OSE, 2005, February).
- Stacking of water rights is often done for “high-water usage crops” (NM ISC, 2020, May).

The Middle Rio Grande Regional Water Plan (NM ISC & NM OSE, 2017, January) does not mention stacking of irrigation water rights specifically. However, the document states, “The regions are encouraged to explore strategies for agricultural conservation, especially those that
result in consumptive use savings through changes in crop type or *fallowing of land while concentrating limited supplies for greater economic value on smaller parcels*” (italics added, NM ISC & NM OSE, 2017, January). This appears to be advocating fallowing lands and using the irrigation water from that land on another parcel of land to maximize economic value.

Exhibit 5: NM SEO Water Use and Reports (dated May 21, 1996), from the WildEarth Guardians’ Motion for Summary Judgement (2019, November 1) informs us, “There is evidence [in the MRG] of water rights stacking, that is, irrigating less acreage than stipulated in the water rights permits and applying more than 3 acre-feet of water to each irrigated acre”. The exhibit further states that though stacking is going on, “There is no evidence that the maximum amount of surface water delivered to farms during the 1965-1994 period of record has exceeded the District’s water right entitlement” (WildEarth Guardians’ Motion for Summary Judgement, 2019, November 1). The exhibit asserts that stacking of irrigation water rights in New Mexico is a common management technique, and “is acceptable provided that the annual consumptive use of water by crops less effective rainfall (i.e., CIR), and the farm delivery, does not exceed the total stipulated water right permit” (WildEarth Guardians’ Motion for Summary Judgement, 2019, November 1). The exhibit notes that a limitation has not been stipulated on the total consumptive use (WildEarth Guardians’ Motion for Summary Judgement, 2019, November 1).

The apparent evidence of stacking irrigation water rights in the MRG is found in the reported farm deliveries for the years 1987-1994, during which time farm deliveries “all exceed 3 acre-feet per harvested acre and range from 3.023 to 3.728 acre-feet per acre and averaged 3.306 acre-feet per acre” (WildEarth Guardians’ Motion for Summary Judgement, 2019, November 1). The alleged evidence comes from the total irrigable acreage (TIA), reported in the Bureau of Reclamation (BOR)’s annual crop reports, which was found to be greater in acreage than inventoried by the NM SEO. In the MRG district, new subdivisions were made after the NM SEO inventory, which instead of increasing the irrigable acreage would have reduced it (WildEarth Guardians’ Motion for Summary Judgement, 2019, November 1). The motion notes, “This suggests that both the harvested and irrigable acreage reported by the Bureau may be too high. If the harvested irrigated acreage for any one calendar year is less than reported by the Bureau, this would increase the amount of water delivered to each acre of harvested cropland” (WildEarth Guardians’ Motion for Summary Judgement, 2019, November 1). This may indicate that stacking of water rights may be going on in a more informal way than in the EBID or other
places. It is possible there is some other reason for the differences between the TIA reported by the BOR and acreage inventoried by the State Engineer’s Office; however, the evidence appears to indicate stacking is going on informally.

The WildEarth Guardians’ Motion for Summary Judgement (2019, November 1) Exhibit 5 further asserts that “water rights stacking may be necessary to meet crop water demand”. The calculations in this exhibit show that if the weighted CIR for the MRG is 2.1 AF per acre and the on-farm irrigation efficiency (AE) is 50% or less, this would make the “minimum farm delivery requirement” (FDR=CIR/AE) “4.2 AF/irrigated acre” (WildEarth Guardians’ Motion for Summary Judgement, 2019, November 1). The exhibit notes that for the county of Socorro in 1993 and 1994, the CIR was 2.391 to 2.521 AF per acre, making the FDR necessary (at AE=50%) of 4.782 to 5.042 AF per acre (WildEarth Guardians’ Motion for Summary Judgement, 2019, November 1). Exhibit 5 of the WildEarth Guardians’ Motion for Summary Judgement (2019, November 1) further states that the practice of stacking water rights allows irrigators/growers to meet their agricultural water needs “without violating the constraints of their water rights”.

Exhibit 5 of the WildEarth Guardians’ Summary for Motion Judgement (2019, November 1) observes that in Eddy and Chaves counties, in the Roswell Artesian Groundwater Basin, “growers may reduce the acreage in production so that they can apply more water to each irrigated acre to get reasonable crop yields” (italics added). The practice of water irrigation rights stacking can help growers increase their crop yields without taking more water than they are permitted and allows for more flexibility with changing crop types or crop locations as well, which can help maximize yields. This stacking of irrigation water rights could allow more flexibility for a grower – allowing them to fallow a certain number of acres to free up water rights to stack on the remaining acreage. In this way, a high-water-use crop like pecans may be able to receive enough water to be successful despite droughts and climate change.

Stacking may be a viable water management tool for irrigators to use in Valencia County, especially for high-water-use crops like pecans. Stacking water rights is a way to maximize irrigation water used for crops without increasing the amount of water that is being taken out of the system overall. It appears that within Valencia County, stacking of water rights could be done on an informal basis by individual farmers, or farmers with ownership in common, who might choose to fallow a certain number of acres to free up water rights for use on their remaining
Farming Pecans in Valencia County, New Mexico

acreage. In some localities, farmers find it profitable to install solar panels on the land they are fallowing to maximize the revenue from the fallowed acres while providing more water for the agricultural acreage requiring irrigation. Installing beehives on the fallowed acreage to keep bees is also a good use for fallowed land. In each of these cases, allowing irrigators to stack water rights allows irrigators to maximize crop yields and quantities (or at least produce reasonable crop yields and qualities) by providing sufficient water for irrigated agricultural acreage while still receiving income from the fallowed land that provided the additional water rights for stacking. Stacking water rights in Valencia County may be a viable water management technique for irrigators as droughts and climate change cause temperatures to increase and water available for irrigation becomes scarcer. The technique of stacking water rights may allow irrigators flexibility to grow high-water-use crops like pecans in Valencia County.

Conclusions

Pecan trees are enticing for growers due to their value compared to other crops, as well as the gross value of pecans per amount of irrigation water applied. In constant 2019 dollars, alfalfa generates a profit of between $200 per acre to $300 per acre (Adams, 2019, September 23). Yet, pecans generate a profit of between $2,500 per acre up to as much as $5,000 per acre, making pecans a highly attractive crop to grow (Adams, 2019, September 23; CACL, 2012). The gross value of irrigated crop production per volume of irrigated water consumed is just $244 per AF for alfalfa while corn silage is higher at $439 per AF (CACL, 2012); however, the gross value of irrigated crop production per volume of irrigation water consumed is $1,128 per AF for pecans in constant 2019 dollars (CACL, 2012). In other words, pecans can be much more profitable than alfalfa both from the perspective of the value of the profit generated and from the perspective of having more value per amount of irrigation water applied. However, to be successful and profitable with a pecan orchard, you undertake a large upfront cost (investment), and must have a large enough orchard to justify the equipment costs. To make the change to a more profitable crop like pecans requires a shift away from the non-commercial tradition of farming in Valencia County to commercial pecan orchards to justify the equipment expense. However, pecan trees’ consumptive water use is high. Pecan orchards will need to be irrigated for years before they will become profitable.

The seasonal ET for pecan orchard ranged from 0.9 to 4.3 AF per acre per season (27 to 133.4 cm per acre per season) while the annual ET, which we can equate to consumptive use,
ranged from 0.9 to 4.9 AF per acre per year (50 to 147.9 cm per acre per year), depending on the time of the season, the growth stage of the pecans, the amount of canopy and leaf development stage, the maturity of the trees, the type of soil and groundcover, the air temperature, and the type of irrigation and management (Miyamoto 1983; Worthington et al, 1987; Miyamoto, 1995; Sorenson, 1997; Frias-Ramerez, 2002; Sammis et al., 2004; Reveles, 2005; Skaggs et al., 2008; Samani et al., 2011; Ahadi et al., 2013; Ibraimo, 2016). The irrigation requirement, or diversionary water requirement, for pecan trees is between 4.3 to 8.2 AF per year (131 to 250 cm or 51.6 to 98.4 inches per acre per year (Miyamoto, 1983; Sammis et al., 2004; Kallestad et al., 2006). Further, Miyamoto (1995) cites a peak irrigation amount for mature pecan trees of 13,000 gallons per acre per day for mature pecan trees, which equates to 0.04 AF per acre per day.

There is a lack of flexibility inherent in growing pecan trees. In dry years with other types of crops, fields can be fallowed when there is not enough water for irrigation (Fleck, 2016), or the types of crops can be changed to grow crops that require less water or to grow crops that are more drought resistant. However, pecan trees are a large investment that will not produce adequately to make a profit for 7-10 years (Adams, 2019, September 23; CACL, 2012). The trees are very reliant on adequate moisture and irrigation, and they must receive this every year to be successful, productive orchards (Garrot et al., 1993; Herrera & Sammis, 2002; Ibraimo et al., 2016; Samani et al., 2011). If water is scarce because of droughts or climate change, pecan orchards cannot be fallowed as other fields can. This means their water requirement cannot be decreased in times of drought without serious consequence (Doorenbos & Kassam, 1979; Garrot et al., 1993, Herrera & Sammis, 2002; Ibraimo et al., 2016; Samani et al., 2011; Skaggs et al., 2008).

Valencia County had 7 acres growing pecan trees in 1987 but between 400 and 462 acres by 2017 (USDA-NASS, 1989, 2019). Valencia County, as of 2017, had 5 farms that were bearing pecans and 16 farms that were growing pecan trees but were not yet bearing any pecans (USDA-NASS, 2019). As the 16 farms’ pecan trees continue to mature and produce nuts, they will require more water than they are currently using (Samani et al., 2011). Independent of droughts or climate change, pecan trees will require the most water upon reaching maturity, during certain stages of nut development, and as the trees’ canopies grow larger and denser. If pecan trees, when mature, require an irrigation amount of between 4.3 and 8.2 AF per year per acre (Miyamoto, 1983, 1995; Sammis et al., 2004; Kallestad et al., 2006) and Valencia County has at
least 400 acres of pecan trees, then the total irrigation or diversionary amount could be as high as 3,280 AF per year once the trees mature (however, if there are 450 acres of pecan trees, the irrigation amount would be as high as 3,690 AF per year). If the planned 850 acres of pecan trees are planted, upon maturity this would equate to 3,655 AF to 6,970 AF per year to water the pecan trees. There is some uncertainty in these numbers given that the average ET in Valencia County is likely to be less than the average ET in southern New Mexico where most of the studies were conducted, as well as uncertainty given the factors that affect the water requirements of pecans besides ET including, but not limited to, soil type, groundcover, canopy cover, stage of nut and/or foliage development, tree age, and irrigation type. The data from OpenET shows us that the water requirements of the pecan trees in Valencia County are increasing with time (OpenET, 2022).

The current water diversions, as of 2015, for irrigated acreage in Valencia County were 142,510 AF up from 140,822 AF in 1990 (NM OSE, 2019, May; NM SEO, 1992, July). The surface water diversions for irrigated agricultural acreage were 134,059 AF in 2015 up from 131,733 in 1990 (NM OSE, 2019, May; NM SEO, 1992, July). The groundwater diversions for irrigated agricultural acreage were 8,452 AF for 2015. As the pecan trees mature, we would expect to see these numbers go up with the increased need for irrigation in mature trees. We would also expect to see these water use numbers increase with increased temperatures causing increased ET during times of heatwaves, droughts, or due to climate change. Droughts are already curbing farmers’ irrigation (MRGCD, 2021, June 23; 2022, January 18).

The high consumptive water use of pecan orchards poses an issue. If more pecan trees are planted and as the trees age they consume larger quantities of water, further stress will be placed on the hydrologic system of Valencia County. More irrigators may turn to pumping groundwater, but this cannot relieve stress on the hydrologic system of Valencia County. Irrigators increased pumping of groundwater will place more pressure on the hydrologic system. Water rights stacking may be a way to relieve some stress on the system, for instance, allowing a portion of a farmer’s land to be fallowed while stacking those water rights on the acreage that is supporting pecan trees. This would ensure the pecan orchard has as close to optimal amounts of water as possible so that the trees can remain healthy and produce optimally.

With a changing climate and changing agricultural needs, it becomes more and more important to manage our scarce water in the most beneficial ways. Farming has been a way of life
in Valencia County for as long as the land can remember. It is important to find creative water resources solutions to preserve the continuing tradition of farming in Valencia County, even as it adapts and changes.
References


*Mimbres Valley Irrigation Co. v. Salopek et al.*, Luna County District Court Case No. 6326, with a Final Decree entered January 14, 1993 (the *Mimbres Adjudication*).


NMSA §72-5-28 (1978)


OpenET. (2022, February 1). *Methodologies.* OpenET. Retrieved February 24, 2022, from https://openetdata.org/methodologies/


Farming Pecans in Valencia County, New Mexico


Appendix A – Tables and Figures

Tables

Table 1  Crops, investment (dollars per acre), lead time until income-producing (years) and other notes about pecans and several other crops, adjusted into constant 2019 dollars (CACL, 2012).

Table 2  Major crops grown in Catron, Grant, Hidalgo, and Lunas Counties (in 2010 except where otherwise stated) with the gross value of crop production per volume of irrigation water consumed (in dollars per acre-foot), adjusted into constant 2019 dollars (CACL, 2012).

Table 3  Estimated price and expenditure elasticities of demand for major tree nuts, 1996-2018 (Asci & Devados, 2021).

Table C.1  Monthly pan evaporation and monthly ET of pecan orchards with different trunk diameters \((d)\) and tree densities \((N)\) in the El Paso Valley, Texas (Miyamoto et al., 1995).

Table C.2  Typical irrigation intervals for net irrigation rates of 5 cm (2 inches) and 10 cm (4 inches) in orchards with differing trunk diameter trees and/or number of trees per ha (Miyamoto et al., 1995).

Table C.3  Dates and amounts (in mm) of flood irrigation to a Mesilla Valley area pecan orchard, 2001-2002 (Sammis et al., 2004).

Table C.4  Monthly ET rates in a mature pecan orchard in the Mesilla Valley, measured using OPEC system during the 2001-2002 growing season (Sammis et al., 2004).

Table C.5  Theoretical and remotely sensed seasonal crop ET values in the Lower Rio Grande, New Mexico, for the year 2008 (Ahadi et al., 2013).

Table C.6  Summary of average seasonal irrigation efficiencies for alfalfa, cotton, and pecans for the Lower Rio Grande, New Mexico, for the year 2008 (Ahadi et al., 2013).

Table C.7  Average on-farm irrigation efficiency for the three years 2008, 2010, and 2011 in the Lower Rio Grande, New Mexico (Ahadi et al., 2013).

Table C.8  Seasonal totals of irrigation plus rainfall, reference evapotranspiration (ET\(_\text{o}\)) and evapotranspiration (ET) for mature ‘Choctaw’ pecan orchard at Cullinan, South Africa, during three consecutive seasons of measurement (Ibraimo et al., 2016).
Table C.9 Mesilla Valley, New Mexico orchard with pecan trees’ irrigation amounts and dates in the year 2000, 7-inch diameter pecan tree trunks growing on a sandy loam with 1.5 inches/foot of available soil moisture and assuming a 3-foot root zone (Herrera & Sammis, 2002).

Table C.10 Mesilla Valley, New Mexico orchard with pecan trees’ irrigation amounts and dates in the year 2000 for a mature orchard growing on a sandy loam with 1.5 inches/foot of available soil moisture and assuming a 3-foot root zone (Herrera & Sammis, 2002).

Table C.11 Mesilla Valley, New Mexico orchard with pecan trees’ irrigation amounts and dates in the year 2000, 7-inch diameter pecan tree trunks growing on a clay soil with 2.25 inches/foot of available soil moisture (Herrera & Sammis, 2002).

Table C.12 Mesilla Valley, New Mexico orchard with pecan trees’ irrigation amounts and dates in the year 2000 for a mature orchard with trees growing on a clay soil with 2.25 inches/foot of available soil moisture and assuming a 3-foot root zone (Herrera & Sammis, 2002).

Figures

Figure 1 View of the Rio Grande from Reynold’s Forest in Belen, New Mexico (Griego, 2022).

Figure 2 Map of New Mexico highlighting Valencia County (Griego, 2022).

Figure 3 Map of Valencia County from the Comprehensive Land Use Plan for Valencia County (MRCOG, 2005, October).

Figure 4 1987-2017 Valencia County farm size by irrigated acres (Griego, 2022).

Figure 5 Surface water withdrawals for irrigated agriculture in the Middle Rio Grande (MRG) for the years 1990-2015 (Griego, 2022).

Figure 6 Groundwater withdrawals for irrigated agriculture in the Middle Rio Grande (MRG) for the years 1990-2015 (Griego, 2022).

Figure 7 Valencia County population, 1987-2017 (USCB, n.d.).

Figure 8 Value of pecan production in the United States, 1987-2017, adjusted into constant 2019 dollars (Griego, 2022).

Figure 9 Utilized production of pecans in the United States, 1980-2020 (Griego, 2022).
Figure 10 Per capita utilization of pecans in the United States, 1980-2020 (Griego, 2022).

Figure 11 Simulated effects of expenditure change on quantity demanded, 2018 prices and quantities (Asci & Devados, 2021).

Figure 12 Crop sales and net cash farm income in Valencia County, New Mexico between 1987-2017, adjusted into constant 2019 dollars (Griego, 2022).

Figure 13 Government assistance to Valencia County, New Mexico farms between 1987-2017, adjusted into constant 2019 dollars (Griego, 2022).

Figure 14 Crop Sales vs. Government Payments between 1987-2017, adjusted into constant 2019 dollars (Griego, 2022).

Figure 15 Rio Grande at San Felipe Gage: Mean River Discharge (CFS): 1987-2017 (Griego, 2022).

Figure 16 Rio Grande at Albuquerque Gage: Mean River Discharge (CFS): 1987-2017 (Griego, 2022).

Figure 17 USDA-NASS CropScape graphic of Valencia County agriculture in 2010 (USDA-NASS, 2021).

Figure 18 2010 Valencia County Agriculture (Griego, 2022).

Figure 19 USDA-NASS CropScape graphic of Valencia County agriculture in 2020 (USDA-NASS, 2021).

Figure 20 2020 Valencia County Agriculture (Griego, 2022).

Figure 21 Length of the Frost-Free Season in Valencia County, New Mexico – Los Lunas Station: 1959-2017 (Griego, 2022).

Figure C.1 The relationship between annual pecan ET and fractional cover (fc) for various orchards in the Lower Rio Grande Valley (Samani et al., 2011).

Figure C.2 Measured and predicted ET of a pecan orchard with a fractional cover (fc) of 52% (Samani et al., 2011).

Figure C.3 Measured and predicted ET of a pecan orchard with a fractional cover (fc) of 77% (Samani et al., 2011).

Figure C.4 Number of occurrences versus annual crop ET for pecan fields in the Lower Rio Grande, New Mexico, for the year 2008 (Ahadi et al., 2013).

Figure C.5 Comparison between actual and estimated evapotranspiration (ET) using the generic procedure of FAO-56, with climate adjusted single (time averaged) crop
coefficient, Kc, values published for stone fruits for a mature pecan orchard during (A) 2009/2010 season (B) 2010/2011 season and (C) 2011/2012 season at Cullinan, South Africa (Ibraimo et al., 2016).

**Figure C.6** Mesilla Valley, New Mexico orchard with pecan trees’ modeled daily water use and irrigation dates in the year 2000, tree trunks of 7-inches in diameter growing on a sandy loam with 1.5 inches/foot of available soil moisture and assuming a 3-foot root zone (Herrera & Sammis, 2002).

**Figure C.7** Mesilla Valley, New Mexico orchard with pecan trees’ daily water use for the year 2000 and dates of irrigation for a mature orchard with trees growing on sandy loam with 1.5 inches/foot of available soil moisture and assuming a 3-foot root zone (Herrera & Sammis, 2002).

**Figure C.8** Mesilla Valley, New Mexico orchard’s modeled pecan tree water use and irrigation dates in the year 2000, tree trunks of 7-inches in diameter growing on a clay soil with 2.25 inches/foot of available soil moisture and assuming a 3-foot root zone (Herrera & Sammis, 2002).

**Figure C.9** Mesilla Valley, New Mexico orchard’s modeled pecan tree water use and irrigation dates in the year 2000 for a mature orchard with trees growing on a clay soil with 2.25 inches/foot of available soil moisture and assuming a 3-foot root zone (Herrera & Sammis, 2002).
Appendix B – Commonly Used Terms in Agricultural Irrigation

The “consumptive water use” of a pecan orchard can be defined as the loss of water through evapotranspiration (ET) (Miyamoto et al., 1995). Consumptive use can be considered “the basis for estimating irrigation water needs” as well as scheduling irrigation (Miyamoto et al., 1995).

“Irrigation application efficiency” (IAE or AE) can be defined as “the ratio of the water volume used by the crop to the irrigation water volume applied” (Sammis et al., 2004; see also ASCE, 1978). AE varies significantly depending on the type of system as well as irrigation management practices (Sammis et al., 2004).

Another term used in these contexts is “water use efficiency” (WUE) which was defined by Jensen et al. (1981) as the “dry matter produced per unit area per unit of evapotranspiration (ET) (in tons/ha per mm)” (Sammis et al., 2004). Begg and Turner (1976) defined WUE as “the total dry matter per unit of ET” (Sammis et al., 2004). Fischer and Turner (1978) and Sinclair et al. (1984) gave the definition of WUE as “photosynthesis per unit of water that is transpired” (Sammis et al., 2004).

A third term used is “irrigation water use efficiency” (IWUE) which can be defined as the ratio of the crop yield to the applied seasonal irrigation water (including rain) and is measured in tons per ha per mm (Sammis et al., 2004; see also Howell, 1994). Sammis et al. (2004) observe, “IWUE is affected by water lost to drainage, canopy interception, soil type, cultural practices and plant species.” Sammis et al. (2004) assert, “IWUE can be increased by proper irrigation timing using irrigation scheduling model-based soil water balance, soil moisture or soil water potential measurements, or plant-based measurements like the crop water stress index.”

Literature also refers to “deficit irrigation”. Pierce (2020, July 10) states, “simple deficit irrigation generally refers to the practice of applying irrigation water in amounts less than the orchard ET” or below the crop’s full water requirement (Fereres & Soriano, 2007). With deficit irrigation, the crop is allowed to become somewhat water stressed – this can be done for either the whole growing season or for a shorter period of time during the season as an adaptation for when water scarcity exists. Also, literature refers to “regulated deficit irrigation” (RDI) in which there are “specific deficits aimed either temporally or spatially to provoke a particular positive response or to mitigate a negative one” (Pierce, 2020, July 10). However, there are drawbacks to using these methods.
Appendix C – Previous Studies & Literature Review

Pecan Orchard ET, Irrigation Requirements, & Related Factors

Doorenbos and Kassam (1979) sought to quantify how ET relates to yield. Doorenbos and Kassam (1979) suggested that this relationship is mainly linear. They recommend that the relationship be defined in terms of maximum potential ET and yield so as to account for variations in crop variety, climate, and other factors not accounted for (Doorenbos & Kassam, 1979). They use the formula:

\[
\left(1 - \frac{Y_a}{Y_m}\right) = k_y \left(1 - \frac{ET_a}{ET_m}\right),
\]

where \(Y_a\) = the actual harvested yield, \(Y_m\) = the maximum harvested yield, \(k_y\) = the yield response factor, \(ET_a\) = the actual evapotranspiration, and \(ET_m\) = the maximum evapotranspiration (Doorenbos & Kassam, 1979). This relates the relative yield decrease to relative ET deficit through \(k_y\) which is a ‘yield response factor’ (empirically derived and estimated after analyzing experimental data from the field) (Doorenbos and Kassam, 1979; Skaggs et al., 2008). Doorenbos and Kassam (1979) found that the equation or formula above explained 80-85% of yield variation due to different water treatments (Doorenbos and Kassam, 1979; Skaggs et al., 2008). However, to estimate \(k_y\), the yield data must be found experimentally or, alternatively, producers must supply accurate yield information (Skaggs et al., 2008; see also Doorenbos and Kassam, 1979). The availability of accurate data can prove to be an issue for this reason.

Miyamoto (1983) gives a brief overview of earlier research done of mature pecan trees in Brownwood, TX and the El Paso, TX – Las Cruces, NM region which found the trees needed 18 cm (8.1 inches) of irrigation water per month during the summer, and that pecan trees generally consume between 2.2 AF (68 cm) to 3.2 AF (100 cm) per season, although pecan trees may consume up to 4.3 AF (130 cm) of water per season depending upon the size and age of the tree (Miyamoto, 1983; Skaggs et al., 2008). Miyamoto (1983) continued this type of research in the El Paso – Las Cruces Mesilla valleys using the soil water depletion method (using a neutron moisture probe). The pecan trees (‘Western’) were surface irrigated and ranged in age from 8 to 35 years old (Miyamoto, 1983). It was determined that for close-spaced (60-120 trees/ha), full-grown trees, the seasonal (April 1 – October 15) consumptive use ranged from 3.2 AF (100 cm) to 4.3 AF (130 cm), comparable to previously done research (Miyamoto, 1983; Skaggs et al., 2008).
Worthington et al. (1987) used Class A evaporation pan techniques and lysimeters to compare seasonal (April – October) consumptive water use in a mature pecan orchard in El Paso, Texas with the seasonal consumptive use in a younger orchard. Consumptive use was found to be 0.9 AF (27 cm) seasonally in the younger orchard, while consumptive use in the more mature orchard was 3.6 AF (109 cm) per season (Worthington et al., 1987; Skaggs et al., 2008).

Steinberg et al. (1990) used weighing lysimeters to measure the water use or ET of young pecan trees in Stephenville, Texas. The daily ET (which we can equate to consumptive use) for these trees was found to be 8.8 mm (0.35 inches) during the month of August (Steinberg et al., 1990; Skaggs et al., 2008) which would equate to 272.8 mm (10.7 inches) for the month.

Miyamoto et al. (1995) sought to quantify the consumptive use of pecans. The researchers note that ‘extreme soil variability’ exists in the majority of irrigated fields throughout the southwest (Miyamoto et al., 1995), which complicates matters. Miyamoto et al. (1995) observed that the consumptive use of a pecan orchard can be defined as the loss of water through ET and the researchers further assert that consumptive use is “the basis for estimating irrigation water needs” as well as scheduling irrigation. Miyamoto et al. (1995) claim, “[Previous] studies show the summer peak consumptive use of mature and crowded orchards under surface irrigation is about equal to pan evaporation rates” (see also Miyamoto, 1983; Worthington et al., 1987).

This equates to a peak water requirement of 0.04 AF per acre per day (1.2 cm a day or 0.5 inches) or “13,000 gallons/day per acre” of water for a mature pecan orchard (Miyamoto et al., 1995). The researchers note that in a “crowded orchard” the annual consumptive use can get as high as approximately 4.3 AF per acre annually (130 cm), but further observe that this value can “fluctuate yearly as the atmospheric evaporative demand fluctuates” (Miyamoto et al., 1995; see also Miyamoto, 1983). The consumptive use of pecan trees can depend on the maturity of the trees, the size of the trees, the spacing of the trees, and the stage of leaf and nut development (Miyamoto et al., 1995).

Table C.1, below, is reproduced from Miyamoto et al. (1995) and represents the “monthly pan evaporation and monthly ET of pecan orchards with different trunk diameters (d) and tree densities (N) in the El Paso Valley, Texas” (Miyamoto et al., 1995; see also Miyamoto, 1983). The final column shows the seasonal use in centimeters.
Table C.1: Monthly pan evaporation and monthly ET of pecan orchards with different trunk diameters (d) and tree densities (N) in the El Paso Valley, Texas (Reproduced from Miyamoto et al., 1995).

<table>
<thead>
<tr>
<th></th>
<th>April</th>
<th>May</th>
<th>June</th>
<th>July</th>
<th>August</th>
<th>September</th>
<th>October</th>
<th>Seasonal use</th>
</tr>
</thead>
<tbody>
<tr>
<td>Pan evaporation &amp;</td>
<td>1.00</td>
<td>1.10</td>
<td>1.17</td>
<td>1.12</td>
<td>0.91</td>
<td>0.74</td>
<td>0.28</td>
<td>192</td>
</tr>
<tr>
<td>Evapotranspiration (^{\text{index}}) &amp;</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>1500</td>
<td>0.14</td>
<td>0.20</td>
<td>0.31</td>
<td>0.35</td>
<td>0.33</td>
<td>0.26</td>
<td>0.19</td>
<td>51</td>
</tr>
<tr>
<td>2000</td>
<td>0.17</td>
<td>0.25</td>
<td>0.41</td>
<td>0.50</td>
<td>0.48</td>
<td>0.38</td>
<td>0.14</td>
<td>71</td>
</tr>
<tr>
<td>3000</td>
<td>0.22</td>
<td>0.34</td>
<td>0.60</td>
<td>0.77</td>
<td>0.74</td>
<td>0.62</td>
<td>0.23</td>
<td>107</td>
</tr>
<tr>
<td>4000</td>
<td>0.23</td>
<td>0.38</td>
<td>0.75</td>
<td>0.89</td>
<td>0.86</td>
<td>0.74</td>
<td>0.27</td>
<td>125</td>
</tr>
</tbody>
</table>

*These values are for surface-irrigated orchards, and can vary with irrigation regimes to be used.

*Miyamoto et al. (1995) explain the reproduced table, Table C.1, shows “examples of typical daily consumptive use in surface irrigated pecan orchards with a trunk diameter \(d\) (cm) and a tree population density of \(N\) (no./ha)” in the climate of El Paso, Texas (see also Miyamoto, 1983). The actual consumption of pecan trees can vary based on a number of factors, as noted above. For instance, in warmer climates the researchers note, “the consumptive use in April, May, September, and October would be somewhat higher than the listed values” (Miyamoto et al., 1995). In September and October, pecan leaves can still transpire water unless there is an early major freeze in the region (Miyamoto, 1983; Miyamoto et al., 1995). The researchers further note the effects of water stress or other stress on pecan trees saying, “early stress (April-May) tends to reduce shoot growth, stress in mid-summer (July-August) can reduce nut size and photosynthesis, and late-season stress (September-October) reduces nut-filling and shuck opening” (Miyamoto et al., 1995).

Table C.2, below, shows examples of some irrigation intervals that were computed from Table C.1 for the depths of the assumed net irrigation which can be used to develop “an approximate irrigation calendar” (Miyamoto et al., 1995). However, the researchers note that adjustments should be made to the calendar based on the actual readings from tensiometers so as to avoid over watering when rain events occur or under watering during unusually hot or dry conditions (Miyamoto et al., 1995).
Table C.2: Typical irrigation intervals for net irrigation rates of 5 cm (2 inches) and 10 cm (4 inches) in orchards with differing trunk diameter trees and/or number of trees per ha (Reproduced from Miyamoto et al., 1995).

<table>
<thead>
<tr>
<th>Net irrigation of 5.0 cm (2 inches)</th>
<th>April</th>
<th>May</th>
<th>June/July</th>
<th>Aug.</th>
<th>Sept.</th>
</tr>
</thead>
<tbody>
<tr>
<td>Index 1500</td>
<td>35</td>
<td>25</td>
<td>16</td>
<td>15</td>
<td>19</td>
</tr>
<tr>
<td>Index 2000</td>
<td>29</td>
<td>20</td>
<td>11</td>
<td>10</td>
<td>13</td>
</tr>
<tr>
<td>Index 3000</td>
<td>23</td>
<td>15</td>
<td>7</td>
<td>7</td>
<td>8</td>
</tr>
<tr>
<td>Index 4000</td>
<td>22</td>
<td>13</td>
<td>6</td>
<td>7</td>
<td>8</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Net irrigation of 10 cm (4 inches)</th>
<th>April</th>
<th>May</th>
<th>June/July</th>
<th>Aug.</th>
<th>Sept.</th>
</tr>
</thead>
<tbody>
<tr>
<td>Index 1500'</td>
<td>(50)</td>
<td>50</td>
<td>32</td>
<td>30</td>
<td>38</td>
</tr>
<tr>
<td>Index 2000'</td>
<td>(50)</td>
<td>40</td>
<td>22</td>
<td>20</td>
<td>26</td>
</tr>
<tr>
<td>Index 3000</td>
<td>46</td>
<td>30</td>
<td>14</td>
<td>14</td>
<td>16</td>
</tr>
<tr>
<td>Index 4000</td>
<td>44</td>
<td>26</td>
<td>13</td>
<td>12</td>
<td>14</td>
</tr>
</tbody>
</table>

These indices are the product of trunk diameter (d) in cm and the number of trees/ha (N). If d and N are expressed in inches and no./acre, multiply 623 to convert to the product to metric units.

These intervals are adjusted for the requirement to apply the second nitrogen fertilization.

Source: Miyamoto et al., 1995

Miyamoto et al. (1995) observed that in surface-irrigated orchards, the first irrigation begins often before budbreak (March 10-15). Although this occurs sometimes later in orchards that are sprinkler irrigated, it generally occurs at least by the first week of April; this is when the root growth and shoot growth rates begin to speed up (Miyamoto et al., 1995). In surface irrigated orchards, the second irrigation usually takes place at the end of April (Miyamoto et al., 1995). However, irrigation and consumptive use becomes much more intensive with the heat of summer when the pecan trees photosynthesize at the maximum rate (Miyamoto et al., 1995; see also Mielke, 1981). By the time the pecan trees enter the “nut filing stage”, the depth of irrigation can be reduced (Miyamoto et al., 1995).

Sorenson (1997) used the water balance method along with computer modeling to estimate ET in commercial pecan orchards in Las Cruces, New Mexico (Sorenson, 1997; Skaggs et al., 2008). Sorenson reported that their calculated ET was actually an overestimation due to the underestimation of drainage; however, from the water balance method, the estimates for the two
sites were 8.8 AF (269 cm) yearly for the orchard and 7.1 AF (216 cm) yearly for the orchard in 1994, and 6.8 AF (206 cm) for the orchard and 13.1 AF (399 cm) for the orchard in 1995 (Sorenson, 1997; Skaggs et al., 2008). Sorenson’s (1997) ET estimates of the two sites using the Arizona Scheduling System (AZSCHED) were 3.6 AF (109 cm) for the year for the orchard and 3.9 AF (118 cm) for the year for the orchard in 1994, and 3.5 AF (108 cm) yearly for the orchard and 4.4 AF (134 cm) yearly for the orchard in 1995.

Frias-Ramirez (2002) estimated ET in a commercial pecan orchard in Las Cruces, New Mexico, using the water balance method, which resulted in an estimated seasonal ET of 3.7 AF (112 cm) in 1996 and 3.4 AF (102 cm) in 1997 (Frias-Ramirez, 2002; Skaggs et al., 2008).

Sammis et al. (2004) studied ET in a mature, commercial pecan orchard to the south of Las Cruces in 2001 and 2002. The orchard was flood irrigated and the pecan variety was ‘Western Schley’. The pecan orchard was bordered by an alfalfa field and other pecan orchards. The total irrigation amounts were 6.4 AF (1940 mm) in 2001 and 6.1 AF (1870 mm) in 2002 (Sammis et al., 2004). The average tree height was 42.0 feet (12.8 m), diameter of the trees was 11.8 inches (30 cm), and a tree spacing of 31.8 feet by 31.8 feet (9.7 m by 9.7 m) (Sammis et al., 2004). The studied employed the one-propeller eddy covariance (OPEC) and energy budget methods, and seasonal (April – November) ET was measured as 4.1 AF (126 cm) in 2001 and in 2002 was 3.8 AF (117 cm) (Sammis et al., 2004; see also Skaggs et al., 2008; Samani et al., 2011). The annual ET measured was 4.0 AF (146 cm) for 2001, and in 2002 annual ET measured 4.5 AF (137 cm) (Sammis et al., 2004; see also Skaggs et al., 2008; Samani et al., 2011). The maximum daily ET was 3.5 inches per day (88 mm per day), and the yearly average irrigation application efficiency (AE) was 79% for 2001 and 2002 (Sammis et al., 2004). It should be noted that the yields that were measured and reported by the farmer/owner of the orchard were 2349 kg/ha in 2001 and 3681 kg/ha in 2002 (Sammis et al., 2004; see also Skaggs et al., 2008).

Table C.3, below, reproduced from Sammis et al. (2004) shows the dates and amounts (in mm) of flood irrigations to the Mesilla Valley area pecan orchard in 2001 through 2002. The total irrigation amount for 2001 was 6.4 AF or 1940 mm. The total irrigation amount for 2002 was just slightly lower at 6.1 AF or 1870 mm.
Table C.3: Dates and amounts (in mm) of flood irrigation to a Mesilla Valley area pecan orchard, 2001-2002 (Reproduced from Sammis et al., 2004).

<table>
<thead>
<tr>
<th>Date</th>
<th>Amount (mm)</th>
<th>Date</th>
<th>Amount (mm)</th>
</tr>
</thead>
<tbody>
<tr>
<td>3 March 2001</td>
<td>88.5</td>
<td>14 March 2002</td>
<td>115.0</td>
</tr>
<tr>
<td>9 April 2001</td>
<td>111.8</td>
<td>17 April 2002</td>
<td>114.4</td>
</tr>
<tr>
<td>1 May 2001</td>
<td>118.0</td>
<td>5 May 2002</td>
<td>203.6</td>
</tr>
<tr>
<td>14 May 2001</td>
<td>121.0</td>
<td>21 May 2002</td>
<td>122.1</td>
</tr>
<tr>
<td>29 May 2001</td>
<td>118.1</td>
<td>3 June 2002</td>
<td>114.3</td>
</tr>
<tr>
<td>8 June 2001</td>
<td>115.8</td>
<td>14 June 2002</td>
<td>125.2</td>
</tr>
<tr>
<td>18 June 2001</td>
<td>121.9</td>
<td>23 June 2002</td>
<td>115.0</td>
</tr>
<tr>
<td>29 June 2001</td>
<td>123.4</td>
<td>4 July 2002</td>
<td>111.3</td>
</tr>
<tr>
<td>9 July 2001</td>
<td>122.7</td>
<td>15 July 2002</td>
<td>96.8</td>
</tr>
<tr>
<td>19 July 2001</td>
<td>127.5</td>
<td>25 July 2002</td>
<td>95</td>
</tr>
<tr>
<td>2 July 2001</td>
<td>100.0</td>
<td>5 August 2002</td>
<td>94</td>
</tr>
<tr>
<td>6 August 2001</td>
<td>95.3</td>
<td>14 August 2002</td>
<td>87.9</td>
</tr>
<tr>
<td>16 August 2001</td>
<td>99.3</td>
<td>23 August 2002</td>
<td>81.3</td>
</tr>
<tr>
<td>27 August 2001</td>
<td>98.8</td>
<td>30 August 2002</td>
<td>94.3</td>
</tr>
<tr>
<td>7 September 2001</td>
<td>119.6</td>
<td>14 September 2002</td>
<td>107.2</td>
</tr>
<tr>
<td>20 September 2001</td>
<td>82.3</td>
<td>23 September 2002</td>
<td>80.4</td>
</tr>
<tr>
<td>4 October 2001</td>
<td>91.2</td>
<td>4 October 2002</td>
<td>112.8</td>
</tr>
<tr>
<td>21 October 2001</td>
<td>85.1</td>
<td>22 October 2002</td>
<td>83.6</td>
</tr>
<tr>
<td>Total</td>
<td>1940</td>
<td></td>
<td>1870</td>
</tr>
</tbody>
</table>

Source: Sammis et al., 2004

Table C.4, below, reproduced from Sammis et al. (2004) shows the monthly ET rates in a mature pecan orchard in the Mesilla Valley. ET rates were measured using the OPEC system during the 2001 through the 2002 growing seasons. These values were compared with Miyamoto’s (1983) values. The seasonal ET in 2001 was 4.1 AF (1260 mm), in 2002 was 3.8 AF (1170 mm), and Miyamoto’s (1983) seasonal ET was 4.3 AF (1310 mm).
Table C.4: Monthly ET rates in a mature pecan orchard in the Mesilla Valley, measured using the OPEC system during the 2001-2002 growing season (Reproduced from Sammis et al., 2004).

<table>
<thead>
<tr>
<th>Year</th>
<th>April (mm)</th>
<th>May (mm)</th>
<th>June (mm)</th>
<th>July (mm)</th>
<th>August (mm)</th>
<th>September (mm)</th>
<th>October (mm)</th>
<th>November (mm)</th>
<th>Seasonal (mm)</th>
</tr>
</thead>
<tbody>
<tr>
<td>2001</td>
<td>88</td>
<td>177</td>
<td>202</td>
<td>221</td>
<td>210</td>
<td>185</td>
<td>136</td>
<td>40</td>
<td>1260</td>
</tr>
<tr>
<td>2002</td>
<td>136</td>
<td>176</td>
<td>218</td>
<td>199</td>
<td>198</td>
<td>170</td>
<td>73</td>
<td>3</td>
<td>1170</td>
</tr>
<tr>
<td>Miyamoto (1983)</td>
<td>70</td>
<td>119</td>
<td>225</td>
<td>278</td>
<td>290</td>
<td>239</td>
<td>86</td>
<td></td>
<td>1310</td>
</tr>
</tbody>
</table>

The first hard frosts were 20 November 2001 and 6 November 2002.

a 1–20 November.
b 1–6 November.

Source: Sammis et al., 2004

The monthly ET reached a maximum in the study of 0.7 AF (221 mm or 8.7 inches) per month during the month of July (Sammis et al., 2004). During the “non-growing season” of November through March, the average ET was 1.6 inches (40 mm) per month (Sammis et al., 2004). In 2001, the annual average ET was 4.8 AF (1460 mm), while in 2002 the average annual ET was 7.8 AF (1370 mm) (Sammis et al., 2004). The researchers further note that during the winter months, ET will depend “both on the climactic conditions and the total amount of rain that falls (Sammis et al., 2004). When compared with Miyamoto’s previous measurements, the OPEC system reported lower monthly water use in June, July, and August, but higher use in April and May (Sammis et al., 2004). It should be noted that 2001 and 2002 represent dry, hot years, receiving only 2.9 inches (74 mm) and 6.6 inches (168 mm) of rainfall for 2001 and 2002, respectively, since normal rainfall for this region is 9.2 inches (234 mm) yearly (Sammis et al., 2004).

Bawazir & King (2004) measured ET in a mature pecan orchard that was flood irrigated. In 2002 and 2003, they used a 3-D sonic anemometer and a one-propeller eddy covariance (OPEC) system. Bawazir & King (2004) reported a seasonal ET of 4.3 AF (130.5 cm) in 2002 and 4.4 AF (133.4 cm) in 2003. They reported annual ET measurements of 4.7 AF (141.7 cm) in 2002 and 4.9 AF (147.9 cm) in 2003 (Bawazir & King, 2004; Samani et al., 2011).

Reveles (2005) also used OPEC and energy budget techniques to measure pecan trees’ ET in a large commercial orchard to the south of Las Cruces, New Mexico. During this study an annual pecan ET was estimated of 4.6 AF (139 cm) in 2004 (Reveles, 2005; Skaggs et al., 2008).
Kallestad et al. (2006) studied pecan orchards in the LRG Basin including the irrigation requirements and yields of pecan trees. They noted that pecan trees have a high consumptive use of water in comparison with other crops (Kallestad et al., 2006). The study further notes pecan trees require a significant amount of soil moisture be present in order to be as productive and healthy as possible (Kallestad et al., 2006; see also Sparks, 2002; Wolstenholme, 1979). In a mature orchard in commercial pecan production, irrigation is a significant factor that affects the pecan yield produced (Kallestad et al., 2006). Kallestad et al. (2006) found that with border irrigation, which is a type of flood irrigation, the irrigation requirement to produce pecans in the area of the study ranges from 6.2 AF (1.9 m) per year to 8.2 AF (2.5 m) per year, dependent upon soil characteristics.

Kallestad et al. (2006) notes that the AEs in the Mesilla Valley, New Mexico of flood-irrigated orchards have been reported as high as 89% (see also Al-Jamal et al., 2001). Kallestad et al. (2006) observe, “Local yields in mature, well-managed, non-stressed orchards typically exceed 3300 pounds per acre in an “on” year”. However, the researchers note, “many factors affect actual yield including: alternate bearing, tree age, tree spacing, pruning regime, prior water or nitrogen stress, and disease” (Kallestad et al., 2006).

Skaggs et al. (2008) notes that “although extensive pecan ET research has been conducted over the last 25 years, all of the previous research is site-specific, and clearly dependent upon production conditions at each farm or orchard studied” (Skaggs et al., 2008). The authors note that with the exclusion of Sorenson’s (1997) self-identified overestimation, “previous research has found a fairly narrow range of pecan ET” (Skaggs et al., 2008). They further note that the annual results from Sammis et al. (2004) and Reveles (2005) ranged from 4.5 AF (137 cm) to 4.8 AF (146 cm) but point out that these orchards are both very intensively managed and are part of the region’s “largest commercial pecan farming operations” (Skaggs et al., 2008). Skaggs et al. (2008) assert that the management styles on these farms are “distinctly different from the majority of pecan farms in New Mexico’s Elephant Butte Irrigation District”. Thus, those values found may be more relevant in large commercial pecan farming operations than for smaller acreage pecan orchards.

Skaggs et al., (2008) combined “remotely sensed parcel-level estimates of ET” with the yield information which was obtained from a “small group of producers”. Skaggs et al. (2008) used simple regression techniques along with yield and ET data to calculate ky for the larger
study area. ET estimates were provided using regional ET estimator (REEM, developed previously; Samani et al., 2007, 2009) for 10 “geographically dispersed pecan parcels” (Skaggs et al., 2008). The researchers normalized the yields as well as the estimates of ET, and then a “simple regression analysis” was performed (Skaggs et al., 2008). The formula used by Skaggs et al. (2008) is as follows:

\[
\left(1 - \frac{Y_a}{Y_m}\right) = f\left(1 - \frac{ET_a}{ET_m}\right)
\]

where \(Y_a\) = the actual yield, \(ET_a\) = the actual ET, \(Y_m\) = the maximum yield, and \(ET_m\) = the maximum ET. The resulting expression is (Skaggs et al., 2008):

\[
\left(1 - \frac{Y_a}{Y_m}\right) = 1.692 \times \left(1 - \frac{ET_a}{ET_m}\right), n = 10.
\]

The R-squared value was 0.82 for this equation, which the researchers noted made these results consistent with Doorenbos and Kassam (1979). In this equation, \(k_y\) is 1.692, and is the constant slope coefficient; Skaggs et al. (2008) explain, “this coefficient is the yield penalty which results from pecan consumptive water use at less than the regional maximum obtained under field, not experimental, production conditions”. They further elucidate, “If a pecan orchard is experiencing a 20% ET deficit (i.e., it is being irrigated such that the trees are consuming 80% of the water they are able to consume), and there is a 34% yield penalty (i.e., actual yield is 66% of potential yield)” (Skaggs et al., 2008). This high \(k_y\) value reveals a “high sensitivity to water deficit, and places pecans in the same category as bananas, maize, and sugarcane with respect to yield response to water deficit” (Skaggs et al., 2008; Doorenbos and Kassam, 1979). The researchers observe that it is likely that yields in the area studied would increase if orchards were willing and able to decrease orchard ET deficits by irrigating according to the trees’ need for water (Skaggs et al., 2008). Along with this, they further state that the area’s pecan orchards’ total consumptive use of water would increase (Skaggs et al., 2008). In the 228 orchards studied, Skaggs et al. (2008) concluded that consumptive use would increase by “approximately 14.5 million \(m^3\) (11,755 AF) if the orchards were well-watered”. The study further asserts, “current low levels of water productivity and deficit irrigation practices are actually resulting in a relatively large water savings” (Skaggs et al., 2008).

By the end of the study, Skaggs et al. (2008) found a maximum annual ET for 2002 of 4.3 AF (131 cm), minimum annual ET was 2.2 AF (66.7 cm), with the average ET weighted by the
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Land area was 3.5 AF (105.2 cm). Of these orchards, 213 or 85% had a total annual ET ranging between 2.6 AF (80.1 cm) and 3.9 AF (120.0 cm) for 2002 (Skaggs et al., 2008).

Skaggs et al. (2008) noted that often farmers are hesitant to disclose their on-farm yields, may consider requests for information to invasions of their privacy, and may underreport or overreport their actual crop yields. This makes it much harder to fully understand the link between water availability, ET, and yield.

In another study, Samani et al. (2011) used the regional ET estimator (REEM) developed previously (Samani et al., 2007, 2009; used by Skaggs et al., 2008) to calculate ET as a “residual surface energy balance”. The model that Samani et al. (2011) developed has the advantage that it is a model specifically for pecans to estimate ET. The stated goal was to provide an easy-to-use tool for pecan farmers’ use in developing irrigation schedules for their orchards (Samani et al., 2011). Samani et al. (2011) wanted to create something that could be used for farms in other localities “by transferring the reference crop coefficients using Kc-GDD relationships” (Samani et al., 2011) or the crop coefficient – growing degree days relationship, which was developed by other researchers for use for mature pecan orchards (Bawazir & King, 2004; Samani et al., 2011; Sammis et al., 2004). This was done by relating crop coefficients, empirically, of a “well-managed, mature reference orchard (Kc-ref; fc = 80%) to canopy cover” using Kc, the crop coefficient for a given orchard, Kc-ref, the crop coefficient of a fully mature reference orchard (where the values of Kc were calculated using climate data and ETc measurements), and fc, the fractional canopy cover or canopy cover (Samani et al., 2011). The equation used was developed using pecan fractional cover using infrared imaging and after calculating daily, monthly, and annual ET values from remote sensing done of 279 orchards in the LRGV (Samani et al., 2011). Figure C.1, below, reproduced from Samani et al. (2011) shows the relationship between annual pecan ET and fractional cover (fc) for various orchards. As fractional cover goes up, ET goes up as well.
Figure C.1: The relationship between annual pecan ET and fractional cover (fc) for various orchards in the Lower Rio Grande Valley (Reproduced from Samani et al., 2011).

Source: Samani et al. (2011)

Samani et al. (2011) explains the relationship between crop ET and reference ET saying, “Once the average monthly $K_C$ [crop coefficient] values are estimated, the crop $ET_C$ can be calculated using the relationship between crop $ET_C$ and reference evapotranspiration estimated from climate data” using the following equation:

$$ET_C = K_C \times ET_O$$

where $ET_C$ = daily, weekly, or monthly consumptive use, $ET_O$ = reference evapotranspiration calculated from either the Penman-Monteith equation (ASCE-EWRI, 2005) or the Hargreaves-Samani equation (1985) depending on the climate data available (Samani et al., 2011).

This method was used to estimate ET values in two pecan orchards in the LRGV (Samani et al., 2011). One orchard was a mature orchard with an average fractional cover of 77% while the other orchard was young with an average fractional cover of 52% (Samani et al., 2011). The remote sensing techniques used by Samani et al. (2011) in the LRGV along with ET measurements from the field for this research resulted in reported mean monthly $ET_C$ with a fractional canopy cover of 52% of 5.5 inches (140 mm), while the predicted value was 5.8 inches (146 mm). With a fractional canopy cover of 77%, the mean monthly measured $ET_C$ was 6.5 inches (164 mm), while the predicted value was 6.6 inches (167.2 mm) (Samani et al., 2011). Here we can clearly see that the more mature tree uses more water.
Figure C.2 and Figure C.3, graphs from Samani et al. (2011) are reproduced below. They note that pecan trees’ ET can vary with “age, canopy cover, soil type, crop density, and method of water management” (Samani et al., 2011). Figure C.2 shows measured and predicted ET for a fractional canopy cover ($f_c$) of 52%. In most months in the season, measured values of ET were lower than predicted values, except in June the measured ET was higher than the predicted ET and in August they are very close with measured ET again being lower slightly than predicted ET values.

*Figure C.2: Measured and predicted ET of a pecan orchard with a fractional cover ($f_c$) of 52% (Reproduced from Samani et al., 2011).*

$Source: Samani et al. (2011)$

Figure C.3 shows measured and predicted ET for an orchard with a fractional canopy cover ($f_c$) of 77%. Here, predicted ET was higher than measured ET in the pecan orchard in June and October. In May and August, predicted and measured ET values are very close. In April, July, and September, measured ET values were higher than the predicted values with the most pronounced difference between the two seen in April.
The researchers report that per year a mature pecan orchard "can consume about 1.4 m (4.5 feet)" based on annual ET values ranging from 1.6 AF (500 mm) to 4.6 AF (1400 mm) (Samani et al., 2011). The authors observe that pecan trees “will grow only to match the availability of water” (Samani et al., 2011). They further note, “In case of water shortage, the pecan canopy dies back” (Samani et al., 2011). Thus, we see that sufficient water is important to the yield as well as the overall health of the tree.

Ahadi et al. (2013) evaluated on-farm irrigation efficiency for three major crops in the Lower Rio Grande Basin (LRG) including alfalfa, cotton, and pecans. The study included 152 alfalfa fields which were evaluated along with 189 pecan fields, and 38 cotton fields, which reported an average on-farm irrigation efficiency of 64%, but values ranged from 11% to 95% (Ahadi et al., 2013).

The LRG valley is an agricultural watershed that is reliant on irrigation for the production of crops. This irrigation water is supplied through “annually allocated surface water from the Rio Grande managed by the Elephant Butte Irrigation District (EBID) and supplemental groundwater” from irrigation wells that are privately owned (Ahadi et al., 2013). The main water application method used on most fields in the study area is surface application. The study notes that a “key parameter in local water management” is irrigation efficiency (Ahadi et al., 2013). The study notes that with surface irrigation in the LRG, on-farm efficiency is dependent on
“various on-farm design and management factors such as soil type, field length, crop type, crop cultural practices, irrigation scheduling, and irrigation methods” (Ahadi et al., 2013).

Table C.5, below, reproduced from Ahadi et al. (2013), shows both the theoretical seasonal ETs and the remotely-sensed seasonal crop ET values. The study area is for the LRG in New Mexico for the year 2008. Pecan trees’ ET ranged from 0.9 to 4.0 AF (275-1223 mm) with a theoretical ET of 4.1 AF (1262 mm) for the year.

Table C.5: Theoretical and remotely sensed seasonal crop ET values in the Lower Rio Grande, New Mexico, for the year 2008 (Reproduced from Ahadi et al., 2013).

<table>
<thead>
<tr>
<th>Crop</th>
<th>Number of fields</th>
<th>ET remote sensing, mm</th>
<th>Theoretical ET, mm</th>
</tr>
</thead>
<tbody>
<tr>
<td>Alfalfa</td>
<td>751</td>
<td>386–1217</td>
<td>1451</td>
</tr>
<tr>
<td>Pecan</td>
<td>1375</td>
<td>275–1223</td>
<td>1262</td>
</tr>
<tr>
<td>Cotton</td>
<td>577</td>
<td>350–879</td>
<td>904</td>
</tr>
</tbody>
</table>

Source: Ahadi et al. (2013)

On-farm irrigation efficiency was calculated by taking the seasonal ET (mm) calculated using remote sensing minus the effective precipitation during the growing season, and this quantity is the divided by the farm delivery requirement (FDR) (which is “the sum of applied groundwater plus applied surface water”), “consistent with the methods used by New Mexico adjudication courts to establish FDR” (Ahadi et al., 2013).

The theoretical crop ET can be calculated with the following equation (Ahadi et al., 2013):

\[ ET = K_c \times ET_r \]

Where ET is the theoretical crop evapotranspiration, \( K_c \) is the crop coefficient, and \( ET_r \) is the reference evapotranspiration (Ahadi et al., 2013). The \( ET_r \) was calculated by Ahadi et al. (2013) by using Hargreaves and Samani (1985), Penman-Monteith (Allen et al., 1998; ASCE-EWRI, 2005), and Allen et al. (1998) and ASCE-EWRI standardized reference evapotranspiration (2005) (Ahadi et al., 2013).

Figure C.4, below, is reproduced from Ahadi et al. (2013) and illustrates the “number of occurrences vs. annual crop ET for 1375 pecan fields in New Mexico’s Lower Rio Grande (LRG) for year 2008” (Ahadi et al., 2013). The greatest number of occurrences appear at 2.6 to 3.3 AF (800-1000 mm) per year with 3.6 AF (1100 mm) per year and 2.3 AF (700 mm) per year, respectively, having the next greatest number of occurrences.
The researchers elucidate, stating, “only 50 fields among the 1375 pecan fields had ET values close to the theoretically optimum ET” required for “well-watered, healthy, disease-and-insect free, actively growing, and overall well-managed crops” (Ahadi et al., 2013). Apparently, most had ET values that varied from the ‘theoretically optimum ET’.

Table C.6, below, reproduced from Ahadi et al. (2013), is a summary of average seasonal irrigation efficiency for alfalfa, cotton, and pecans. The study area is New Mexico’s LRG in the year 2008. The average seasonal irrigation efficiency for pecans in 2008 in the LRG was 59.7% based on 189 fields.

Table C.6: Summary of average seasonal irrigation efficiency for alfalfa, cotton, and pecans for the Lower Rio Grande, New Mexico, for the year 2008 (Reproduced from Ahadi et al., 2013).

<table>
<thead>
<tr>
<th>Crop</th>
<th>Irrigation Eff. % range average</th>
<th>No. fields</th>
</tr>
</thead>
<tbody>
<tr>
<td>Alfalfa</td>
<td>11–95 (65.1)</td>
<td>152</td>
</tr>
<tr>
<td>Pecans</td>
<td>14.5–95 (59.7)</td>
<td>189</td>
</tr>
<tr>
<td>Cotton</td>
<td>11–95 (76.3)</td>
<td>38</td>
</tr>
</tbody>
</table>

Source: Ahadi et al. (2013)
The study notes that “high efficiency values do not necessarily reflect good water management and are often the result of deficit irrigation” (Ahadi et al., 2013; see also Al-Jamal et al., 1997) and the contribution of shallow groundwater to the ET (Ahadi et al., 2013). This value of 59.7% average irrigation efficiency can be compared to the values found in Sammis et al.’s (2004) study. Sammis et al. (2004) found two “well-managed pecan orchards” in the region to have irrigation efficiencies of between 57-63% (Ahadi et al., 2013). It is also of interest to note that “the on-farm irrigation efficiency” utilized in “a recent water rights settlement between the Office of the State Engineer and the New Mexico Pecan Growers was 72%” (Ahadi et al., 2013). The study further notes that 2008 was “a relatively wet year with above average available water” (Ahadi et al., 2013).

Table C.7, below, reproduced from Ahadi et al. (2013), shows the LRG’s average on-farm irrigation efficiency for the years of 2008, 2010, and 2011. During the ‘wet’ year of 2008, the surface water allotment from the EBID was 914 mm which translates to about 3 AF per acre (0.915 ha-m/ha). Farmers used an extra 0.4 AF (115.8 mm) of pumped groundwater to supplement their surface water allocation (Ahadi et al., 2013). The LRG basin, in this study, showed an average on-farm irrigation efficiency of 64%, ranging from 63-66% (Ahadi et al., 2013).

Table C.7: Average on-farm irrigation efficiency for the three years 2008, 2010, and 2011 in the Lower Rio Grande, New Mexico (Reproduced from Ahadi et al., 2013).

<table>
<thead>
<tr>
<th>Year</th>
<th>EBID surface water allotment (mm)</th>
<th>Groundwater diversion (mm)</th>
<th>Total water applied (mm)</th>
<th>(ET-Re) REEM (mm)</th>
<th>Eff. %</th>
</tr>
</thead>
<tbody>
<tr>
<td>2008</td>
<td>914</td>
<td>115.8</td>
<td>1029.8</td>
<td>649.1</td>
<td>63</td>
</tr>
<tr>
<td>2010</td>
<td>609.6</td>
<td>463.3</td>
<td>1072.9</td>
<td>707</td>
<td>66</td>
</tr>
<tr>
<td>2011</td>
<td>100.6</td>
<td>939.4</td>
<td>1040</td>
<td>678.7</td>
<td>65</td>
</tr>
</tbody>
</table>

Source: Ahadi et al. (2013)

Ibraimo et al. (2016) sought to quantify water use including the ET of mature pecan orchards for three different seasons in a semi-arid subtropical climate compared with a previous study done in New Mexico. Ibraimo et al (2016) note that in order for ‘optimal’ nut production, a sufficient water supply is extremely important. An adequate water supply becomes even more important in areas of arid or semi-arid climate where rainfall amounts are low and often sporadic (Ibraimo et al., 2016). Pecans can become water stressed if their water needs are not met, and
this can reduce the quality of the nuts as well as reduce the yield (Garrot et al., 1993; Ibraimo et al., 2016). Ibraimo et al. (2016) assert, “irrigation water management and planning [are] vital factors for maximization of orchard profitability”.

Previous studies examined by Ibraimo et al. (2016), conducted in New Mexico, reported the seasonal crop ET of mature, flood-irrigated pecan orchards ranges from 3.6 AF (1095 mm) to 4.3 AF (1307 mm) (Ibraimo et al., 2016; Miyamoto, 1983; Sammis et al., 2004; Samani et al., 2009). Researchers observed that this large variation reported for mature pecan trees was mainly due to differences in managing techniques such as differences in spacing of trees and pruning techniques which changes the canopy cover or the “fraction of ground covered or shaded by vegetation” (Ibraimo et al., 2016; Wang et al, 2007). There are many additional factors which affect ET including the ‘cultivator’ or species of pecan tree, the soil type, the irrigation techniques and system, the climate, and the presence of mulch on the soil surface or the presence of a cover crop in the orchard (Ibraimo et al., 2016; Pereira et al., 2015).

Ibraimo et al. (2016) conducted a study in Cullinan in the Gauteng Province of South Africa in an area with a semi-arid, subtropical climate with long, hot summers and short, cold winters (Ibraimo et al., 2016). The study pecan orchard was a 22 ha, commercial, mature, mixed cultivator orchard planted with ‘Choctaw’ and ‘Barton’ rootstocks, spaced approximately 30 feet by 30 feet by 30 feet (9 m by 9 m by 9 m), and irrigated using a single micro-sprinkler per tree (Ibraimo et al., 2016). A total of 1.2 inches (31 mm) of irrigation water was delivered to the trees every 6 days for 24 hours (Ibraimo et al., 2016). The amount of irrigation water delivered was adjusted with rainfall events. The average yield during the study period of 2009 to 2012 was 1.9 tons per ha per acre per year, with the ‘off’ season (2010/2011) yield 1.3 tons per ha per acre and the ‘on’ season yield was 2.2 tons per ha (Ibraimo et al., 2016). Soil evaporation was measured with micro-lysimeters, and the daily reference evapotranspiration (ET₀) was calculated using the FAO-56 Penman-Monteith equation (Allen et al., 1998) using weather data from a nearby automatic weather station (Ibraimo et al., 2016).

Table C.8 is taken from Ibraimo et al. (2016) and shows the seasonal totals of the combination of rainfall and irrigation from Cullinan in South Africa along with the reference evapotranspiration (ET₀) and evapotranspiration (ET) for a mature pecan orchard in the region. ‘Choctaw’ pecan trees are grown in this South African pecan orchard (Ibraimo et al., 2016). Ibraimo et al. (2016) reports that the seasonal ET in the “measurement orchard” for the three
seasons ranged between 3.2 AF (985 mm) to 3.4 AF (1050 mm) (Ibraimo et al., 2016). ET₀ ranged from 3.1 AF (944 mm) to 3.4 AF (1034 mm) (Ibraimo et al., 2016). As seen in the table below, Table C.8, the combined irrigation and rainfall amounts exceed either of the ET measurements for the three seasons.

Table C.8: Seasonal totals of irrigation plus rainfall, reference evapotranspiration (ET₀) and evapotranspiration (ET) for a mature 'Choctaw' pecan orchard at Cullinan during three consecutive seasons of measurement (Reproduced from Ibraimo et al., 2016).

<table>
<thead>
<tr>
<th>Season</th>
<th>Irrigation + rainfall (mm)</th>
<th>ET₀ (mm)</th>
<th>ET (mm)</th>
</tr>
</thead>
<tbody>
<tr>
<td>2009/2010</td>
<td>1182</td>
<td>1020</td>
<td>1035</td>
</tr>
<tr>
<td>2010/2011</td>
<td>1117</td>
<td>944</td>
<td>985</td>
</tr>
<tr>
<td>2011/2012</td>
<td>1196</td>
<td>1034</td>
<td>1050</td>
</tr>
</tbody>
</table>

Source: Ibraimo et al., (2016)

Ibraimo et al. (2016) took the Kc values published in FAO-56 (Allen et al., 1998) for stone fruit and adjusted them for the climate of the study site, as well as crop height. They used these adjusted values to estimate the monthly ET of a mature pecan orchard which is irrigated via micro-sprinkler irrigation (Ibraimo et al., 2016). Ibraimo et al. (2016) report on average “fair agreement” (MAPD 15-25%). However, looking at a more detailed view of the season, Ibraimo et al. (2016) report “good agreement between measured and predicted ET (MAPD below 15%)” in the summer months of December – March. However, they report “unacceptable agreement” (above 25% MAPD) at the beginning and end of a season in the form of an underestimation of water use, as seen in the graphs reproduced below in Figure C.5 (Ibraimo et al., 2016). R² values “equal or greater than 0.6 were considered acceptable” (Ibraimo et al., 2016). Model performance was considered “very good” if the mean absolute percent difference (MAPD) was under 10%, MAPD between 10-15% was considered “good”, MAPD between 15-25% was considered “fair”, and an MAPD of over 25% was considered “unacceptable” (Ibraimo et al., 2016).

Figure C.5: Comparison between actual and estimated evapotranspiration (ET) using the generic procedure of FAO-56, with climate adjusted single (time-averaged) crop coefficient (Kc) values published
These graphs give $R^2$ values and MAPD values. $R^2$ is the coefficient of determination while MAPD is an abbreviation for ‘Mean Absolute Performance Difference” (Ibraimo et al., 2016).

**Graph Source:** Ibraimo et al. (2016)

**Soils & Soil Moisture**

Researchers at Texas A&M determined that soils that are “either poorly drained or shallow do not support profitable production” (Nesbitt et al., 2013). Pecans grow the best on well-drained soils that contain adequate nutrients. Researchers at Texas A&M concluded that commercial orchards have a better likelihood of success if the soils are at least 32 inches deep.
Pecan trees need adequate soil moisture to flourish and have bountiful harvests with high quality nuts (Herrera & Sammis, 2002; Kallestad et al., 2006; Sparks, 2002; Wolstenholme, 1979). Researchers at NMSU note that “irrigation water should be applied before 50-60% of the available water is depleted” (Herrera & Sammis, 2002). The researchers further note that in order to determine how much water is needed for irrigation of the orchard, the root zone’s depth needs to be known (Herrera & Sammis, 2002). This can be challenging since as the pecan tree grows, the tree’s rooting depth changes. Additionally, the water requirement for pecan trees increases as the tree grows (Herrera & Sammis, 2002).

Figure C.6, below, reproduced from Herrera and Sammis (2002), models pecan trees’ daily water use, in the year 2000, for New Mexico’s Mesilla Valley followed by a table of the dates of irrigation, Table C.9, below. The orchard consisted of pecan trees with trunks of a 7-inch diameter, “growing on a sandy loam with 1.5 inches/foot of available soil moisture and assuming a 3-foot root zone” (Herrera & Sammis, 2002). For the year, the pecan tree ET rate was 2.9 AF (88.9 cm) in this orchard. The ET peaked between days 183-245.

*Figure C.6: Mesilla Valley, New Mexico orchard with pecan trees' modeled daily water use and irrigation dates in the year 2000. Pecan tree trunks were of a 7-inch diameter growing on a sandy loam*
with 1.5 inches/foot of available soil moisture and assuming a 3-foot root zone (Reproduced from Herrera & Sammis, 2002).

Source: Herrera & Sammis (2002)
Table C.9: Mesilla Valley, New Mexico orchard with pecan trees’ irrigation amounts and dates in the year 2000. Pecan tree trunks were of a 7-inch diameter growing on a sandy loam with 1.5 inches/foot of available soil moisture and assuming a 3-foot root zone (Reproduced from Herrera & Sammis, 2002).

<table>
<thead>
<tr>
<th>Irrigation Amount</th>
<th>Date of Irrigation</th>
</tr>
</thead>
<tbody>
<tr>
<td>Inches</td>
<td></td>
</tr>
<tr>
<td>4.00</td>
<td>1/1*</td>
</tr>
<tr>
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</tr>
<tr>
<td>4.00</td>
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<td>9/19</td>
</tr>
<tr>
<td>4.00</td>
<td>10/7</td>
</tr>
</tbody>
</table>

* A January irrigation is needed to fill the root zone to field capacity, if winter rainfall has not filled the root zone.

Source: Herrera & Sammis (2002)

Figure C.7, below, reproduced from Herrera and Sammis (2002), shows modeled pecan tree daily water use for the year 2000 in New Mexico’s Mesilla Valley. Daily ET peaks on days 183 to approximately 260. Figure C.7 is followed by Table C.10 with the dates of irrigation for “a mature orchard growing on sandy loam with 1.5 inches/foot of available soil moisture and assuming a 3-foot root zone” (Herrera & Sammis, 2002). The pecan tree ET rate is 4.8 AF (144.8 cm) for the year.
Figure C.7: Mesilla Valley, New Mexico orchard modeled pecan trees' daily water use for the year 2000 and dates of irrigation for a mature orchard growing on a sandy loam with 1.5 inches/foot of available soil moisture and assuming a 3-foot root zone (Reproduced from Herrera & Sammis, 2002).

Source: Herrera & Sammis (2002.)
Table C.10: Mesilla Valley, New Mexico orchard pecan trees' irrigation dates and amounts for the year 2000 for a mature orchard growing on a sandy loam with 1.5 inches/foot of available soil moisture and assuming a 3-foot root zone (Reproduced from Herrera & Sammis, 2002).

<table>
<thead>
<tr>
<th>Irrigation Amount</th>
<th>Date of Irrigation</th>
<th>Irrigation Amount</th>
<th>Date of Irrigation</th>
</tr>
</thead>
<tbody>
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<td>Inches</td>
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</tr>
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<td>8/19</td>
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<tr>
<td>4.00</td>
<td>7/15</td>
<td>4.00</td>
<td>10/8</td>
</tr>
</tbody>
</table>

* A January irrigation is needed to fill the root zone to field capacity, if winter rainfall has not filled the root zone.

Source: Herrera & Sammis (2002)

Figure C.8, below, reproduced from Herrera and Sammis (2002), shows modeled pecan tree water use in the year 2000 in New Mexico’s Mesilla Valley. Daily ET peaks between days 160-275.

*Figure C.8: Mesilla Valley, New Mexico orchard’s modeled pecan tree water use and irrigation dates in the year 2000. This is for an orchard with 7-inch diameter tree trunks with the trees growing on a clay*
soil with 2.25 inches/foot of available soil moisture and assuming a 3-foot root zone (Reproduced from Herrera & Sammis, 2002).

Source: Herrera & Sammis (2002)

Table C.11, below, shows the irrigation dates and amounts in this orchard. These data were for an orchard with 7-inch diameter tree trunks. The trees were growing on clay soil with “2.25 inches/foot of available soil moisture and assuming a 3-foot root zone” (Herrera & Sammis, 2002). For this orchard, the ET rate of the pecan trees was 2.9 AF (88.9 cm or 35 inches) for the year.
Table C.11: Mesilla Valley, New Mexico orchard’s irrigation dates and amounts in the year 2000. This is for an orchard with 7-inch diameter tree trunks with the trees growing on a clay soil with 2.25 inches/foot of available soil moisture and assuming a 3-foot root zone (Reproduced from Herrera & Sammis, 2002).

<table>
<thead>
<tr>
<th>Irrigation Amount</th>
<th>Date of Irrigation</th>
</tr>
</thead>
<tbody>
<tr>
<td>Inches</td>
<td></td>
</tr>
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<td>9/14</td>
</tr>
<tr>
<td>4.00</td>
<td>10/13</td>
</tr>
</tbody>
</table>

* A January irrigation is needed to fill the root zone to field capacity, if winter rainfall has not filled the root zone.

Source: Herrera and Sammis (2002).

Figure C.9, below, reproduced from Herrera and Sammis (2002), shows modeled pecan tree daily water use for the year 2000 in New Mexico’s Mesilla Valley as well as irrigation dates. Daily ET peaks between days 160-280.
Figure C.9: Mesilla Valley, New Mexico orchard's modeled pecan tree water use and irrigation dates in the year 2000. This is for a mature orchard with the trees growing on a clay soil with 2.25 inches/foot of available soil moisture and assuming a 3-foot root zone (Reproduced from Herrera & Sammis, 2002).


Table C.12, below, gives the dates and amounts of irrigation for this orchard. The orchard was a mature pecan orchard that was growing on clay soil with “2.25 inches/foot of available soil moisture and assuming a 3-foot root zone” (Herrera & Sammis, 2002). The yearly ET rate of this pecan orchard was 4.8 AF (144.8 cm).
Table C.12: Mesilla Valley, New Mexico orchard's pecan tree irrigation dates and amounts in the year 2000. This is for a mature orchard with the trees growing on a clay soil with 2.25 inches/foot of available soil moisture and assuming a 3-foot root zone (Reproduced from Herrera & Sammis, 2002.).

<table>
<thead>
<tr>
<th>Irrigation Amount</th>
<th>Date of Irrigation</th>
</tr>
</thead>
<tbody>
<tr>
<td>4.00 inches</td>
<td>1/1*</td>
</tr>
<tr>
<td>4.00 inches</td>
<td>3/23</td>
</tr>
<tr>
<td>4.00 inches</td>
<td>4/29</td>
</tr>
<tr>
<td>4.00 inches</td>
<td>5/19</td>
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<td>4.00 inches</td>
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<td>4.00 inches</td>
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<tr>
<td>4.00 inches</td>
<td>9/14</td>
</tr>
<tr>
<td>4.00 inches</td>
<td>9/27***</td>
</tr>
</tbody>
</table>

* A January irrigation is needed to fill the root zone to field capacity, if winter rainfall has not filled the root zone.

** The model indicated that the soil water profile would have been close to the 50% depletion level by the third week in October, but it was decided not to irrigate because it would have been too late to benefit trees during the current season.

Source: Herrera & Sammis (2002)

As we can see from the graphs, pecan trees’ moisture requirements vary with the time of season, the soil type, and the tree’s age. Researchers at NMSU note, “Watering pecan trees should entail more than just applying water to orchards every 14 to 21 days” (Herrera & Sammis, 2002). Knowing how often to appropriately water pecan trees is more complex than just the number of days since the last watering, but also the soil type and the soil’s ability to hold water along with the age of the tree and stage of growth/nut development (Herrera & Sammis, 2002). The amount of water that pecan trees need at the start of the growing season is far less than the
water demand in June and July because temperatures are higher, nuts are growing, and the trees’ foliage has reached full development (Herrera & Sammis, 2002). It is very important to understand the variation in water requirements and soil moisture needs because the growth of a pecan tree can be reduced even before the tree shows signs of stress like permanent wilting (Herrera & Sammis, 2002). To have good yields and growth, the soil moisture needs to be adequate for the tree to flourish (Herrera & Sammis, 2002). Researchers at NMSU state, “Pecans have growth stages when significant yields or quality reductions will occur if adequate soil moisture levels are not maintained” (Herrera & Sammis, 2002).

The “effective root zone” or the “effective rooting depth” is the “depth for soil moisture management in irrigation” (Herrera & Sammis, 2002). Researchers at NMSU observe that irrigation water should penetrate 3 feet down from the soil surface for pecan trees, and they recommend measuring the depth of soil moisture to ensure adequate irrigation (Herrera & Sammis, 2002). In addition to well-drained soils with adequate soil moisture, pecan trees must be fertilized regularly (Nesbitt et al., 2013).

**Tree Spacing & Orchard Floor Management**

Tree spacing is very important in a pecan orchard. To be productive, pecan trees need to have plenty of sunlight. Researchers at Texas A&M determined that “inadequate sunlight hinders pecan production even before the limbs of adjacent trees touch one another” (Nesbitt et al., 2013). It was determined that, in the summer, at least 50% of the “orchard floor should receive sunlight at mid-day” (Nesbitt et al., 2013). Miyamoto et al. (1995) note that with tree spacings of about 40 to 40 feet (9 to 12 m) an orchard floor could “be covered with roots” in under 10 years. Nesbitt et al. (2013) advise that to avoid problems such as smaller nuts, reduced production, lower percent kernel, increased issues with insects and diseases, and to delay crowding in the orchard, pecan trees should be planted 50 feet apart. It also should be noted that if trees are not spaced to receive adequate sunlight, alternate bearing will be intensified. This means that in a nut tree like pecans, the tree’s tendency to “bear nuts in 2-year cycles with a large crop followed by a small or no crop” will become more noticeable with inadequate sunlight (Nesbitt et al., 2013).

With such high light intensities in New Mexico’s arid environment, “orchard managers often use mechanical pruning techniques to maximize light infiltration of the canopy” (Thompson & Conner, 2012).
Researchers at Texas A&M found that weeds growing on the orchard floor “compete with pecans for water and nutrients” (Nesbitt et al., 2013). They further found that weeds can reduce growth and the development of kernels (Nesbitt et al., 2013). Researchers at Texas A&M recommended a “sod and strip system” or “shallow, clean cultivation” (Nesbitt et al., 2013). Sod and strip systems are described as leaving a weed-free band (generally herbicide treated) down the rows of trees with sod being grown between the weed-free bands; this sod is then maintained by regular mowing (Nesbitt et al., 2013). Shallow, clean cultivation, however, is described as removing all plants except for the pecan trees, with “disk harrow (disking)” (Nesbitt et al., 2013). Shallow, clean cultivation is often practiced when orchards are flood irrigated (Nesbitt et al., 2013).

**Harvesting**

For some smaller orchards, harvesting may be able to be done by hand; however, most orchards will require mechanical harvesting (Nesbitt et al., 2013). Some equipment required for mechanical harvesting includes trunk shakers to get the crop on the ground, harvesters to pick up pecans, sticks, leaves, and other debris, as well as cleaners to separate the good pecans from the trash (Nesbitt et al., 2013). Pecans must be processed immediately following harvesting in order to avoid developing issues such as embryo rot, darkening of kernels, or sprouting (Nesbitt et al., 2013).
Appendix D – CropScape Categories/CDL Codes Analyzed

Categories/CDL Codes Analyzed for Valencia County

The CDL codes on CropScape that were analyzed for Valencia County:

(1) Corn
(2) Cotton
(4) Sorghum
(21) Barley
(22) Durum Wheat
(23) Spring Wheat
(24) Winter Wheat
(28) Oats
(29) Millet
(36) Alfalfa
(37) Other Hay/Non-alfalfa
(42) Dry Beans
(48) Watermelons
(49) Onions
(53) Peas
(59) Sod/Grass Seed
(61) Fallow/Idle Cropland
(68) Apples
(69) Grapes
(74) Pecans
(111) Open Water
(121) Developed/Open Space
(122) Developed/Low Intensity
(123) Developed/Medium Intensity
(124) Developed/High Intensity
(131) Barren
(141) Deciduous Forest
(142) Evergreen Forest
(143) Mixed Forest
(152) Shrubland
(176) Grass/Pasture
(190) Woody Wetlands
(195) Herbaceous Wetlands
(204) Pistachios
(205) Triticale
(216) Peppers
(225) Double Crop-Winter Wheat/Corn
(226) Double Crop-Oats/Corn
(227) Lettuce
(229) Pumpkins
(236) Double Crop-Winter Wheat/Sorghum
(237) Double Crop-Barley/Corn

**Categories/CDL Codes Used for Land Use Charts**

Using Microsoft Excel pie charts were constructed for 2010 and 2020, respectively. The pie chart of the overview of land use in the county will group land use as listed below.

**Agriculture:**

(1) Corn
(2) Cotton
(4) Sorghum
(21) Barley
(22) Durum Wheat
(23) Spring Wheat
(24) Winter Wheat
(28) Oats
(29) Millet
(36) Alfalfa
(37) Other Hay/Non-alfalfa
(42) Dry Beans
Watermelons
Onions
Peas
Sod/Grass Seed
Fallow/Idle Cropland
Apples
Grapes
Pecans
Grass/Pasture
Pistachios
Triticale
Peppers
Double Crop-Winter Wheat/Corn
Double Crop-Oats/Corn
Lettuce
Pumpkins
Double Crop-Winter Wheat/Sorghum
Double Crop-Barley/Corn
Barren:
Barren
Developed:
Developed/Open Space
Developed/Low Intensity
Developed/Medium Intensity
Developed/High Intensity
Forest:
Deciduous Forest
Evergreen Forest
Mixed Forest
Shrubland:
(152) Shrubland

Open Water:
(111) Open Water

Wetlands:
(190) Woody Wetlands
(195) Herbaceous Wetlands

For land use (excluding shrubland) pie graphs for 2010 and 2020, respectively, the same categories as above were used; however, the shrubland category was excluded.

Categories/CDL Codes Used for Agricultural Land Use Pie Graphs

For agricultural land use pie graphs for 2010 and 2020, respectively, the following CDL codes were grouped into the following categories.

Alfalfa:
(36) Alfalfa

Vegetables:
(1) Corn
(49) Onions
(53) Peas
(216) Peppers
(225) Double Crop Winter Wheat/Corn
(226) Double Crop Oats/Corn
(229) Pumpkins
(237) Double Crop Barley/Corn

Other Agriculture:
(2) Cotton
(4) Sorghum
(21) Barley
(22) Durum Wheat
(23) Spring Wheat
(24) Winter Wheat
(28)  Oats
(29)  Millet
(37)  Other Hay/Non-Alfalfa
(42)  Dry Beans
(48)  Watermelons
(59)  Sod/Grass Seed
(205)  Triticale
(236)  Double Crop Winter Wheat/Sorghum

To specifically look at pecans the below CDL code were used.

Pecans:

(74)  Pecans