A SPATIOTEMPORAL ECONOMIC ANALYSIS OF CROP PRODUCTION IN THE TEXAS HIGH PLAINS

By

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ABSTRACT

The Texas High Plains is one of the most prolific crop-producing areas in the United States. Agriculture plays a vital role in the economy of this region. The agricultural industry in this area faces various challenges: environmental, economic, etc. Due to extreme weather conditions and climate change, crop production in the Texas High plains is facing a great threat. Crop production needs irrigation water. The primary source of irrigation water in this region is the Ogallala Aquifer. The saturated thickness of this aquifer is being depleted day by day, which is a big concern for the irrigation of crop production (Guerrero et al., 2019).

A survey of the literature shows that few studies have investigated the cropping pattern for a specific crop based on production amount, but there is no study that broadly investigated the cropping pattern based on harvested acres for this region. So, it is important for policy purposes to investigate the spatiotemporal change of cropping patterns in this region. The main objective of this research is to visualize the historical change of cropping patterns in the Texas High Plains from the standpoint of geographical concentration and spatial autocorrelation.

Historical county-level agricultural census data were collected from the United States Department of Agriculture’s (USDA) National Agricultural Statistical Services (NASS) from 1978 to 2017. Exploratory data analysis (EDA) techniques were employed to examine the geographical concentration and the spatial dependence of crop production among nearby locations.

Results of temporal changes indicate that harvested acres and the number of farms trend down through the study period. Maps were generated for each variable of interest which shows how much cropland acres have changed over time. The Gini coefficient and the quantiles of size distributions were computed for all variables of interest to analyze the change in geographical distribution. Total harvested cropland acres were nearly uniformly distributed across the 39 counties whereas irrigated harvested cropland acres were concentrated in a smaller number of counties, which is an indication of the change in geographical concentration in the Texas High Plains. Both total and irrigated harvested corn, cotton, sorghum grain, and wheat acreages were concentrated in a smaller number of counties over time while wheat production was mostly concentrated in the northern part of the region. The number of acres harvested for a specific crop relative to the number of total cropland acres show that most counties had more than 50 percent of its harvested cropland as cotton indicating that cotton is the prominent crop in the Texas High Plains. The percentage of acres of irrigated harvested cropland relative to total harvested cropland acreage has decreased over time. The Moran's I test statistics for both irrigated and non-irrigated cropland areas suggest that there was spatial dependence among the neighboring counties in the production of crops in this region. In summary, there was a spatiotemporal change in cropping patterns in the Texas High Plains over the study period.

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CHAPTER I

INTRODUCTION

The Texas High Plains is one of the most intensive agricultural areas in the United States. The region covers about 37,676 square miles and is comprised of 39 counties. Agriculture is the major economic driver in this region. The Texas High Plains is home to a substantial portion of the agricultural production of Texas. The significance of agricultural production in this region is magnificent compared to the rest of the Texas. In 2017, total acres of cropland were 29,360,229 in Texas. Among these total acres, the 39 counties of the Texas High Plains cover 6,595,607 acres (78 percent of total Texas cropland) (USDA NASS, 2017).

The history of agriculture involves the human-induced spatial movement of crop production. The agricultural industry in this region faces unique agronomic, environmental, and economic challenges due to extreme weather conditions, water scarcity, and changing economic environments. The climate is semi-arid, and the change of climate results in a reduction in regional rainfall and an increase in crop water demand; as a result, irrigated agricultural production in this region is facing a great threat (Thayer, 2018). Due to low precipitation rates, most agricultural producers in the region are dependent on the Ogallala Aquifer for irrigation water (McCullough, 2016).

The Ogallala Aquifer was formed by ancient runoff from the Rocky Mountains. This aquifer was first discovered by the United States Geological Survey (USGS) in the 1890s (Hornbeck et al., 2014). After World War II, farmers enabled different technologies for large-scale irrigation to extract the groundwater from the Ogallala Aquifer (Hornbeck et al., 2014). The use of groundwater has been increasing for irrigation; however, according to the USGS, after 1974 the water tables have declined substantially from the predevelopment level (McGuire et al., 2003).

In 1978, the total irrigated harvested cropland area was 4,393,257 acres in the Texas High Plains (USDA NASS, 1978). However, the total irrigated harvested cropland area decreased to only 2,940,888 acres in 2017 (USDA NASS, 2017). The major irrigated crops grown in this area are corn, sorghum, and wheat however cotton, sorghum, and wheat can be grown in both irrigated and non-irrigated areas. In 2017, total irrigated acres harvested for corn, cotton, sorghum, and wheat were 519,029, 1,517,214, 98,708, and 236,879 acres, respectively. The availability of irrigated water and the temperate weather conditions has made the area suitable for crop production. From 2012 to 2017, the Texas High Plains was in the top third and fifth position among other states in the U.S. for cotton and sorghum production, respectively. For the same time period, the Texas High Plains was also in the top 15^{th} position for corn and wheat production throughout the country (Benavidez et al., 2019).

To visualize the historical changes of the spatial and temporal patterns of crop production, several exploratory data analysis (EDA) techniques are used by researchers. The Gini coefficient is also one of the oldest measures to summarize the change of geographical concentration used in many studies since it provides a way to simplify the complex values to a single number (McBride, 1997). There are few studies that have analyzed the spatiotemporal patterns of crop production in Texas High Plains. However, most of these studies on changes in regional economic activity in this region have focused mainly on the impacts of one-time major events. To help regional producers and the public make better and more informed decisions, it is essential to have visuals that communicate complex information on the spatiotemporal dynamics of changes in regional economic activity in a simple value. Regional producers and the public should benefit from ability to access and visualize the spatial and temporal patterns of regional crop production activity information. Therefore, this study aims to examine historical changes in spatiotemporal patterns of crop production in Texas High Plains from the standpoint of geographical concentration and spatial autocorrelation. In particular, this study attempts to answer the following research questions:

1. Do geographical concentration patterns of crop production show spatial trends and have the trends changed over time?
2. Is there any spatial dependence in the production of major crops across the Texas High Plains counties?

CHAPTER II

LITERATURE REVIEW

The purpose of this section is to review the previous studies that are related to the spatiotemporal analysis of agriculture. Since this study examines the historical patterns of crop acreage in the Texas High Plains, studies related to cropland used in this region are also reviewed. Specifically, three main strands of literature are reviewed: 1) spatial and temporal analysis in agriculture, 2) exploratory spatial data analysis, and 3) cropping patterns in the Texas High Plains.

Spatial and temporal analysis in agriculture

Understanding spatial and temporal changes in the production of major crops in a specific area is important for effective, evidence-based agricultural and economic policies. McBride (1997) examined the historical change in geographical distribution and concentration of livestock production in the United States. Specifically, changes geographical concentration in hogs, dairy, beef, and poultry production between 1969 and 1992 were analyzed using one of the oldest measures of inequality – the Gini coefficient. The results showed that the greatest change in geographical concentration was in egg production of layer hen and pullet inventory during the study period. Results also suggested that geographical concentration in the other livestock industry was not as high as broiler production.

Beddow et al. (2015) examined the historical change of spatial movement of plants and animals from 1879 to 2007. Environmental, biological, and spatial change plays a vital role in crop production. There are also other factors such as soil type, elevation, rainfall, pests and disease, sunlight, and temperature that limit agricultural productivity. To assess the effects of climate change on agriculture, the Ricardian approach, which is a measure to analyze the farmland values, was used. This study focused only on U.S. corn production. Agricultural census data from 1889 to 2007 were used in the analysis. The analysis results indicate that U.S. corn production increased dramatically during the twentieth century.

Laingen (2015) focused on spatial and temporal changes in U.S. sorghum production from 1930 to 2015. The data used was collected from USDA's NASS Quick Stats 2.0 Interactive Data Query Tool. This study monitored national as well as county-level sorghum production trends. Historically, sorghum production declined in the mid to late 1950s. Sorghum was mainly grown in Nebraska, Kansas, Texas, Oklahoma, and Missouri since sorghum is a drought-tolerant crop. The principal buyer of sorghum in the late 1950's was Mexico and in 2014 China imported more than 90 percent of sorghum from the U.S. This study also evaluated the risk of sorghum production relative to corn production using yield data. The research results suggest that that corn yields have always been higher than sorghum, but the yield risk of sorghum is much less than that of corn.

Hicke et al. (2004) focused on the temporal behavior of net primary production (NPP) for croplands across the United States using data collected from NASS. This study used the methods outlined in Lobell et al. (2002) and Prince et al. (2001) to estimate the contribution of cropland NPP and convert the value to estimate the production for each county. According to the study results, the estimated NPP varies across regions due to several reasons including changes in crop selection decisions, management practices, climates, and economics. Based on NPP values, results show that crop production was concentrated in the Great Plains and Midwest regions at the national level. The NPP values were positive throughout the western counties at the county-level in the United States.

Zipper et al. (2016) analyzed the effects of drought on U.S. maize and soybean as well as the variability of crop production associated with drought. This study suggested management strategies that help to sustain long-term crop productivity. Data on maize and soybean production from 1958 and 2007 were collected from NASS. This study used standardized precipitation and evaporation index (SPEI) to assess the impacts of meteorological drought on agricultural production. A meteorological dataset was utilized to calculate monthly precipitation deficit and monthly SPEI. To assess irrigation impacts on drought sensitivity, a two-tailed t-test and multivariate adaptive regression splines (MARS) was used. The results indicate that crop yield variability over time was typically lower in higher-yielding regions and that yield was much greater for maize than soybean production. However, maize was much more sensitive to short term meteorological drought than was soybeans.

Sukcharoen et al. (2020) focused on the crop price expectations of irrigated producers and analyzed the groundwater pumping decision in the Western Kansas region within a profit maximization framework. The purpose of this study was to analyze a relationship between producers' crop price expectations and groundwater pumping decisions. County-level data were collected from Northwest Kansas Groundwater

Management Districts 4 (GMD4) and monthly precipitation data were collected from the PRISM Climatic Group. Kansas monthly cash price data were used to construct expected crop prices from 1997 to 2016. This study focused on the five most common irrigated crops (namely alfalfa, corn, sorghum grain, soybean, and wheat). The estimation results suggest that producers of northwest Kansas adjust the quantity of groundwater pumped in response to change in precipitation for various irrigated crops. However, there was no statistically significant relationship between crop price expectations and groundwater pumping decisions.

Franczyk et al. (2009) investigated the spatial trends of water use in Oregon and examined biological and socioeconomic factors to explain the spatial patterns from 1985 to 2005. Oregon is divided into 36 counties and their water resources and water demand are unique. Irrigated crop production is one of the most important parts of Oregon's economy. Water availability in this region mostly depends on climate (precipitation) and the Cascade Mountain range. Water-use data were collected from the United States Geological Survey (USGS) Oregon Water Services Center Water Use Program, and weather data were retrieved from the PRISM Climate Group. To examine the spatial patterns of water use, Moran's I local index of spatial autocorrelation and spatial regression model were employed. GIS, Ordinary Least Squares (OLS), and spatial regression models were used to analyze the relationship between water use and other physical and socioeconomic variables. Results suggest that the pattern of total water withdrawals in Oregon differs greatly due to climate variability and that there is a positive moderate spatial autocorrelation with differing degrees of spatial dependence among neighboring counties.

Wallander et al. (2012) focused on determining the environmental and economic implications of shifting corn production. Specifically, the study investigated how farm-level land-use decisions affected corn supplies and other competing crops. Corn is one of the most grown crops in the agricultural industry in the United States. Production of ethanol dramatically increased in the year 2006-2008. According to this research, between 2000 and 2009, corn-based ethanol production increased by nine billion gallons. The authors provided some evidence for why and how farmers altered their land-use decisions. Specifically, as the price of corn increased relative to the prices of other crops such as soybeans, wheat, and cotton, farmers would be more interested in producing corn than other crops. Data used in the analysis were collected from USDA's NASS and Agricultural Resource Management Survey (ARMS). National, state, and county-level data from several states in the corn-belt (Iowa, Illinois, Minnesota, South Dakota, Kansas, Mississippi, and Arkansas) were collected from 2000 to 2009. Farms were categorized according to the major crop grown in that region. According to this research, 20 percent of an increase in corn prices between 2007 and 2008 was due to domestic ethanol demand. Other factors influencing corn prices included energy prices, exchange rates, and adverse weather. Research shows the relative importance of corn acreage for corn expansion by expanding double-cropping practice, increasing the amount of land planted, diverting corn from exports, food production, and livestock feed. Results also show a significant difference in aggregate and farm-level data of corn. Corn and soybean planting in alternate years (a three-year rotation of corn-corn-soy) makes a good adjustment to higher corn demand. The research found that market adjustment and crop rotation have a great influence on the expansion of corn prices at both farm and aggregate levels. Results also suggest that farm-sector and farm-level adjustments to increased ethanol production could differ in the future.

Yunda et al. (2020) analyzed the comprehensive agricultural productivity discrepancy in the context of spatial and temporal characteristics in the main agricultural production areas of Jilin Province, China. This study also describes how the agricultural productivity of the Jilin Province increased through the improvement of social and economic development. Agricultural productivity is measured as the ratio of input to output. The modernization of agriculture most of the time depends on the improvement of comprehensive agricultural productivity. Data were collected from the *Jilin Statistical Yearbook* (Statistic Bureau of Jilin, 2005–2018). Four methods used for comprehensive agricultural productivity analysis were: 1) Evaluation Index System, 2) Spatial Differentiation Indices, 3) Spatial Convergence and Divergence, and 4) Measurement of Comprehensive Agricultural Productivity. The results show a significant positive correlation between the comprehensive agricultural productivity and area planted with grain. The evolution of comprehensive agricultural productivity discrepancy over time showed a fluctuating downward trend from 2004 to 2017.

Exploratory spatial data analysis

Geographical Information system (GIS) is a very powerful tool to visualize spatial patterns like the area of different crop fields on a farm. GIS-based maps can be created to explore historical patterns of crops, urbanization trends, land use or cover change, and water use in the industry. The change in production decisions or land use can be easily visualized from these maps. Several studies that have applied GIS-based approaches for exploratory spatial data analysis purposes are reviewed in this section.

Martinez-Casasnovas et al. (2005) proposed a method that allows long-term crop patterns mapping using time series of crop maps. The crop maps were derived from the supervised classification of remote sensing data. This study applied the GIS overlay analysis operations to derive the spatial and temporal relationships between crops. Results show that the application of the method to the study area revealed a great variability of cropping patterns.

Guerrero et al. (2019) focused on the impact of dairy industry expansion on water use, crop composition, and the local economy. Data on dairy cow inventory and annual irrigated crop acres were collected from the Federal Milk Marketing Order and Farm Service Agency, respectively. The Wilcoxon test and SAS PROC NPERWAY methods were employed to determine the significant difference in the number of acres of crop grown at the beginning of 2000 and the most current data of 2015. Moran's I statistics were presented to visualize the spatial autocorrelation among neighboring dairy industries in Texas High Plains. Water use under the baseline scenario and the alternative hypothetical scenario were evaluated to determine the impact of dairies on total water use in the study region. Results showed that total irrigated area decreased by 17.8 percent from 2000 to 2015, which indicates a tradeoff between the increased irrigation requirement from the demand for feed by the dairies and the overall irrigation demand in the region. Moran's I statistics suggested that spatial autocorrelation of dairy inventory by county in the study region had a positive increase from 2000 to 2015.

Xiao et al. (2006) examined the urbanization trends of Hebei Province in China using Geographical Information System (GIS) and remote sensing. The objective of the study was to explore the temporal and spatial characteristics of urban expansion and examine the land cover change due to urbanization between 1987 and 2001. To achieve these goals, multi-annual socio-economic statistical and two types of satellite multi-spatial images were collected from 1934 to 2001. GIS software (MapInfo5.0) was used to create maps of the urban area of Shijiazhuang city in different historical periods. The annual urban growth rate (AGR) was calculated to evaluate the spatial distribution of the urban expansion intensity. Results indicate that the urban area of Shijiazhuang city expanded by 96 percent from 1934 to 2001. However, the annual growth rate varied significantly during the different periods and the fastest expansion stage was from 1981 to 2001. Results from the landscape change due to high-speed urbanization show that urban regions greatly increased while the agricultural lands decreased significantly.

Cropping patterns in the Texas High Plains

Agriculture in the Texas High Plains is different from other areas in the United States. The Texas High Plains is a semi-arid region, and irrigation is vital to this region. The depletion of groundwater sources is a growing concern for crop production in this region. This section reviews the articles related to cropping patterns in Texas High Plains.

Terrell et al. (2002) analyzed the economic impact of cropping patterns in Texas High Plains. The economy of this region is highly dependent on the agriculture and agribusiness sector. Corn, cotton, sorghum, and wheat are the four major crops grown in Southern High Plains (SHP). According to Texas Agricultural Statistics Services, cotton is the prominent crop and irrigation water mainly comes from the Ogallala Aquifer in this region. Irrigated cropland acreage in the SHP region has declined from 1.58 million hectares in 1958 to 1.33 million hectares in 1994 (Texas Water Development Board, 1996). Dynamic linear programming and the IMPLAN program were used to estimate the optimal cropping pattern and the economic impact resulting from the decrease in the availability of groundwater in this region over a 30-year period. Although the saturated thickness of the Ogallala Aquifer was decreased, the results indicate that non-irrigated crop production was expected to increase over the 30-year planning horizon and sprinkler irrigation also increased significantly. The effect of the depletion of the Ogallala Aquifer resulted in a shift in the adoption of sprinkler irrigation methods in this region. However, counties such as Castro, Lamb, Parmer, Hale, and Lubbock were all experiencing a large increase in the proportion of non-irrigated acreage over the planning horizon, which indicates that the regional cropping patterns in the SHP began to shift toward more non-irrigated agriculture.

Hornbeck et al. (2014) focused on the historical change of groundwater availability mainly from the Ogallala Aquifer, the short- and long-run effects of agricultural adaption to water resources, and the threat of drought. Groundwater is a valuable agricultural asset that resists drought in the short run and increases the production of crops in long run. This study provides an overview and background on the Ogallala Aquifer. According to this research, the Ogallala Aquifer was formed by ancient runoff from the Rocky Mountains and was first discovered in the 1890s by the United States Geological survey. Depletion of the aquifer may encourage the farmer to produce drought tolerant crops. Data were collected from the Census of Agriculture and the United States geological survey, and the baseline model was used for adaptation of groundwater in agricultural production. A placebo test was employed to explore the local spillover effects throughout the nearby counties of the Ogallala Aquifer. Groundwater reduces the negative impact of drought on the water-intensive crop. Historical changes in spatial cropping patterns at the county-level were observed in this study. Results indicate that from 1970 to 1997, irrigation increased by 11 percent for those counties that lied over the Ogallala Aquifer. Since corn and wheat are both water-intensive crops, irrigated corn and wheat acres increased throughout the time period in the study region but total acres for both crops decreased.

Perrin et al. (2018) analyzed irrigated agricultural production in eight states that underlie the Ogallala Aquifer (southern South Dakota, southeast Wyoming, eastern Colorado, Nebraska, western Kansas, eastern New Mexico, northwest Oklahoma, and northwest Texas). This study also estimated the crop production damage caused by extreme temperature. Data on crop production and weather information were collected from 1960 to 2007 for 205 counties from these eight states. A regression technique was used to estimate the irrigation elasticity (IR), which is related to the county dry matter yields to the share of the irrigated county area. Data were used to estimate the irrigation elasticity to observe the yield of each county separately. To estimate extra production due to irrigation, the authors first analyzed the yields at the county-level then multiplied by IR elasticity. In 2007, most of the irrigated agricultural production was produced in Nebraska which was worth around two billion dollars. The agricultural production of Nebraska mostly depends on irrigation from the aquifer. Nebraska overlies 36 percent of the total HPA area and 69 percent of the total water volume. This study finds that Nebraska benefited most from water withdrawn for irrigation than did Kansas and Texas.

Xue et al. (2017) examined the production levels and management practices of corn producers in the Texas High Plains with reduced or limited levels of irrigation. Corn has a high evapotranspiration (ET) demand (both daily and seasonally) in the Texas High

Plains (Howell et al. 1995; 1996). Although corn yield varied from year to year, there was a clear linear increasing trend from 1975 to 2015. The application of less irrigation water than the plants require for full crop ET (100 percent level), can be future research in the Texas High Plains Management practices are more important than breeding when water exists in limited conditions. Irrigation management is the most effective way to sustain high crop productivity. The irrigation system has changed significantly over time from furrow irrigation to sprinkler. Soil moisture sensors can provide information on soil moisture fluxes in the root zone, which provides information on when to initiate and terminate irrigation events. Hybrid selection is also another impacting factor for corn producers. The authors stated that breeding for drought tolerance in corn is a major goal to improve yield stability under drought conditions. Results show that newly developed drought-tolerant corn hybrids have been shown to provide yield benefits by 10-15 percent under limited (reduced) irrigation water levels. Irrigated corn management practices in the Texas High Plains require proper management, hybrid selection, seeding rate, and planting date to get a higher yield.

Based on the literature review above, there were very few studies that examined the spatiotemporal patterns of crop production in the Texas High Plains. Therefore, this research adds to the existing literature by analyzing county-level, time-series data on crop production. In particular, several exploratory data analysis techniques were employed to examine and visualize the changes of spatiotemporal crop production patterns in this region over the past 40 years.

CHAPTER III

DATA AND METHODS

Study area

The study analyzes temporal changes in county-level spatial patterns of crop production in the Texas High Plains. The study area consists of the following 39 counties in the Northern and Southern High Plains Texas Agricultural Statistics Service (TASS) districts: Andrews, Armstrong, Bailey, Briscoe, Carson, Castro, Cochran, Crosby, Dallam, Dawson, Deaf Smith, Floyd, Gaines, Glasscock, Gray, Hale, Hansford, Hartley, Hemphill, Hockley, Howard, Hutchinson, Lamb, Lipscomb, Lubbock, Lynn, Martin, Midland, Moore, Ochiltree, Oldham, Parmer, Potter, Randall, Roberts, Sherman, Swisher, Terry, and Yoakum (Figure 1). The region is comprised mostly of agricultural land, with nearly 11.4 million acres of cropland in 2017 (USDA-NASS, 2019). The climate is semi-arid with low rainfall. Annual precipitation varies largely across these 39 counties with long-term averages of 14.2-23.7 inches (PRISM Climate Group, 2020). Due to the low precipitation, crop production in the area relies heavily on irrigation water from the Ogallala Aquifer. Given the depletion of the Ogallala Aquifer, it is important for policy purposes to examine historical changes in spatiotemporal patterns of crop production within the region.

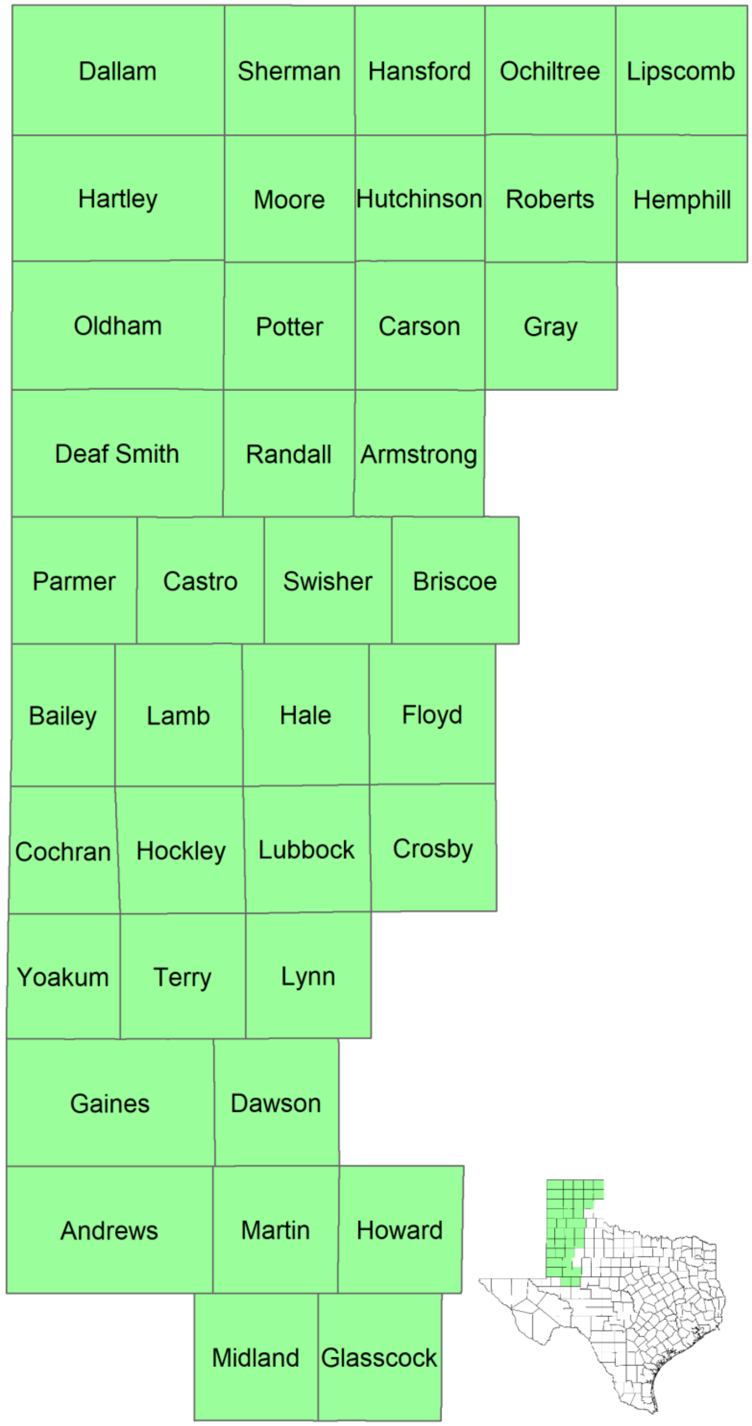

Figure 1. The 39-county area of the Northern and Southern High Plains Texas Agricultural Statistics Service (TASS) districts and its location in the State of Texas.

Agricultural census data

Historical county-level agricultural census data for the years 1978, 1982, 1987, 1992, 1997, 2002, 2007, 2012, 2017 were collected from the United States Department of Agriculture's (USDA) National Agricultural Statistics Service (NASS). Variables included in this study are total and irrigated harvested cropland area, number of farms, total and irrigated corn harvested areas for grain , number of farms with corn harvested for grain ,total and irrigated cotton harvested area , number of farms with cotton harvested, total and irrigated sorghum harvested area for grain , number of farms with sorghum harvested for grain, total and irrigated wheat harvested area for grain , and number of farms with wheat harvested for grain . Four crops – corn, cotton, sorghum, and wheat – were chosen because these are the most prominent crops in the Texas High Plains and census data were available for these crops throughout the study period. Census data were chosen for the analysis as they present a near-complete, county-level enumeration of U.S. crop production data, making the examination of spatial variations across counties over multiple periods of time possible (Beddow et al. 2015).

Limitations of agricultural census data

Although the agricultural census collects data for each farm, it does not report farm by farm data due to confidentiality reasons (Aalders et al., 2006). Any items that could potentially be identified as individual producers of a particular commodity in a county, the USDA's NASS does not report the information. In such cases, the data are suppressed and shown as "D", meaning "withheld to avoid disclosing data for individual operations." This means that the census data are not complete for the purpose of spatial data analysis.

In this study, there are two types of missing data: one is related to the total acres harvested and the other is related to irrigated acres harvested. Both types of missing data were estimated as follows. First, the total acres harvested were estimated using the acreage data by size of farm, which was obtained from the Census of Agriculture. For example, the total acres of harvested cropland for Midland County were estimated, Table 1. The acreage data were missing for two classes of farm size: 1 to 9 and 220 to 259. For these two classes, the midpoint and the number of farms were used to calculate the estimated acres harvested. Specifically, there are 37 farms with 1 to 9 acres. Therefore, the estimated acres harvested for this class was calculated as:

$$\left(\frac{1+9}{2}\right) \times 37 = 185$$

Similarly, there is only one farm with 220 to 259 acres. Using a similar method, the estimated acres harvested for this class was calculated as:

$$\left(\frac{220+259}{2}\right) \times 1 = 239.5$$

Then, the acres harvested for Midland County in 2007 were totaled (including estimations) and was estimated to be 35,970.5 acres.

Table 1. Estimated total harvested cropland acres for Midland County, 2007.

Farm Size (Acres)	Number of Farms	Acres Harvested	Estimated Acres Harvested
1 to 9	37	NA	185.0
10 to 49	40	629	629.0
50 to 69	15	387	387.0
70 to 99	9	200	200.0
100 to 139	4	338	338.0
140 to 179	9	781	781.0
180 to 219	3	464	464.0
220 to 259	1	NA	239.5
260 to 499	6	1020	1,020.0
500 to 999	8	2880	2,880.0
1000 to 1999	11	10,156	10,156.0
2000 or more	19	18,691	18,691.0
		Total Estimated Acres Harvested	**35,970.5**

Second, missing data for irrigated harvested acres were estimated using the county-level data on the percentage of acres irrigated from the previous census year and the region's average change in the percentage of acres irrigated between the two census years. Table 2 illustrates how the irrigated acres of harvested cropland were estimated for Armstrong County for the census year 2017. Using available data, the region's average percentage change in the percentage of acres irrigated between the years 2012 and 2017 was calculated to be approximately -14 percent. Using Armstrong as an example, the percentage of acres irrigated in 2012 was 6.84 percent. Using the region's average percentage change value, the percentage of acres irrigated in 2017 was estimated to be 5.88 percent $((1 - 0.14) \times 6.84\%)$. Given that the harvested acres in 2017 was 49,012 acres, the irrigated acres were estimated to be 2,881 acres.

Table 2. Estimated irrigated harvested cropland acres for Armstrong County, 2017.

Total Acres		Irrigated Acres		Percent Irrigated		Estimated Irrigated Acres in 2017
2012	2017	2012	2017	2012	2017	
51,313	49,012	3,510	NA	0.0684	NA	2,881

Note: The region's average percentage change in the percentage of acres irrigated between the years 2012 and 2017 was -14 percent.

Methods

This study examined spatial and temporal changes in cropland acreage in Texas High Plains from the standpoint of geographical concentration and spatial dependence. First, to examine how much (or little) cropland acreage in the Texas High Plains has changed over time, maps were generated for each variable of interest. For creating maps, the number of classes depends on the range of values. Therefore, the maps can be used to identify counties with an extremely large (or small) number of acres.

Second, to analyze the overall change in geographical concentration, the Gini coefficient, one of the most commonly used measures of geographical concentration of industries, was calculated (Krugman, 1991; Haggett et al., 1977; McBride, 1997; Cullis and Van Koppen, 2007; Liu et al., 2019. In this study, geographical concentration of cropland acreage refers to the relative share of harvested acreage contributed by each county. In particular, the Gini coefficient was calculated as:

$$G = \left(\sum_{i=1}^{n} (2i - n - 1) x_i \right) / n^2 \mu$$

where x is a number of acres harvested, n is the total number of counties, i is the rank of values in ascending order, and μ is the mean value of x. The Gini coefficient takes values between zero and one. A value of zero means that each county harvests the same number of acres, whereas a value of one indicates that all of the production is concentrated in only one county.

Third, to examine spatiotemporal changes in geographical concentration, size distributions are computed for all variables of interest. To do so, the counties were first ordered in descending order based on the number of acres. The cumulative distribution of harvested acres was then generated. The number of counties with 25, 50, and 75 percent of total harvested acres was then determined. A map-based visual representation of geographical concentration for each census year was then created. This facilitates the visual identification of geographical pattern of change between the census years. Additionally, to investigate spatiotemporal changes in irrigation decisions, a quantile map was generated using data on irrigated acreage as percent of total acreage for each variable of interest and each census year.

Finally, to examine spatial autocorrelation, or dependence in the crop choices across the 39 Texas High Plains counties, a Moran's I statistic was calculated (Moran, 1950). Spatial autocorrelation is characterized by a correlation among nearby locations. Specifically, the Moran's I statistic measures how one county's spatial information content of the field is similar to the surrounding counties. In this study, the statistical test was performed to test whether the relative proportion of each crop harvested was randomly distributed across counties. In this study, the relative proportion of each crop was computed as the ratio of the number of acres harvested with each crop and to the number of total cropland acres. The test was conducted using both total acreage and irrigated acreage figures. The Moran's I statistic ranges from -1 to 1. The value of -1 indicates perfect dispersion, indicating perfect clustering of dissimilar values; the value of

0 indicates no autocorrelation among the neighboring counties; and the value of 1 means perfect clustering of similar values. In other words, a higher value of Moran's I indicates that observations are clustered near other high values compared to lower values (Peng et al., 2017). The p-value of Moran's I index determines whether the null hypothesis of no spatial autocorrelation can be rejected.

CHAPTER IV

RESULTS

Harvested cropland

Total and irrigated harvested acres of cropland during the study period (1978-2017) are illustrated in Figure 2. The total harvested acres were more volatile than the irrigated harvested acres throughout the study period. From 1978 to 2017, total harvested cropland acres declined by roughly 15 percent from 7.7 to 6.6 million acres (Table 3). On the other hand, irrigated cropland area decreased by about 33 percent from 4.4 million acres in 1978 to 2.9 million acres in 2017.

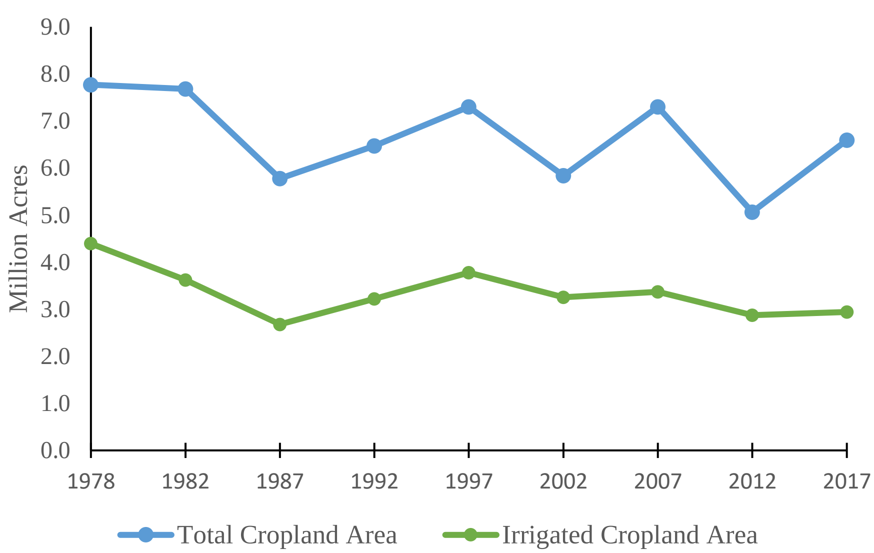

Figure 2. Total and irrigated harvested cropland area (in million acres) in the Texas High Plains, 1978-2017.

Table 3. Total and irrigated harvested cropland – acres, number of farms, and acres per farm in the Texas High Plains, 1978-2017.

	Irrigated and Non-irrigated			Irrigated		
Year	**Acres**	**Farms**	**Acres per Farm**	**Acres**	**Farms**	**Acres per Farm**
1978	7,770,501	14,851	523	4,393,257	10,442	421
1982	7,678,881	13,325	576	3,623,319	7,939	456
1987	5,779,840	12,619	458	2,678,064	7,516	356
1992	6,468,792	11,152	580	3,219,604	6,943	464
1997	7,302,216	10,136	720	3,777,898	6,729	561
2002	5,835,202	8,524	685	3,254,121	5,870	554
2007	7,299,798	8,254	884	3,366,225	5,277	638
2012	5,064,068	6,745	751	2,873,289	4,922	584
2017	6,595,607	6,166	1070	2,940,888	3,934	748

For both total and irrigated harvested cropland, the total number of farms clearly declined over the study period. The total number of farms with harvested cropland declined by about 58 percent between 1978 and 2017 (from 14,851 to 6,166 farms), Table 3 and Figure 3. Similarly, the total number of farms with irrigated harvested cropland acres declined by about 62 percent (from 10,442 to 3,934 farms) during the same time period. Although total and irrigated harvested cropland acreage also decreased over time, the number of farms decreased by greater percent than harvested cropland acres (Table 3). This implies that the size of each farm has increased, suggesting the trend toward fewer and larger farms.

To analyze how much county-level harvested cropland acreage has changed over time, maps were generated for both total harvested acres of cropland (Figure 4) and irrigated acres of cropland (Figure 5) for all census years. In Figure 4 and Figure 5, harvested acres of cropland were presented in thousands of acres. Classes in the legend bar were created based on the ranges of the values of the acreage distribution.

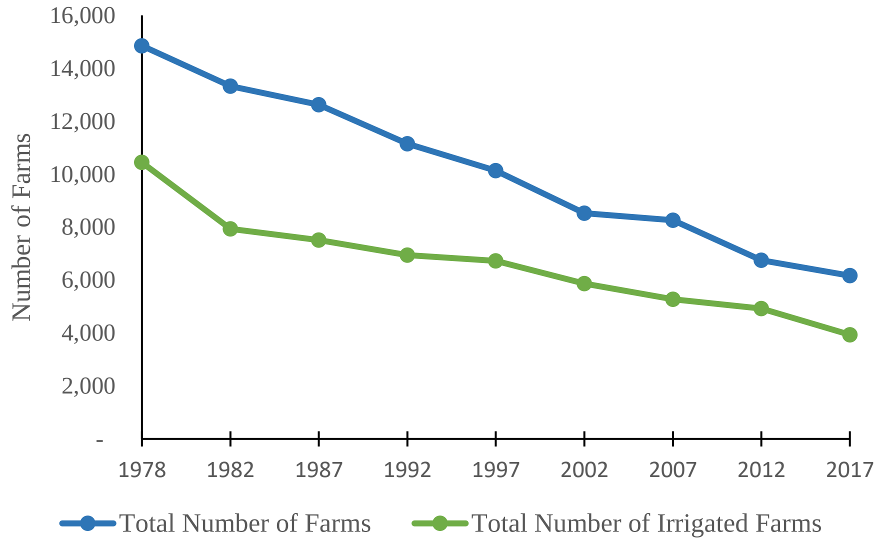

Figure 3. Number of farms with harvested cropland and number of farms with irrigated harvested cropland in the Texas High Plains, 1978-2017.

Most counties in the Texas High Plains experienced major changes in cropland acreage from 1978 to 2017 (Figure 4). Overall, counties in the center of Texas High Plains (namely, Lamb, Hale, Floyd, Hockley, Lubbock, Lynn, Gains, and Dawson) had the largest share of acres of harvested cropland. In 1978, Hale and Gaines Counties had the largest harvested cropland acres among all the 39 counties. In 2012, a number of counties (including Potter, Andrews, Oldham, Roberts, Midland, Hemphill, Howard, and Lipscomb) harvested less than 25,000 acres of cropland. In 2017, the counties with the largest acres of harvested cropland were Gaines, Lynn, and Lubbock. These counties had more than 375,000 acres of harvested cropland.

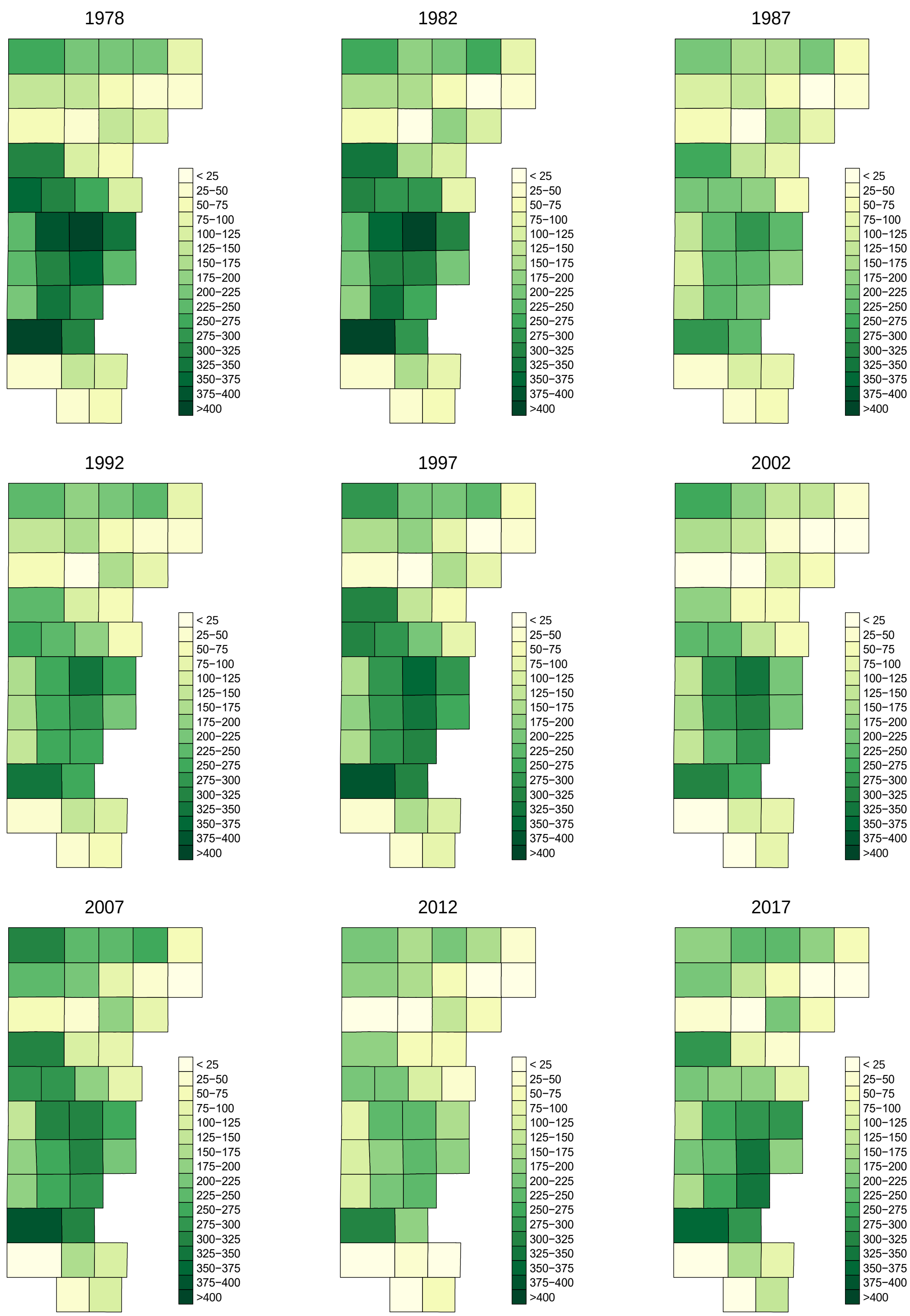

Figure 4. Irrigated and non-irrigated harvested cropland area (in thousand acres) by county, 1978-2017.

Focusing on the spatial distributions of irrigated harvested cropland area illustrated in Figure 5, it is clear that acres of irrigated harvested cropland had been decreasing over the study period. The highest number of irrigated harvested cropland area for a county in 1978 was more than 400,000 acres while that number decreased to 200,000 acres in 2017. During the census years 1978 and 2002, Hale County had the largest area of irrigated harvested cropland. In 2007, 2012, and 2017, Gaines County had the largest number of irrigated cropland acres whereas Hale had the second largest area of irrigated cropland. In 2017, the three counties with the largest irrigated cropland acres were Gaines, Sherman, and Lubbock.

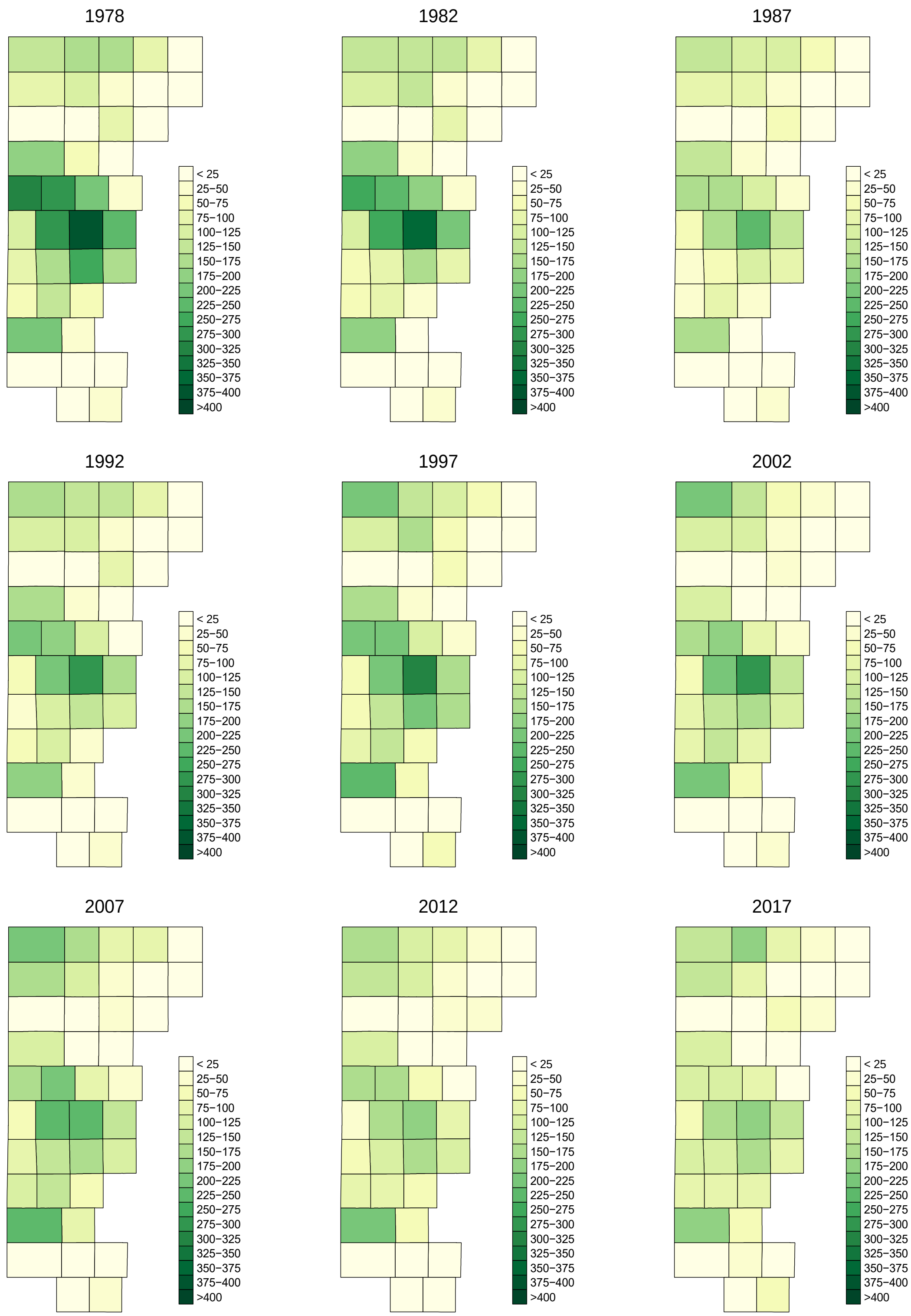

Figure 5. Irrigated harvested cropland area (in thousand acres) by county, 1978-2017.

To analyze the overall change in geographical concentration, Gini coefficients were estimated. Table 4 reports the estimated Gini coefficients for total and irrigated cropland for the nine census years. For total cropland, the Gini coefficient values were relatively stable over time (ranging from 0.305 to 0.380). The relatively low Gini coefficient values suggest that crop production was relatively uniformly distributed across the 39 counties. For the irrigated harvested cropland acreage, the Gini coefficients vary from 0.433 to 0.511. This indicates that irrigated harvested cropland acres were concentrated in a smaller number of counties than the case of total harvested cropland acres.

Table 4. Estimated Gini coefficients for total and irrigated harvested cropland acres, 1978-2017.

Year	Total	Irrigated
1978	0.357	0.492
1982	0.327	0.511
1987	0.305	0.485
1992	0.318	0.485
1997	0.331	0.466
2002	0.380	0.491
2007	0.318	0.471
2012	0.370	0.468
2017	0.344	0.434

Geographical concentration of total and irrigated harvested cropland acreage for each census year is illustrated in Figure 6 and Figure 7, respectively. The fewest counties with 25 percent of total harvested acres are shown in the dark shade. The fewest counties with 50 percent of total harvested acres include both the dark and medium shades. The fewest counties with 75 percent of total harvested acres include the dark, medium, and light shades. All shaded counties comprise 100 percent of total harvested acres.

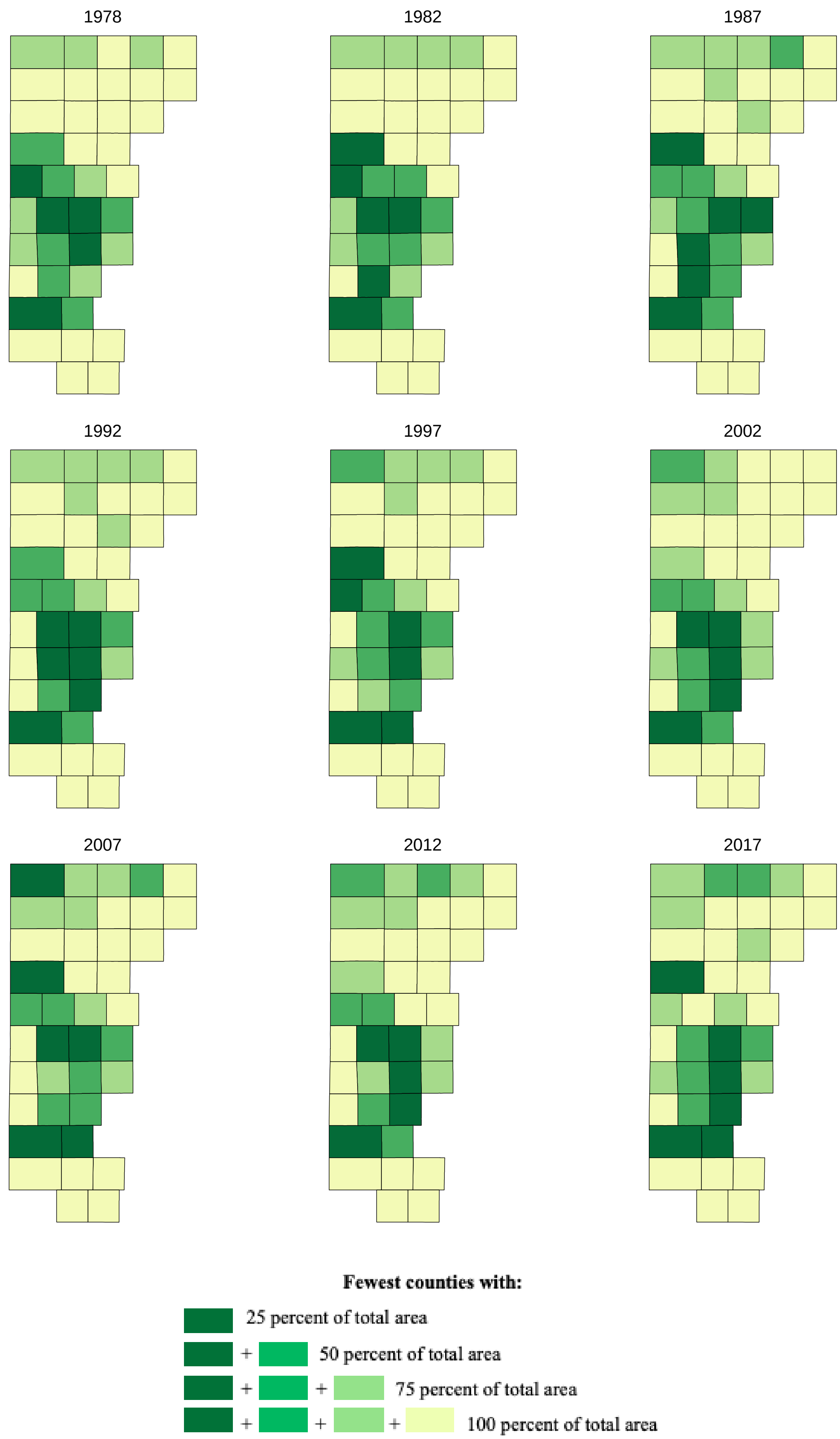

Figure 6. Concentration of irrigated and non-irrigated harvested cropland area (in thousand acres) by county, 1978-2017.

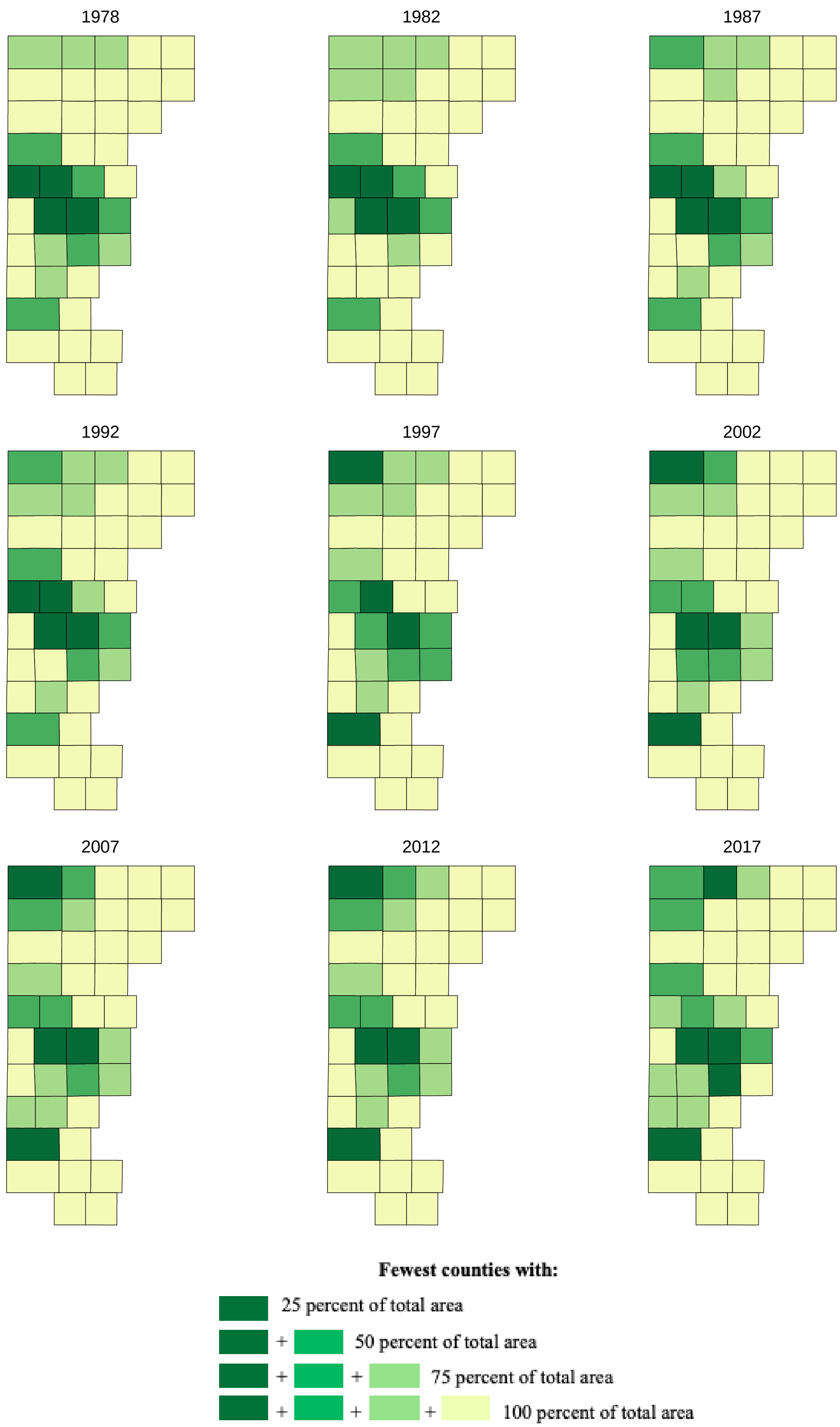

Figure 7. Concentration of irrigated harvested cropland area (in thousand acres) by county, 1978-2017.

Summaries of the county data for the cases of total and irrigated harvest cropland are presented in Table 5 and Table 6, respectively.

As can be seen from Figure 6 and Table 5, depending on the census year, a total of five or six counties covers about 25 percent of harvested cropland area. Hale and Gaines were the two counties with the largest cropland acres from 1978 to 2002. In 2007, the top two counties were Gaines and Lamb. In 2012, the top two counties were Gaines and Lubbock. In 2017, the top two counties were Gaines and Lynn. The combined land area in the top five or six counties covered less than 20 percent of the total land area. Overall, there was almost no change in the geographical concentration of harvested cropland.

Similar to the case of total harvest cropland acreage, there was virtually no change in the number of fewest counties with 25 percent of irrigated cropland area (Figure 7 and Table 6). From 1978 to 2012, four counties had harvested at least a quarter of irrigated cropland area. As can be seen from Figure 7, irrigated harvested cropland was concentrated in the center part of Texas High Plains. This might be because of water availability for irrigation in those counties were better than the other surrounding counties as most of the irrigated crop production occurs due to a greater number of irrigation wells from the Ogallala Aquifer in this region (Guerrero et al., 2019). In 2017, 25 percent of irrigated cropland area was concentrated in five counties including Gaines, Hale, Sherman, Lamb, and Lubbock. The combined land area in the top five or six counties covered less than 15 percent of the total land area.

Table 5. Total harvested cropland – number of Counties, land area, and land area over the Ogallala Aquifer in the areas of greatest concentration.

	1978	1982	1987	1992	1997	2002	2007	2012	2017
Concentration level:	**Number of Counties**								
25% of total harvested cropland area	5	6	6	6	6	5	6	5	6
50% of total harvested cropland area	11	12	13	12	12	11	13	11	12
75% of total harvested cropland area	19	20	21	20	20	19	20	19	20
100% of total harvested cropland area	39	39	39	39	39	39	39	39	39
Concentration level:	**Land Area in Square Miles**								
25% of total harvested cropland area	5,312	6,800	6,798	6,228	6,694	5,320	7,431	5,320	6,703
50% of total harvested cropland area	11,404	12,304	13,215	12,297	12,911	11,311	13,812	11,323	12,356
75% of total harvested cropland area	19,049	19,970	21,028	20,201	20,052	19,676	20,740	19,839	20,630
100% of total harvested cropland area	38,945	38,945	38,945	38,945	38,945	38,945	38,945	38,945	38,945
Concentration level:	**Land Area over the Ogallala Aquifer in Square Miles**								
25% of total harvested cropland area	5,296	6,732	6,669	6,216	6,563	5,306	7,314	5,306	6,573
50% of total harvested cropland area	11,205	12,105	13,008	12,094	12,709	11,236	13,603	11,243	12,153
75% of total harvested cropland area	18,625	19,542	20,521	19,701	19,564	19,157	20,213	19,313	20,158
100% of total harvested cropland area	34,375	34,375	34,375	34,375	34,375	34,375	34,375	34,375	34,375

Table 6. Irrigated harvested cropland – number of counties, land area, and land area over the Ogallala Aquifer in the areas of greatest concentration.

	1978	1982	1987	1992	1997	2002	2007	2012	2017
Concentration level:	**Number of Counties**								
25% of total irrigated cropland area	4	4	4	4	4	4	4	4	5
50% of total irrigated cropland area	9	8	9	9	9	9	9	9	10
75% of total irrigated cropland area	15	15	15	16	16	15	16	16	17
100% of total irrigated cropland area	39	39	39	39	39	39	39	39	39
Concentration level:	**Land Area in Square Miles**								
25% of total irrigated cropland area	3,807	3,807	3,807	3,807	4,913	5,031	5,031	5,031	5,350
50% of total irrigated cropland area	9,603	8,702	10,207	10,207	9,611	9,548	10,103	10,103	11,709
75% of total irrigated cropland area	15,653	16,152	15,654	17,117	17,125	16,205	17,005	17,125	17,790
100% of total irrigated cropland area	38,945	38,945	38,945	38,945	38,945	38,945	38,945	38,945	38,945
Concentration level:	**Land Area over the Ogallala Aquifer in Square Miles**								
25% of total irrigated cropland area	3,802	3,802	3,802	3,802	4,911	5,029	5,029	5,029	5,338
50% of total irrigated cropland area	9,459	8,566	10,064	10,064	9,321	9,532	10,046	10,046	11,530
75% of total irrigated cropland area	15,298	15,888	15,230	16,654	16,664	15,747	16,546	16,664	17,600
100% of total irrigated cropland area	34,375	34,375	34,375	34,375	34,375	34,375	34,375	34,375	34,375

Figure 8 illustrates spatiotemporal changes in the proportion of irrigated harvested cropland area relative to total harvested cropland area. Clearly, the percent of acres of irrigated harvested cropland relative to total harvested cropland acreage decreased over time. In 1978, a total of six counties (namely, Hansford, Moore, Parmer, Castro, Swisher, and Hale) irrigated more than 80 percent of their total cropland area. In 1997, only two counties, Hale, and Moore, irrigated more than 80 percent of the total cropland acre. From 2007 onward, none of the 39 counties irrigated more than 80 percent of the total cropland acres.

Total irrigated harvested cropland area reduced by 35 percent during the study period. Interestingly, in the same time period total non-irrigated harvested cropland area increased by 8 percent. Indicating that producers are moving towards the non-irrigated crop production predominantly due to reduced access to the irrigation water. Restrictions on irrigation water by ground water district due to a depletion of saturated thickness of Ogallala Aquiver can be one of the reasons of reduced irrigated harvested cropland in the Texas High Plains. According to the United States Geological Survey's (USGS) High Plains Aquifer water-level monitoring study, from 1980 to 1996 the water-level of Ogallala Aquifer reduced by 9.9 ft (McGuire, 1999). A survey of literature also shows that after 1950 irrigation has reduced the saturated thickness of Ogallala Aquifer by 50 percent or more in some areas of Texas High Plains (Xue et al., 2017). Therefore, the policy makers should put more importance to the non-irrigated crop production. Drought tolerant varieties having high yield can be great alternatives going forward.

Figure 8. Acres of irrigated harvested cropland as percent of total harvested cropland acreage by county, 1978-2017.

Corn, harvested for grain

The total and irrigated harvested corn grain acres are presented in Figure 9. Total harvested corn acres declined about nine percent from 799,000 acres in 1978 to 726,000 acres in 2017 (Table 7). From 1978 to 1987, both the total and irrigated harvested corn acreages sharply declined and reached a minimum of 409,000 and 397,000, respectively. Overall, except from the years 2012 to 2017, both total and irrigated acres of corn harvested for grain changed in the same direction. This suggests a decline in the irrigated percentage of the region's corn acreage.

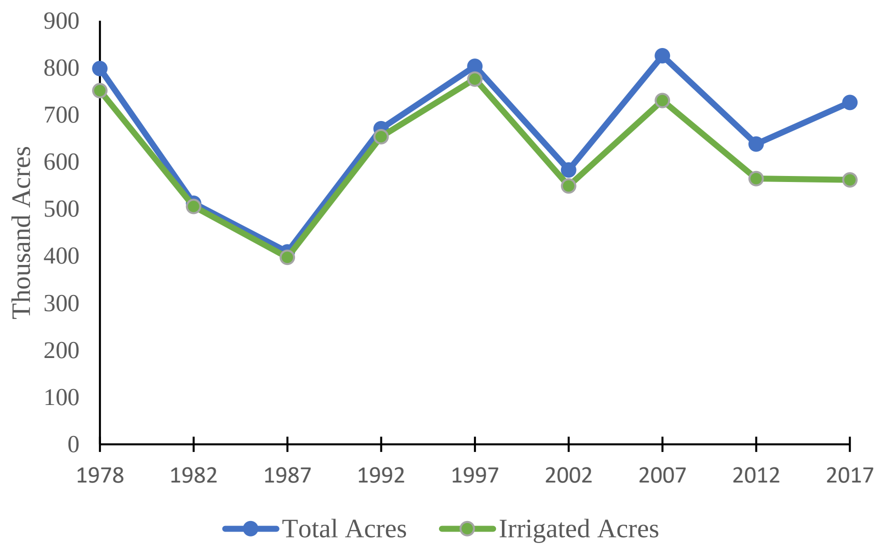

Figure 9. Total and irrigated corn harvested area for grain (in thousand acres) in the Texas High Plains, 1978-2017.

Similar to the case of cropland area, the total number of farms also decreased over the study period (Figure 10). Specifically, from 1978 to 2017, the total number of farms for total and irrigated harvested corn declined by 57 percent and 64 percent, respectively. As a result, total acres per farm increased by more than 50 percent for both total and irrigated corn acreage during the last 40 years (Table 7). Again, this indicates the trend toward fewer and larger farms.

Table 7. Total and irrigated corn harvested for grain – acres, number of farms, and acres per farm in the Texas High Plains, 1978-2017.

	Irrigated and Non-irrigated			Irrigated		
Year	**Acres**	**Farms**	**Acres per Farm**	**Acres**	**Farms**	**Acres per Farm**
1978	798,802	2,939	272	751,446	2,853	263
1982	512,438	1,958	262	505,243	1,904	265
1987	408,781	2,335	175	397,273	2,275	175
1992	670,913	2,493	269	653,844	2,428	269
1997	803,016	2,269	354	776,470	2,200	353
2002	583,294	1,210	482	548,995	1,144	480
2007	825,575	1,539	536	730,492	1,408	519
2012	637,867	1,300	491	564,389	1,172	482
2017	726,321	1,243	584	561,714	1,002	561

Figure 10. Number of farms with total corn harvested for grain and number of farms with irrigated corn harvested for grain in the Texas High Plains, 1978-2017.

Maps for total and irrigated acres of corn harvested for grain are presented in Figure 11 and Figure 12, respectively. As can be seen from Figure 11, Parmer had the largest corn acreage (more than 150,000 of harvested acres) in 1978 and 1982. Nevertheless, its total harvested corn acres gradually decreased over time. In 1987 and 1992, the counties with the largest share of corn acreage were Parmer, Hale, Castro, and Dallam. These counties had at least 50,000 (75,000) acres of their cropland acres planted with corn in 1987 (1992). From 1997 to 2012, Dallam had become the county with the largest corn acreage. In 2017, however, Sherman had become the county with the largest corn acreage. A similar trend is found when focusing solely on the irrigated acres of corn harvested for grain (Figure 12). Specifically, Parmer had the largest corn acreage from 1978 to 1992. From 1997 to 2012, Dallam became a county with the largest share of irrigated corn acreage, whereas Sherman took the first place in 2017.

Figure 11. Irrigated and non-irrigated corn harvested area for grain (in thousand acres) by county, 1978-2017.

Figure 12. Irrigated corn harvested area for grain (in thousand acres) by county, 1978-2017.

Table 8. Estimated Gini coefficients for total and irrigated corn harvested for grain acres, 1978-2017.

Year	Total	Irrigated
1978	0.756	0.773
1982	0.790	0.797
1987	0.749	0.753
1992	0.717	0.723
1997	0.715	0.724
2002	0.782	0.786
2007	0.742	0.746
2012	0.738	0.741
2017	0.636	0.683

Estimated Gini coefficients for total and irrigated acres of corn for grain for all census years are reported in Table 8. For total corn acreage, the Gini coefficient ranges between 0.636 and 0.790. For irrigated corn acreage, the Gini coefficient varies between 0.683 and 0.797. The high value of Gini coefficients indicates that both total and irrigated corn acreages were consistently concentrated in a smaller number of counties over time.

Geographical concentration of total corn acreage is presented in Figure 13. Overall, a total of two to three counties covered a quarter of total acres of corn harvested for grain: Parmer and Castro for the census years 1978 and 1982; Parmer and Hale for the census year 1987; Parmer, Hale, and Castro for the census year 1992; Dallam and Castro for the census year 1997; Dallam and Hartley for the census years 2002, 2007, and 2012; and Sherman and Dallam for the census year 2017. The combined land area in the top two or three counties covered less than 10 percent of the total land area (Table 9). Overall, there was a small change in the geographical concentration of total corn acreage. A similar trend is observed when considering the irrigated corn acreage (Figure 14 and Table 10). These results are expected as most of the corn acreage was irrigated.

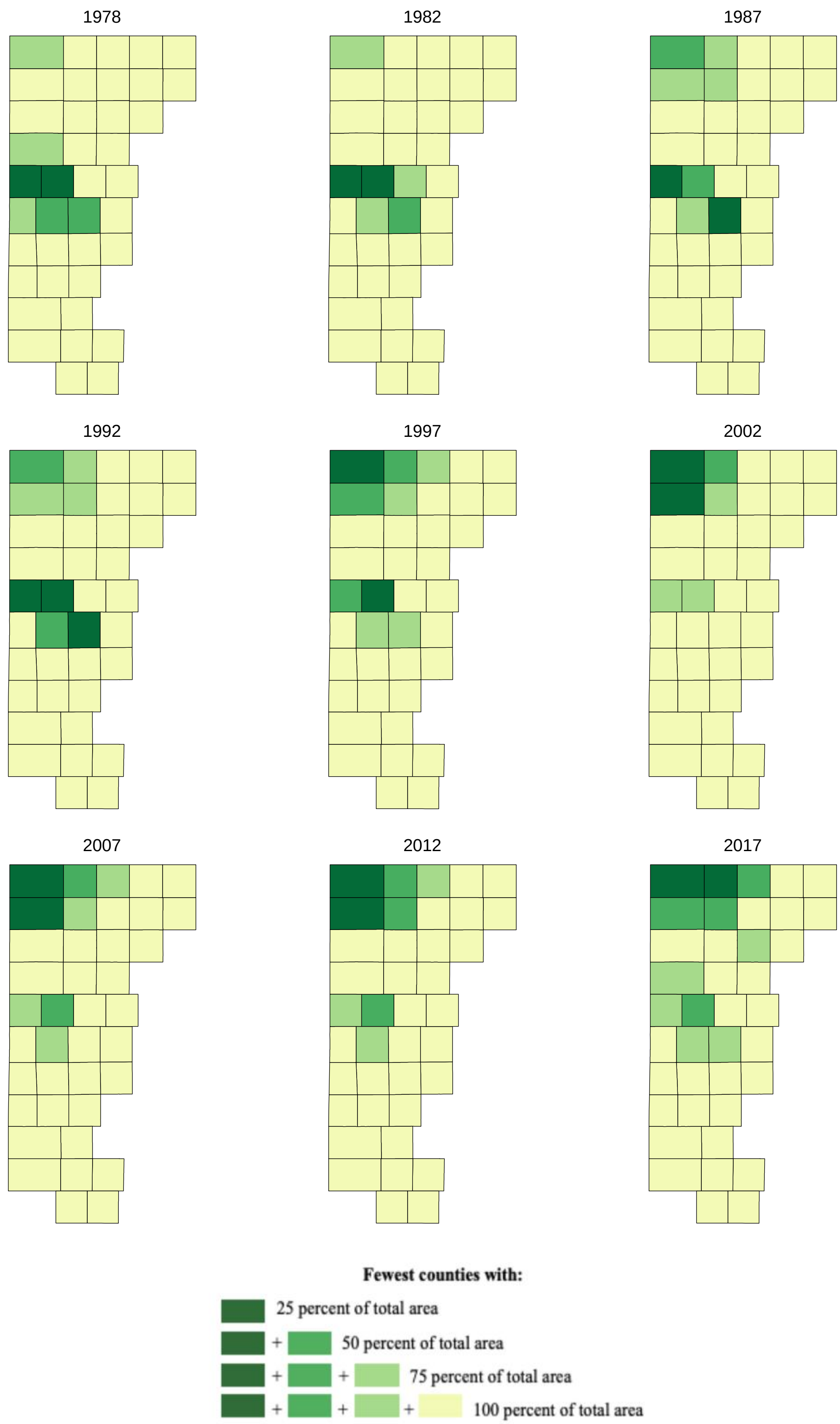

Figure 13. Concentration of irrigated and non-irrigated corn harvested area for grain (in thousand acres) by county, 1978-2017.

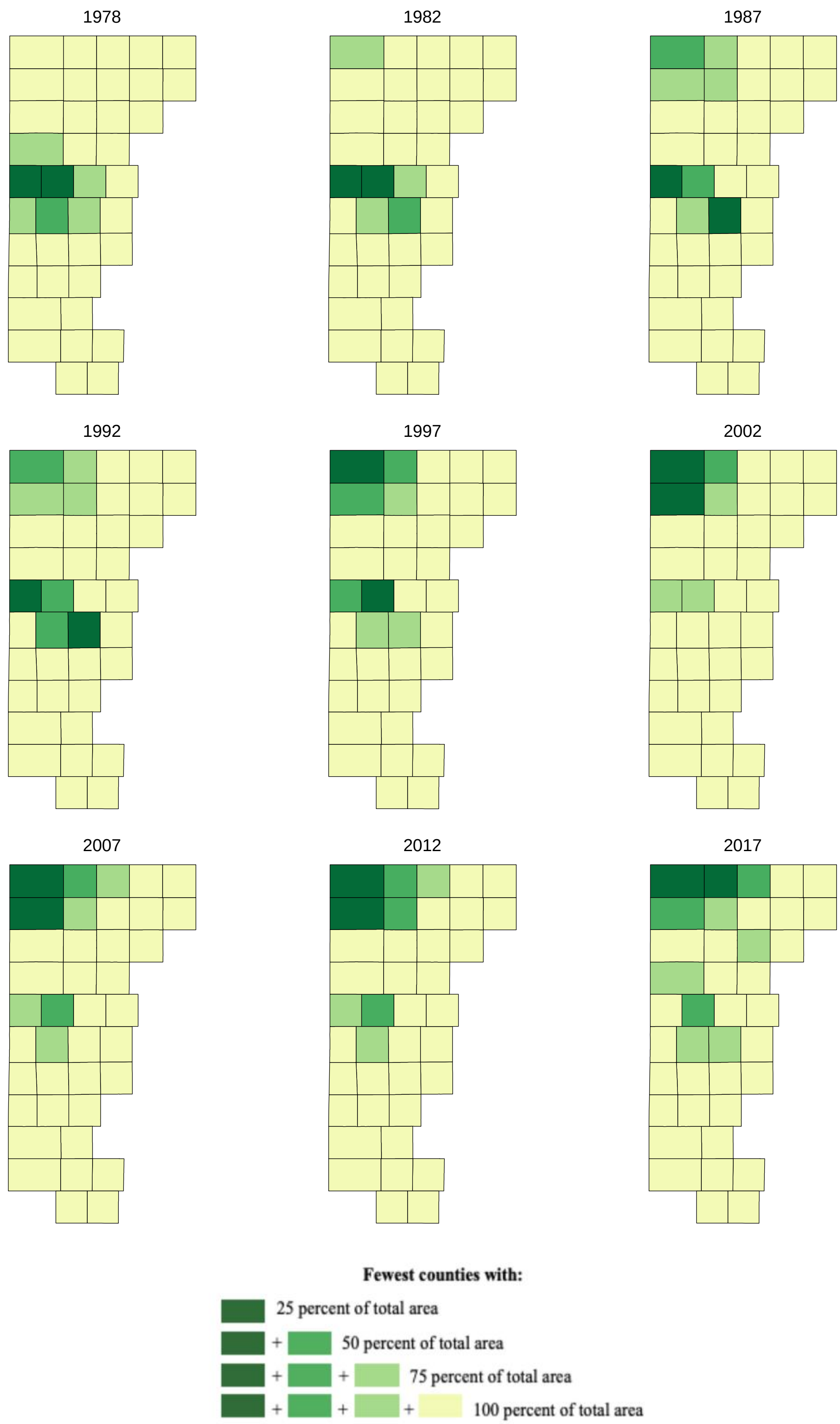

Figure 14. Concentration of irrigated corn harvested area for grain (in thousand acres) by county, 1978-2017.

Table 9. Total corn harvested for grain – number of counties, land area, and land area over the Ogallala Aquifer in the areas of greatest concentration.

	1978	1982	1987	1992	1997	2002	2007	2012	2017
Concentration level:	**Number of Counties**								
25% of total harvested corn grain area	2	2	2	3	2	2	2	2	2
50% of total harvested corn grain area	4	3	4	5	5	3	4	5	6
75% of total harvested corn grain area	7	6	8	8	9	6	8	8	11
100% of total harvested corn grain area	39	39	39	39	39	39	39	39	39
Concentration level:	**Land Area in Square Miles**								
25% of total harvested corn grain area	1,785	1,785	1,890	2,789	2,405	2,969	2,969	2,969	2,429
50% of total harvested corn grain area	3,807	2,789	4,295	5,313	5,677	3,892	4,791	5,701	6,621
75% of total harvested corn grain area	7,638	6,213	8,609	8,609	9,529	6,586	8,525	8,525	11,952
100% of total harvested cropland area	38,945	38,945	38,945	38,945	38,945	38,945	38,945	38,945	38,945
Concentration level:	**Land Area over the Ogallala Aquifer in Square Miles**								
25% of total harvested corn grain area	1,779	1,779	1,884	2,784	2,405	2,929	2,929	2,929	2,426
50% of total harvested corn grain area	3,802	2,784	4,289	5,307	5,629	3,850	4,750	5,592	6,509
75% of total harvested corn grain area	7,566	6,207	8,494	8,494	9,411	6,471	8,406	8,406	11,762
100% of total harvested corn grain area	34,375	34,375	34,375	34,375	34,375	34,375	34,375	34,375	34,375

Table 10. Irrigated corn harvested for grain – number of counties, land area, and land area over the Ogallala Aquifer in the areas of greatest concentration.

	1978	1982	1987	1992	1997	2002	2007	2012	2017
Concentration level:	**Number of Counties**								
25% of irrigated harvested corn area	2	2	2	2	2	2	2	2	2
50% of irrigated harvested corn area	3	3	4	5	5	3	4	5	5
75% of irrigated harvested corn area	7	6	8	8	8	6	8	8	10
100% of irrigated harvested corn area	39	39	39	39	39	39	39	39	39
Concentration level:	**Land Area in Square Miles**								
25% of irrigated harvested corn area	1,785	1,785	1,890	1,890	2,405	2,969	2,969	2,969	2,429
50% of irrigated harvested corn area	2,802	2,789	4,295	5,313	5,677	3,892	4,791	5,701	5,712
75% of irrigated harvested corn area	7,034	6,213	8,609	8,609	8,609	6,586	8,525	8,525	11,067
100% of irrigated harvested corn area	38,945	38,945	38,945	38,945	38,945	38,945	38,945	38,945	38,945
Concentration level:	**Land Area over the Ogallala Aquifer in Square Miles**								
25% of irrigated harvested corn area	1,779	1,779	1,884	1,884	2,405	2,929	2,929	2,929	2,426
50% of irrigated harvested corn area	2,797	2,784	4,289	5,307	5,629	3,850	4,750	5,592	5,667
75% of irrigated harvested corn area	6,961	6,207	8,494	8,494	8,494	6,471	8,406	8,406	10,883
100% of irrigated harvested corn area	34,375	34,375	34,375	34,375	34,375	34,375	34,375	34,375	34,375

Spatiotemporal changes of irrigated acres of corn harvested for grain as percent of total corn acreage are presented in Figure 15. A majority of counties in the Texas High Plains had more than 80 percent of corn acreage irrigated. From the census year 2012 to 2017, it can be seen that the total number of counties with more than 80 percent of their corn acreage irrigated declined from 22 to 13 counties. The reduction in irrigation is likely explained by the decline in the Ogallala Aquifer's water level. It should also be noted that some counties did not have any harvested corn acreage.

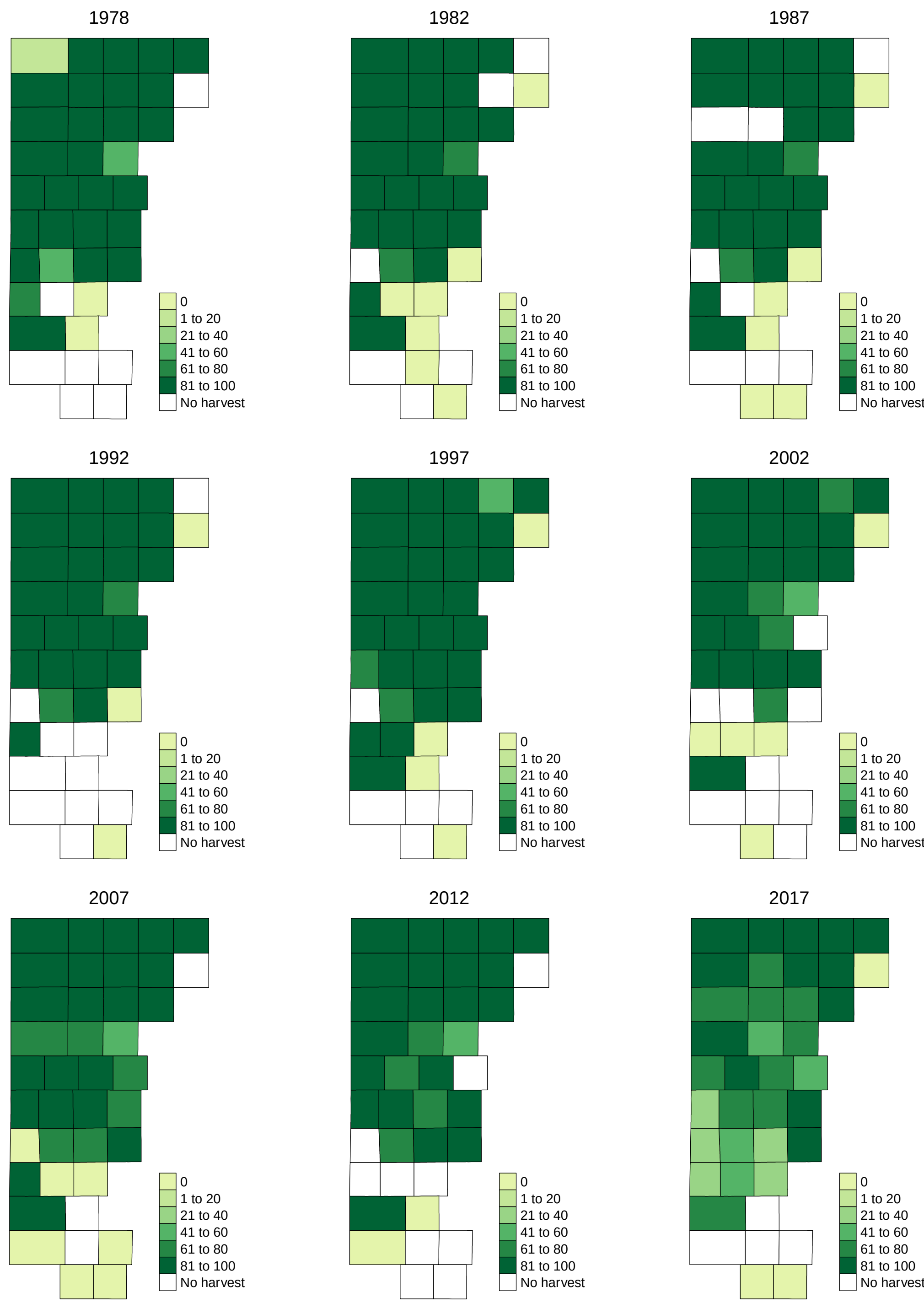

Figure 15. Irrigated corn harvested area for grain as percent of total corn harvested area for grain by county, 1978-2017.

To examine the relative importance of corn production in the Texas High Plains, changes in the number of acres harvested for corn relative to the number of cropland acres are considered. Total and irrigated acres of corn harvested for grain as percent of total and irrigated harvested cropland acreage are shown in Figure 16 and Figure 17, respectively. In 1978, percent share of Parmer County for both total and irrigated harvested corn grain acres was the highest. Specifically, Parmer had more than 50 percent of its cropland area planted with corn. As can be seen from Figure 16, there had been a decline in the percent of corn harvested relative to total cropland acreage. On the other hand, when considering only the irrigated cropland acreage, there was an increase in the proportion of irrigated cropland acreage with corn as in 1978 only one county had more than 50 percent irrigated harvested cropland as corn while in 2017 four counties had more than 50 percent irrigated harvested cropland as corn. This again suggests an importance of irrigation in corn production. This can be influence by several reasons. For example, high yield of irrigated corn compared to the other irrigated crops in terms of grain and silage, increased demand of corn for ethanol production in the Texas High plains etc. Therefore, the policy makers should investigate why producers are willing to move towards corn when it comes to the irrigated harvested crops.

Figure 16. Total corn harvested area for grain as percent of total harvested cropland area by county, 1978-2017.

Figure 17. Irrigated corn harvested area for grain as percent of irrigated harvested cropland area by county, 1978-2017.

Cotton, harvested

Total and irrigated acres of cotton harvested during the census years 1978 and 2017 are presented in Figure 18. Overall, the total and irrigated acres of cotton fluctuated greatly over time. The irrigated cotton acreage, however, had been quite stable over the past 20 years. In 1978, the total and irrigated harvested cotton acres were 3.7 and 1.8 million acres, respectively (Table 11). In 1992, the numbers decreased to 1.5 million acres for total cotton acreage and 0.5 million acres for irrigated cotton acreage. This suggests the decline of cotton production in the Texas High Plains during 1982 and 1992. However, the trend changed after the census year 1992. In 2017, the total and irrigated harvested cotton acres increased to 3.4 and 1.5 million acres, respectively. That is, there had been an increase in cotton acreage in the last 20 years. Therefore, the policy makers should continue the existing government policies for cotton production in the Texas High Plains.

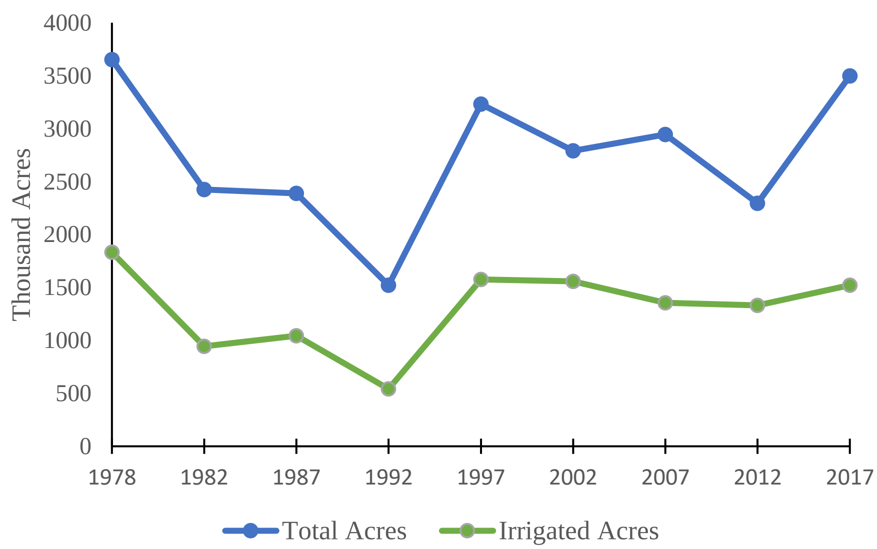

Figure 18. Total and irrigated cotton harvested area (in thousand acres) in the Texas High Plains, 1978-2017.

Table 11. Total and irrigated cotton harvested – acres, number of farms, and acres per farm in the Texas High Plains, 1978-2017.

	Irrigated and Non-irrigated			Irrigated		
Year	**Acres**	**Farms**	**Acres per Farm**	**Acres**	**Farms**	**Acres per Farm**
1978	3,652,036	9,542	383	1,831,419	6,892	266
1982	2,425,296	6,708	362	943,895	3,832	246
1987	2,387,953	7,269	329	1,042,501	4,389	238
1992	1,520,308	3,852	395	541,633	2,024	268
1997	3,231,446	5,658	571	1,576,476	3,959	398
2002	2,791,114	4,742	589	1,557,352	3,558	438
2007	2,945,435	3,989	738	1,354,999	2,958	458
2012	2,295,398	3,859	595	1,332,321	3,156	422
2017	3,496,146	3,266	1,070	1,520,857	2,386	637

The total number of farms with total and irrigated cotton acreage had clearly decreased from 1978 to 2017 (Figure 19). Specifically, for both total and irrigated cotton acreage, the total number of farms declined by around 65 percent during the study period. When considering acres per farm reported in Table 11, it is clear that acres per farm increased over time. In particular, the number of acres per irrigated and non-irrigated farm increased from 383 acres in 1978 to 1,070 acres in 2017. For the irrigated farms, the number of acres per farm increased from 266 acres to 637 acres during the same time period. This clearly indicates the trend toward larger farms.

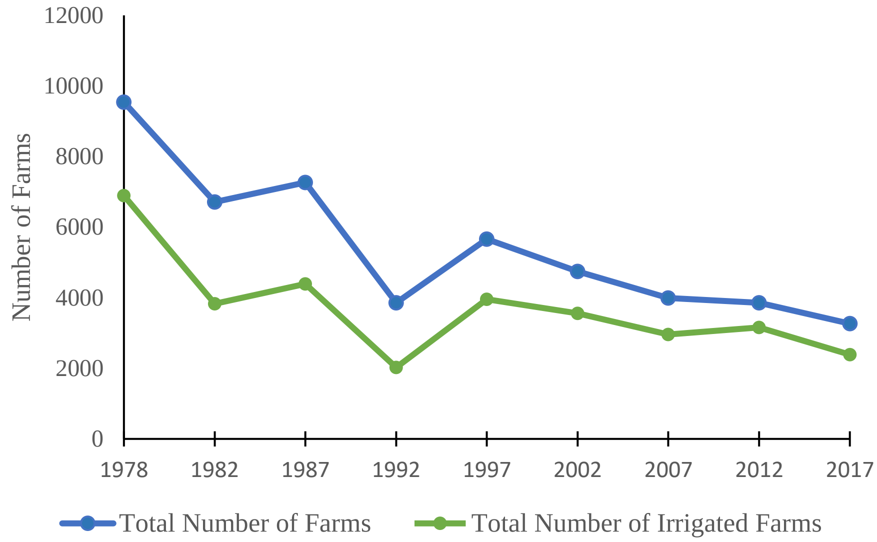

Figure 19. Number of farms with total cotton harvested and number of farms with irrigated cotton harvested in the Texas High Plains, 1978-2017.

Maps for total acres of cotton harvested is presented in Figure 20. In 1978, Gaines had the largest share of total harvested cotton acres (378,644 thousand acres). In 1987, the top three counties with more than 200,000 acres of cotton harvested were Gaines, Dawson, and Terry. In 1992, Gains County had the largest share of cotton acreage. Gains and Hale Counties experienced a slight increase in acres of cotton harvested from 1992 to 1997. In 2002, Lynn became a county with the largest cotton acreage. After that, a greater number of counties harvested more cotton. Similar patterns are observed when considering irrigated acres of cotton harvested (Figure 21). During the census years 1978 and 1987, the counties with the largest acres of cotton harvested were: Lubbock, Gaines, and Hale. In the more recent census years (2007, 2012, and 2017) Lubbock, Gaines, and Hale were still the top three counties.

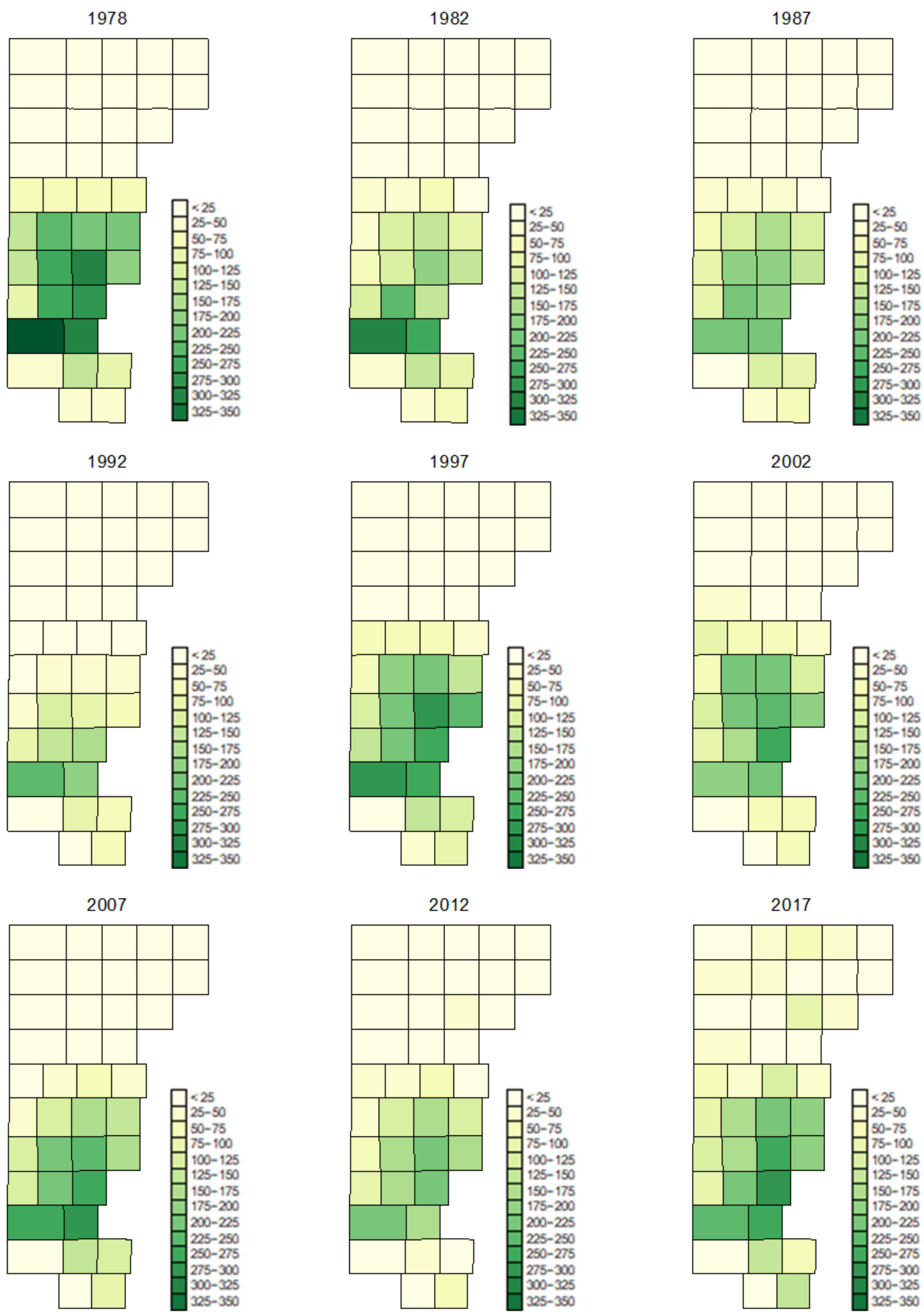

Figure 20. Irrigated and non-irrigated cotton harvested area (in thousand acres) by county, 1978-2017.

Figure 21. Irrigated cotton harvested area (in thousand acres) by county, 1978-2017.

Table 12. Estimated Gini coefficients for total and irrigated cotton harvested acres, 1978-2017.

Year	Total	Irrigated
1978	0.637	0.676
1982	0.649	0.690
1987	0.634	0.683
1992	0.702	0.725
1997	0.625	0.676
2002	0.624	0.657
2007	0.620	0.642
2012	0.599	0.603
2017	0.523	0.545

Estimated Gini coefficients for total and irrigated acres of cotton harvested are reported in Table 12. For both total and irrigated cotton acreage, the Gini coefficients are relatively stable over time. The Gini coefficient ranges between 0.523 and 0.702 (between 0.545 and 0.725) for the total cotton acreage (for the irrigated cotton acreage). The high value of Gini coefficients indicates that total and irrigated acres of cotton harvested were concentrated in small number of counties.

Spatial changes in geographical concentration of total and irrigated harvested cotton acres are presented in Figure 22 and Figure 23. As shown in Figure 22, depending on the census years, total harvested cotton acres were concentrated in a small number of counties. In 1978, a quarter of the total harvested acres were concentrated in Gaines, Lubbock, and Dawson. For the census years 1982 and 1987, the top three counties were Gaines, Dawson, and Terry. In 1992, only two counties, Gaines, and Dawson, are responsible for 25 percent of cotton production in the region. In 1997, the top three counties were Lubbock, Gaines, and Dawson. On the other hand, the top three counties in 2002 were Lynn, Lubbock, and Hockley. In 2007, the top three counties changed slightly

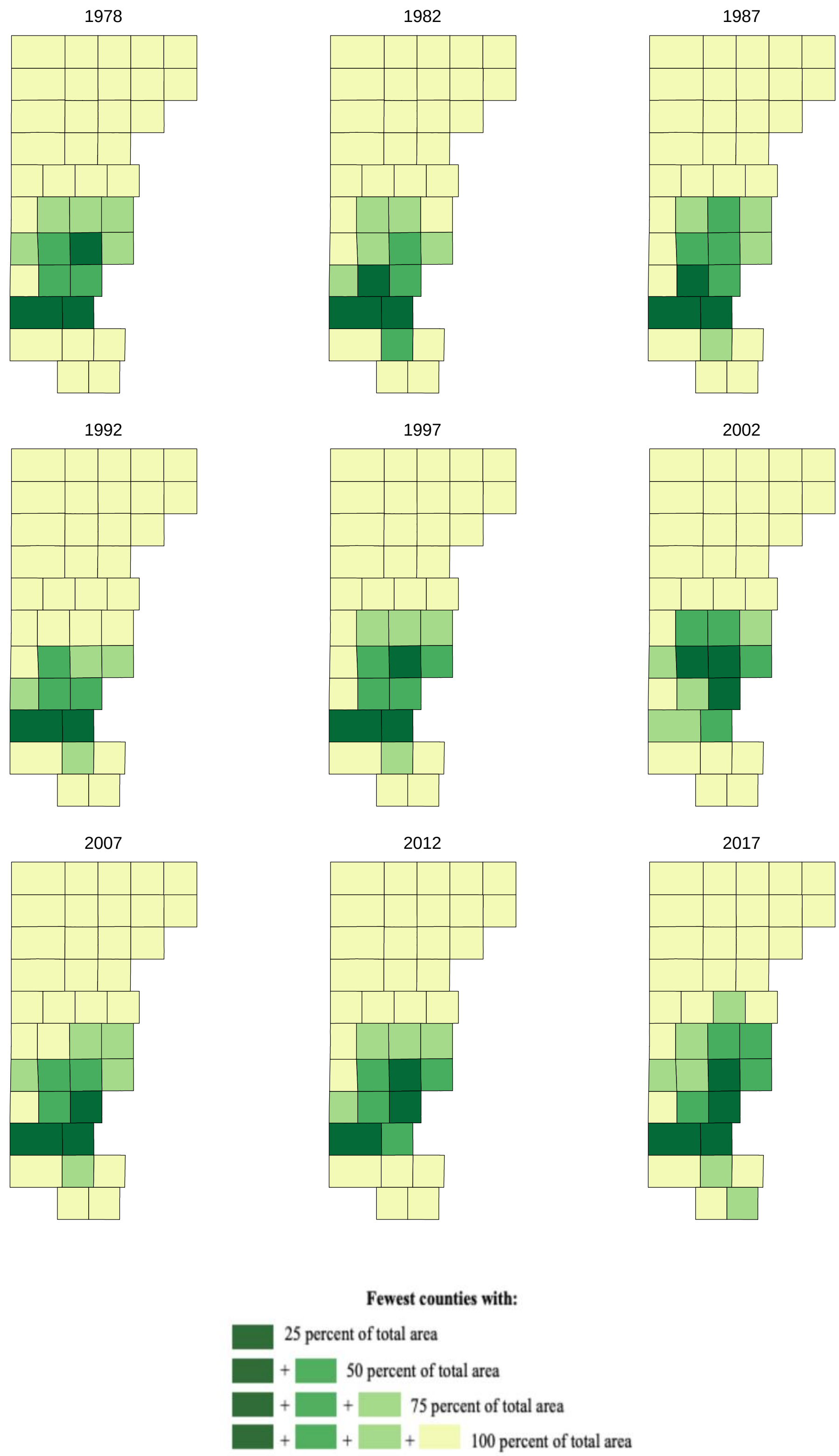

Figure 22. Concentration of irrigated and non-irrigated cotton harvested area (in thousand acres) by county, 1978-2017.

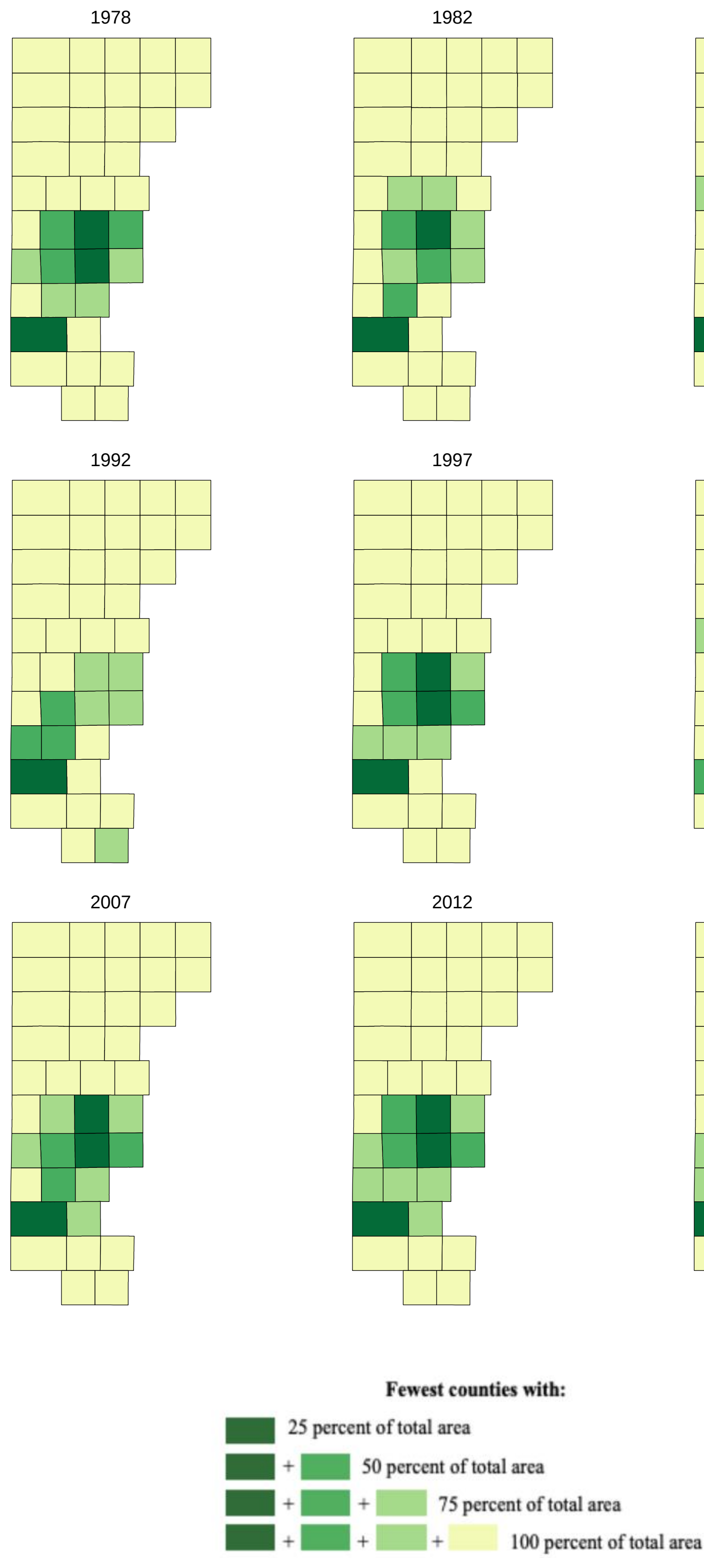

Figure 23. Concentration of irrigated cotton harvested area (in thousand acres) by county, 1978-2017.

to Dawson, Lynn, and Gaines. In 2012 the top three counties that covered at least 25 percent of total cotton production are Lynn, Gaines, and Lubbock, whereas the top three counties in 2017 were Lynn, Lubbock, and Dawson. As can be seen from Table 13, these counties covered less than 12 percent of total cropland area.

Irrigated harvested cotton acres were slightly more concentrated than total harvested acres throughout the time period (Figure 23). In 1978 Lubbock, Gaines, and Hale comprised a quarter of the irrigated cotton acreage. In 1992, however, only one county – Gaines – had at least 25 percent of the region's irrigated cotton acreage. From 1997 to 2017, a quarter of irrigated cotton production was concentrated in only three counties. In 2017, the top three counties were Lubbock, Hale, and Gaines. According to Table 14, these three counties covered less than 10 percent of total cropland area.

Table 13. Total cotton – number of counties, land area, and land area over the Ogallala Aquifer in the areas of greatest concentration.

	1978	**1982**	**1987**	**1992**	**1997**	**2002**	**2007**	**2012**	**2017**
Concentration level:	**Number of Counties**								
25% of total harvested cotton area	3	3	3	2	3	3	3	3	4
50% of total harvested cotton area	6	6	7	5	7	7	6	7	8
75% of total harvested cotton area	11	11	11	9	11	11	11	11	14
100% of total harvested cotton area	39	39	39	39	39	39	39	39	39
Concentration level:	**Land Area in Square Miles**								
25% of total harvested cotton area	3,306	3,296	3,296	2,405	3,306	2,703	3,299	3,297	4,199
50% of total harvested cotton area	5,999	6,006	7,004	5,098	6,901	6,529	5,999	6,901	7,989
75% of total harvested cotton area	10,691	10,639	10,832	8,616	10,832	10,691	10,589	10,716	13,409
100% of total harvested cotton area	38,945	38,945	38,945	38,945	38,945	38,945	38,945	38,945	38,945
Concentration level:	**Land Area over the Ogallala Aquifer in Square Miles**								
25% of total harvested cotton area	3,240	3,237	3,237	2,347	3,240	2,692	3,236	3,283	4,129
50% of total harvested cotton area	5,929	5,903	6,934	5,036	6,625	6,257	5,929	6,625	7,644
75% of total harvested cotton area	10,347	10,331	10,456	8,308	10,456	10,347	10,213	10,371	12,330
100% of total harvested cotton area	34,375	34,375	34,375	34,375	34,375	34,375	34,375	34,375	34,375

Table 14. Irrigated cotton – number of counties, land area, and land area over the Ogallala Aquifer in the areas of greatest concentration.

	1978	**1982**	**1987**	**1992**	**1997**	**2002**	**2007**	**2012**	**2017**
Concentration level:	**Number of Counties**								
25% of irrigated harvested cotton area	3	2	3	1	3	3	3	3	3
50% of irrigated harvested cotton area	6	5	5	4	6	6	6	6	7
75% of irrigated harvested cotton area	10	10	10	9	10	11	11	12	14
100% of irrigated harvested cotton area	39	39	39	39	39	39	39	39	39
Concentration level:	**Land Area in Square Miles**								
25% of irrigated harvested cotton area	3,409	2,508	3,409	1,503	3,409	2,923	3,409	3,409	3,409
50% of irrigated harvested cotton area	6,327	5,317	5,419	4,102	6,237	6,237	6,110	6,237	7,229
75% of irrigated harvested cotton area	9,789	9,920	9,905	8,803	9,813	10,798	10,691	11,491	13,293
100% of irrigated harvested cotton area	38,945	38,945	38,945	38,945	38,945	38,945	38,945	38,945	38,945
Concentration level:	**Land Area over the Ogallala Aquifer in Square Miles**								
25% of irrigated harvested cotton area	3,399	2,506	3,399	1,501	3,399	2,916	3,399	3,399	3,399
50% of irrigated harvested cotton area	6,251	5,307	5,341	4,100	6,023	6,023	5,895	6,023	6,947
75% of irrigated harvested cotton area	9,501	9,637	9,616	7,817	9,525	10,505	10,347	11,146	12,245
100% of irrigated harvested cotton area	34,375	34,375	34,375	34,375	34,375	34,375	34,375	34,375	34,375

Spatiotemporal changes in irrigated harvested cotton acres as a percent of total harvested cotton acres are presented in Figure 24. In 1978, Deaf Smith, Parmer, Castro, and Swisher had more than 80 percent of their total harvested cotton acres as irrigated harvested cotton acres, whereas in 2017, Lipscomb was the only county that irrigates more than 80 percent of its total cotton acreage. It is also important to note that increasing number of counties started to harvest cotton in recent census years. This increase can be driven by the technical improvements in how growers produce cotton, government program changes and a resurgence of cotton demand after 1990 (Glade et al., 1996).

Figure 24. Irrigated acres of cotton harvested as percent of cotton harvested area by county, 1978-2017.

Acres of cotton harvested as percent of total harvested cropland acreage are shown in Figure 25. Most counties had more than 50 percent of its harvested cropland area planted with cotton. Similar patterns are found when focusing only on the irrigated cropland acreage (Figure 26). In addition, these maps show that cotton production was mainly concentrated in the southern part of the region. Importantly, it is noticeable that counties in the northern part of the region started to harvest more cotton in the most recent census years predominantly the non-irrigated cotton varieties. Therefore, policy makers should support this change which will decrease the dependence on irrigation water although non-irrigated cotton has lower yields than irrigated cotton.

Figure 25. Cotton harvested area as percent of total harvested cropland area by county, 1978-2017.

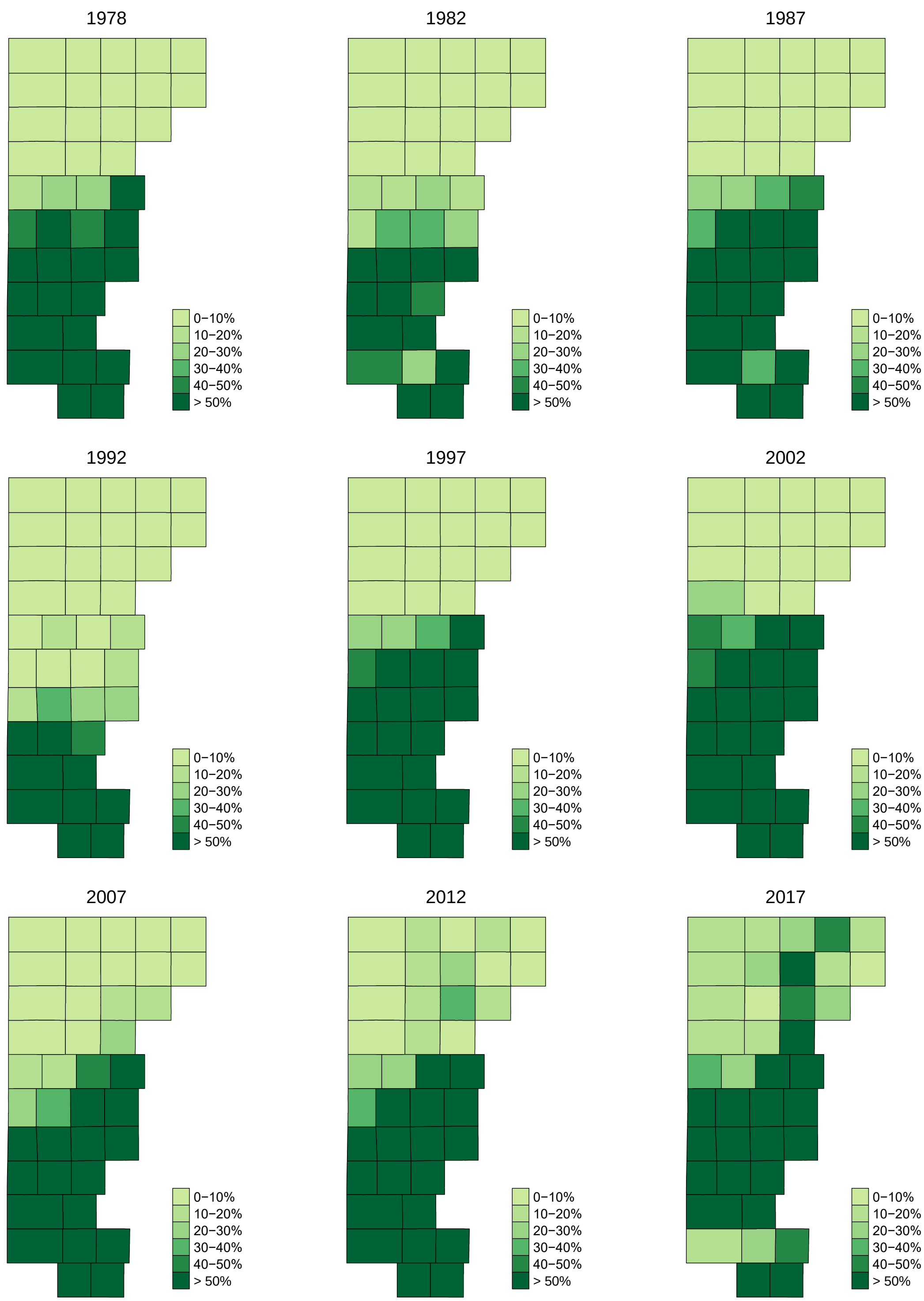

Figure 26. Irrigated cotton harvested area as percent of irrigated harvested cropland area by county, 1978-2017.

Sorghum, harvested for grain

Total and irrigated acres of sorghum harvested for grain during the study period are presented in Figure 27. Since 1992, it is very clear that both total and irrigated acres of sorghum harvested declined over time. Total acres of sorghum harvested decreased from 1.4 million acres in 1978 to only 0.5 million acres in 2017 (Table 15). Similarly, irrigated acres of sorghum harvested declined from 756,121 acres in 1978 to only 103,104 acres in 2017. This implies that crop producers may perceive grain sorghum as less profitable than corn and cotton since non-irrigated sorghum production during the same time period also decreased by 38 percent.

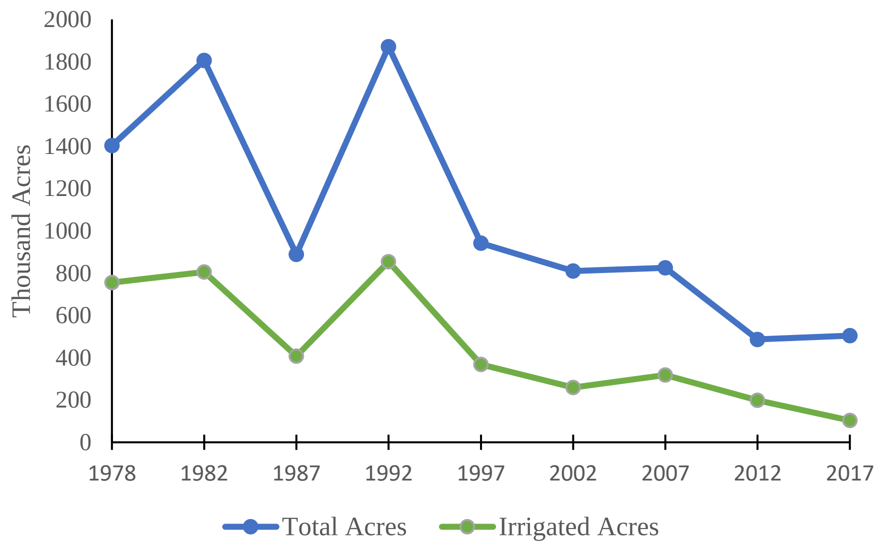

Figure 27. Total and irrigated sorghum harvested area for grain (in thousand acres) in the Texas High Plains, 1978-2017.

Table 15. Total and irrigated sorghum harvested for grain – acres, number of farms, and acres per farm in the Texas High Plains, 1978-2017.

	Irrigated and Non-irrigated			Irrigated		
Year	**Acres**	**Farms**	**Acres per Farm**	**Acres**	**Farms**	**Acres per Farm**
1978	1,403,228	6,378	220	756,121	4,214	179
1982	1,804,923	6,229	290	805,006	3,706	217
1987	889,149	5,337	167	407,930	2,785	146
1992	1,871,373	5,367	349	854,058	3,330	256
1997	940,784	3,576	263	368,532	2,017	183
2002	809,750	2,396	338	258,491	1,193	217
2007	824,686	2,397	344	318,748	1,351	236
2012	486,725	1,453	335	198,745	865	230
2017	503,822	1,141	442	103,104	390	264

Changes in number of farms with total and irrigated acres of sorghum harvested for grain are displayed in Figure 28. Similar to the cases of corn and cotton, the total number of farms clearly declined over time. In 1978, there were 6,378 farms with sorghum acreage and 4,214 farms with irrigated sorghum acreage. However, in 2017, there were only 1,141 farms with sorghum acreage and 390 farms with irrigated sorghum acreage. Because both number of acres and number of farms declined over time since 1992, the number of acres per farm was relatively stable for the case of sorghum (Table 15).

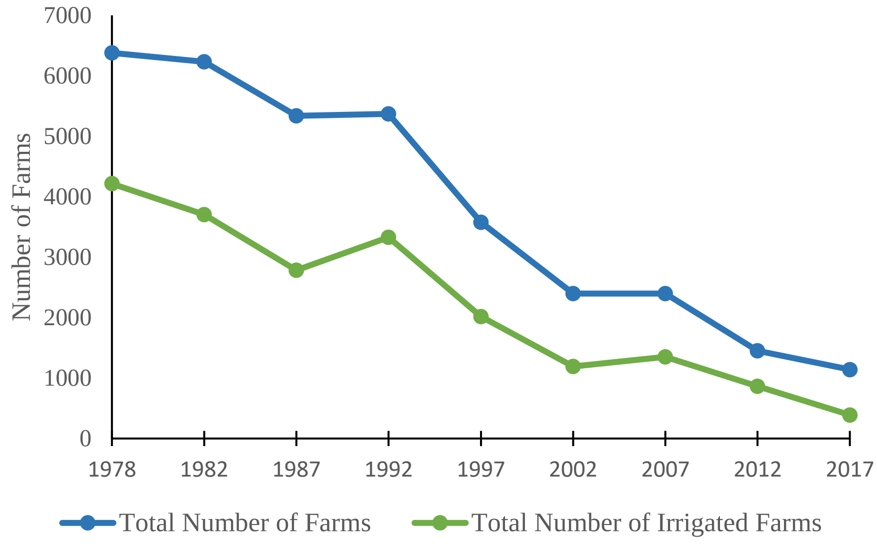

Figure 28. Number of farms with total sorghum harvested for grain and number of farms with irrigated sorghum harvested for grain in the Texas High Plains, 1978-2017.

Maps for total acres of sorghum harvested for grain are presented in Figure 29. In 1978, Dallam and Yoakum had the largest total harvested sorghum grain acres. In 1982, Hockley and Cochran had the largest harvested sorghum acreage among all the 39 counties. In 1992, the two counties (Hockley and Lubbock) that was considered sorghum-dense (having acres of sorghum harvested more than 50,000 acres). In 2017, Ochiltree and Deaf Smith had the largest number of acres of sorghum harvested. Focusing on the maps for irrigated acres of sorghum harvested for grain, it is clear that there was a decline in the region's irrigated sorghum acreage (Figure 30). In 1978, three counties – Sherman, Hansford, and Swisher – had more than 75,000 acres of irrigated sorghum harvested. However, in 2017 all counties had less than 25,000 acres of irrigated sorghum harvested.

Figure 29. Irrigated and non-irrigated sorghum harvested area for grain (in thousand acres) by county, 1978-2017.

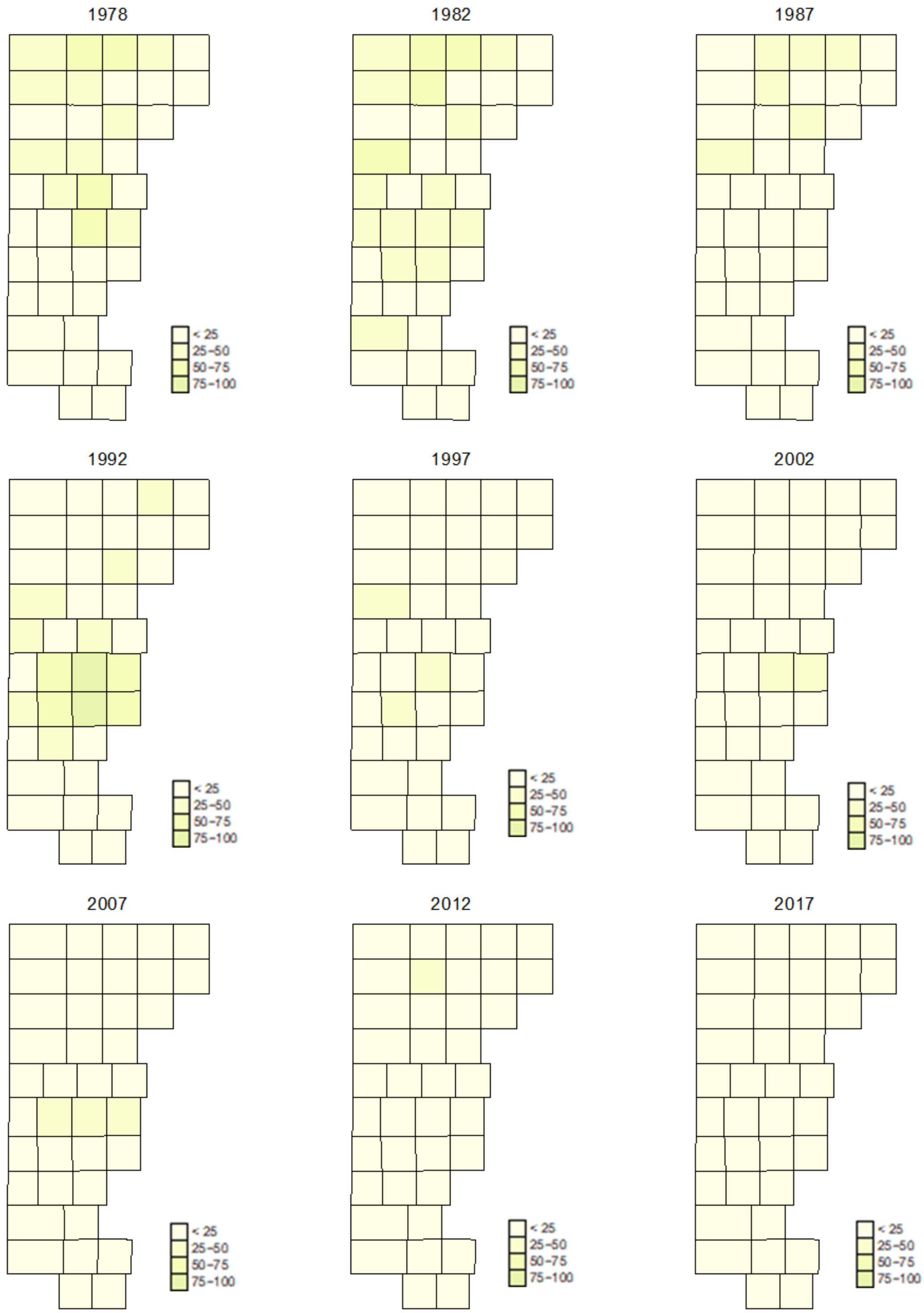

Figure 30. Irrigated sorghum harvested area for grain (in thousand acres) by county, 1978-2017.

Estimated Gini coefficients for total and irrigated acres of sorghum harvested for grain are reported in Table 16. For total sorghum acreage, the Gini coefficient value ranges from 0.375 and 0.497. For irrigated sorghum acreage, the value varies between 0.479 and 0.609. Similar to the cases of corn and cotton, the results suggest that sorghum acreage was concentrated in a small number of counties. As the Gini coefficient values for the case of irrigated acres were higher than those for the case of total acres, it can also be concluded that irrigated sorghum farms were more concentrated in fewer counties. It should also be noted that the Gini coefficient values for the case of sorghum are relatively smaller than those for the cases of corn and cotton. This suggests that sorghum production was more uniformly distributed across the 39 counties than corn and cotton production.

Table 16. Estimated Gini coefficients for total and irrigated sorghum harvested for grain acres, 1978-2017.

Year	Total	Irrigated
1978	0.435	0.532
1982	0.457	0.479
1987	0.375	0.542
1992	0.497	0.564
1997	0.402	0.499
2002	0.413	0.609
2007	0.404	0.534
2012	0.468	0.589
2017	0.496	0.593

Geographical concentration of total and irrigated acres of sorghum harvested for grain are illustrated in Figure 31 and Figure 32, respectively. As can be seen from Figure 31 and Table 17, a total of four or five counties covers at least 25 percent of harvested sorghum acreage. In 1978, the top four counties were Yoakum, Dallam, Sherman, and Deaf Smith. In 1992, the top four counties were Lubbock, Hockley, Crosby, and Cochran. In 2007, the top four counties were Lamb, Floyd, Deaf Smith, and Bailey. In 2017, the top four counties become Deaf Smith, Ochiltree, Lamb, and Carson. The combined land area in the top four or five counties covered less than 15 percent of total land area.

For the case of irrigated acres of sorghum, a total of two to four counties were responsible for 25 percent of irrigated sorghum production (Table 18). As can be seen from Figure 32, irrigated sorghum acreage was mostly concentrated in the northern and middle parts of Texas High Plains. In 1978, Sherman, Hansford, Swisher, and Hale contributed for more than 25 percent of the region's irrigated sorghum production. In 2017, the top three counties were Sherman, Moore, and Deaf Smith. While these few counties were responsible for at least a quarter of irrigated sorghum production, the combined cropland area in these top counties covered less than 12 percent of total land area.

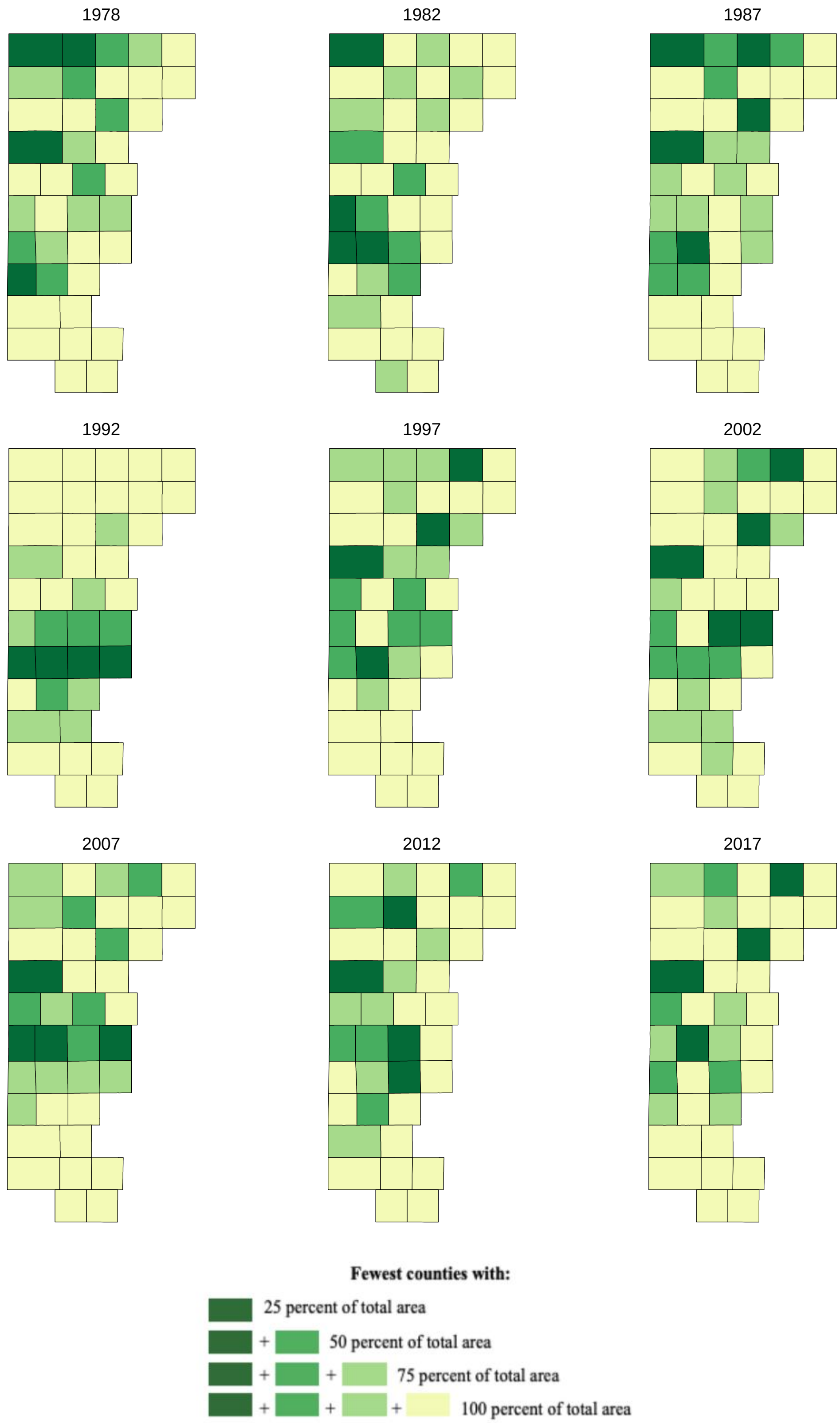

Figure 31. Concentration of irrigated and non-irrigated sorghum harvested area for grain (in thousand acres) by county, 1978-2017.

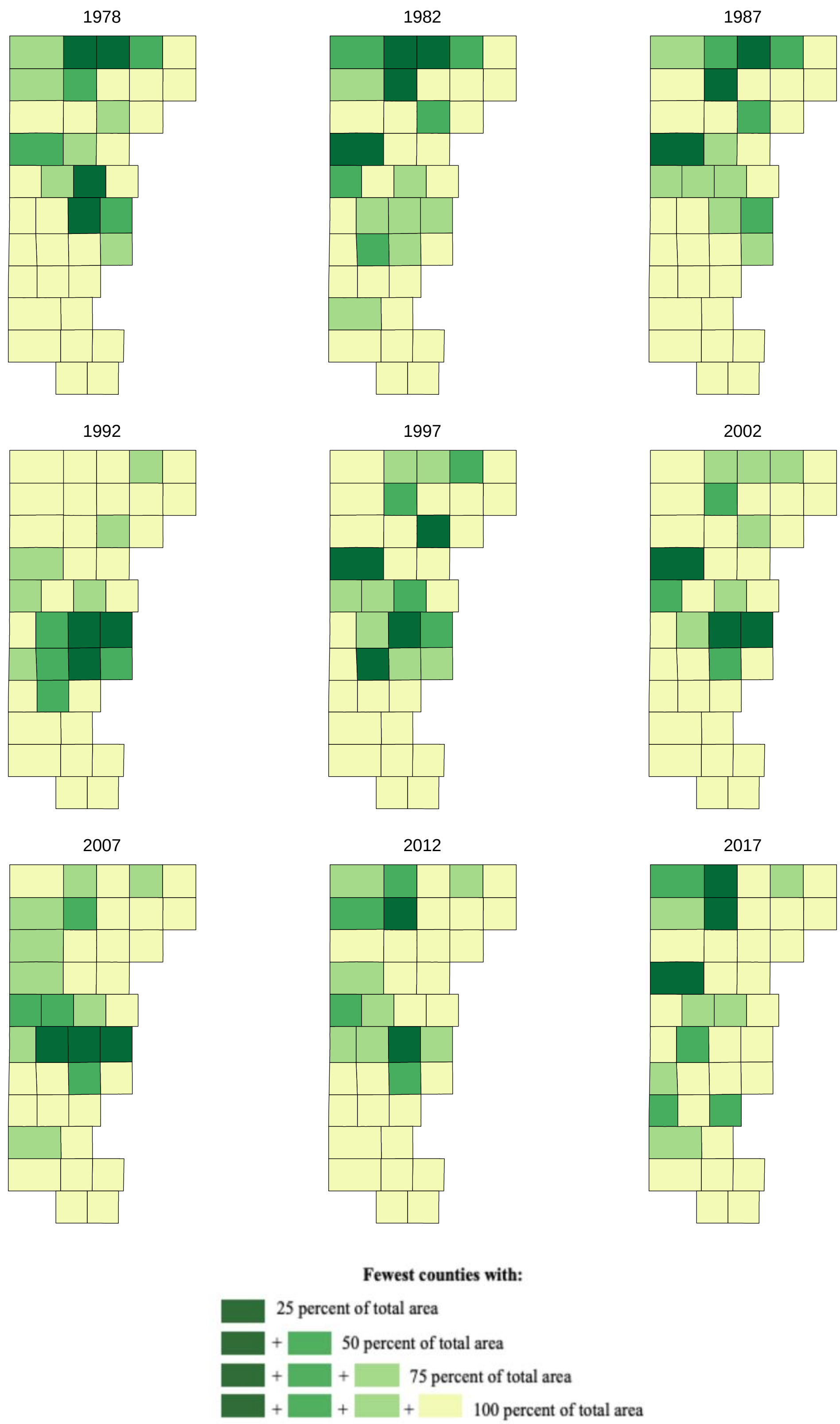

Figure 32. Concentration of irrigated sorghum harvested area for grain (in thousand acres) by county, 1978-2017.

Table 17. Total sorghum harvested for grain – number of counties, land area, and land area over the Ogallala Aquifer in the areas of greatest concentration.

	1978	1982	1987	1992	1997	2002	2007	2012	2017
Concentration level:	**Number of Counties**								
25% of total harvested cropland area	4	4	5	4	4	5	4	4	4
50% of total harvested cropland area	10	9	11	8	10	10	10	9	8
75% of total harvested cropland area	17	17	19	15	19	18	19	16	15
100% of total harvested cropland area	39	39	39	39	39	39	39	39	39
Concentration level:	**Land Area in Square Miles**								
25% of total harvested cropland area	4,727	4,017	5,757	3,486	4,249	5,338	4,336	4,314	4,358
50% of total harvested cropland area	10,048	9,228	10,974	7,393	9,635	9,671	9,879	9,431	7,843
75% of total harvested cropland area	17,086	17,704	18,336	14,842	18,452	17,530	18,954	16,397	14,684
100% of total harvested cropland area	38,945	38,945	38,945	38,945	38,945	38,945	38,945	38,945	38,945
Concentration level:	**Land Area over the Ogallala Aquifer in Square Miles**								
25% of total harvested cropland area	4,664	4,010	5,683	3,274	4,175	5,194	4,201	4,179	4,283
50% of total harvested cropland area	9,900	9,149	10,824	7,111	9,478	9,509	9,653	9,245	7,751
75% of total harvested cropland area	16,786	16,357	17,570	14,418	17,858	17,175	18,472	16,157	14,511
100% of total harvested cropland area	34,375	34,375	34,375	34,375	34,375	34,375	34,375	34,375	34,375

Table 18. Irrigated sorghum harvested for grain – number of counties, land area, and land area over the Ogallala Aquifer in the areas of greatest concentration.

	1978	1982	1987	1992	1997	2002	2007	2012	2017
Concentration level:	**Number of Counties**								
25% of total harvested cropland area	4	4	3	3	4	3	3	2	3
50% of total harvested cropland area	8	9	7	7	8	6	7	6	7
75% of total harvested cropland area	14	16	14	13	15	12	15	13	13
100% of total harvested cropland area	39	39	39	39	39	39	39	39	39
Concentration level:	**Land Area in Square Miles**								
25% of total harvested cropland area	3,749	4,252	3,329	2,898	4,336	3,496	3,015	1,915	3,331
50% of total harvested cropland area	8,068	9,393	7,087	6,617	8,057	6,191	6,610	6,087	7,548
75% of total harvested cropland area	14,685	17,176	14,106	12,519	14,506	11,796	16,146	13,746	14,008
100% of total harvested cropland area	38,945	38,945	38,945	38,945	38,945	38,945	38,945	38,945	38,945
Concentration level:	**Land Area over the Ogallala Aquifer in Square Miles**								
25% of total harvested cropland area	3,743	4,119	3,198	2,822	4,266	3,368	2,947	1,847	3,202
50% of total harvested cropland area	7,862	9,239	6,869	6,336	7,846	5,982	6,461	5,964	7,413
75% of total harvested cropland area	14,188	16,904	13,643	12,155	14,070	11,564	15,113	13,484	13,827
100% of total harvested cropland area	34,375	34,375	34,375	34,375	34,375	34,375	34,375	34,375	34,375

Spatiotemporal changes of irrigated harvested sorghum acres as percent of total acres of sorghum harvested for grain are illustrated in Figure 33. In 1978, nine counties irrigated more than 80 percent of their sorghum acreage. However, in the census years 1997, 2002, 2007, and 2017, all counties irrigated less than 80 percent of their sorghum acreage. More importantly, during the census years 2012 and 2017, a few counties did not harvest sorghum at all.

Figure 33. Irrigated sorghum harvested area for grain as percent of total sorghum harvested area for grain by county, 1978-2017.

Total and irrigated acres of sorghum harvested for grain as percent of total and irrigated harvested cropland acreage are depicted in Figure 34 and Figure 35, respectively. It is very apparent that there was a decline in the relative importance of sorghum production in the Texas High Plains. In the early census years, there were few counties with more than 50 percent of its harvested cropland area planted with sorghum. However, the more recent census years, most farms had less than 10 percent of its harvested cropland area planted with sorghum. Non-irrigated sorghum production during the study period also decreased by 38 percent. This suggests that crop producers in this area moved away from sorghum production. Therefore, the policy makers should investigate the underlying reasons of this shift.

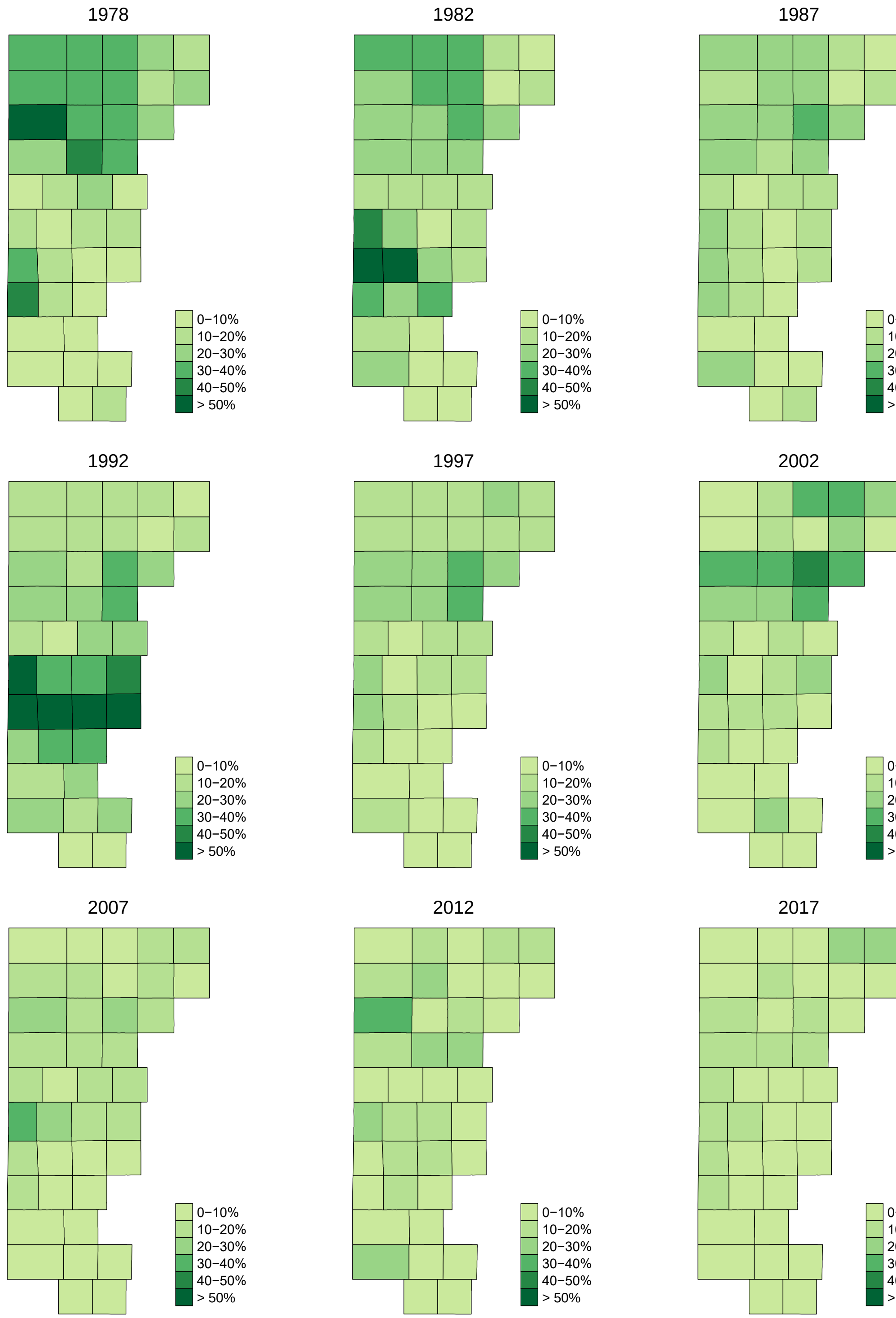

Figure 34. Total sorghum harvested area for grain as percent of total harvested cropland area by county, 1978-2017.

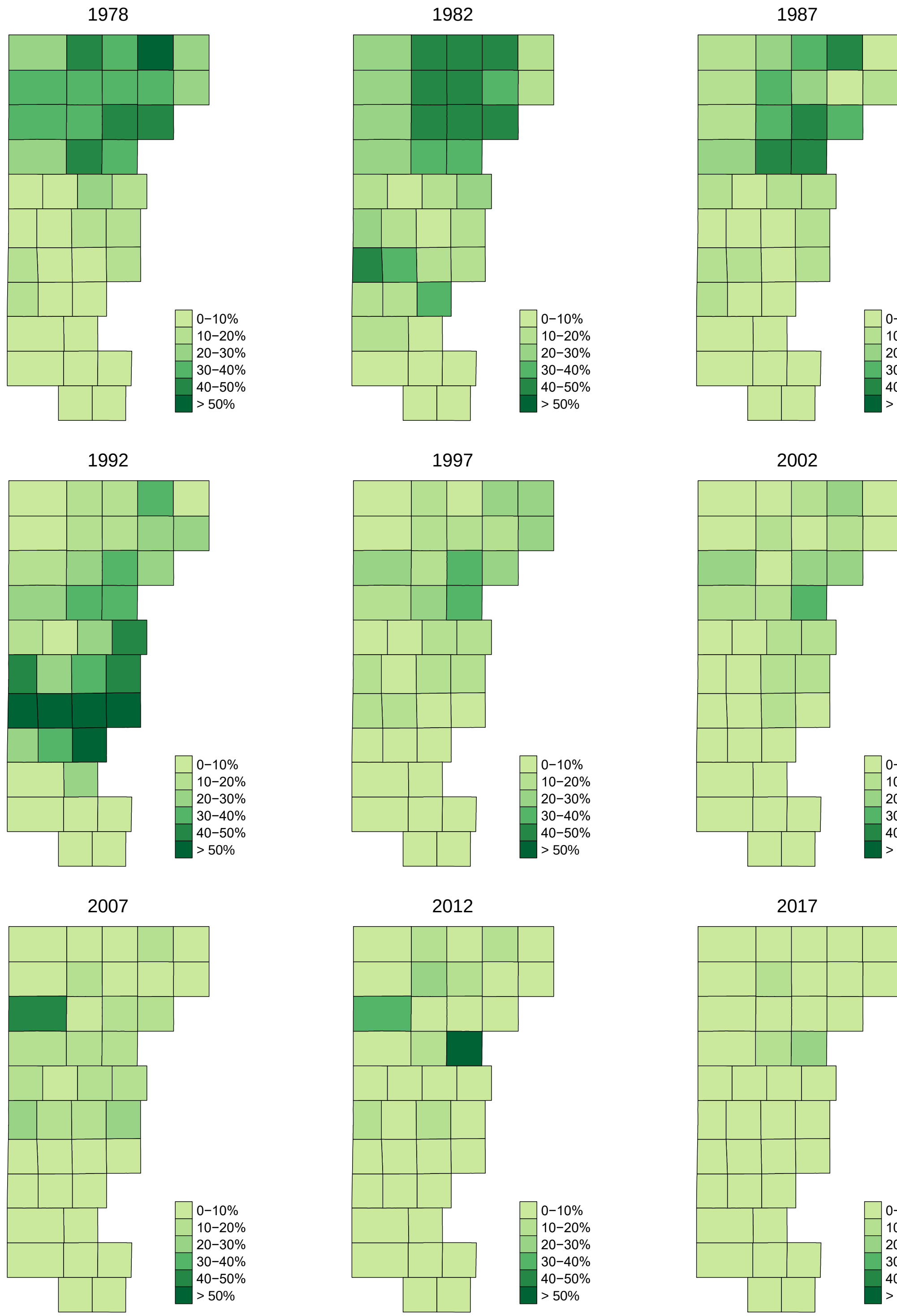

Figure 35. Irrigated sorghum harvested area for grain as percent of irrigated harvested cropland area by county, 1978-2017.

Wheat, harvested for grain

The region's total and irrigated acres of wheat harvested for grain during the census years 1978 and 2017 are depicted in Figure 36. The total acres had been clearly much more volatile than the irrigated acres. The total acres decreased from 1.4 million acres in 1978 to 1.1 million acres in 2017, whereas the irrigated acres decreased from 595,775 acres in 1978 to only 250,723 in 2017 (Table 19). Regarding the number of farms, the total number of farms with wheat acreage declined over time (Figure 37). Specifically, the total number of farms decreased from 5,252 farms in 1978 to 1,970 farms in 2017. For irrigated wheat farms, the total number of farms declined from 3,030 farms in 1978 to only 683 farms in 2017. As a result, the number of acres per wheat farm (per irrigated wheat farm) increased from 264 (197) acres to 556 (367) acres. This suggests that the average wheat farm size increased over time.

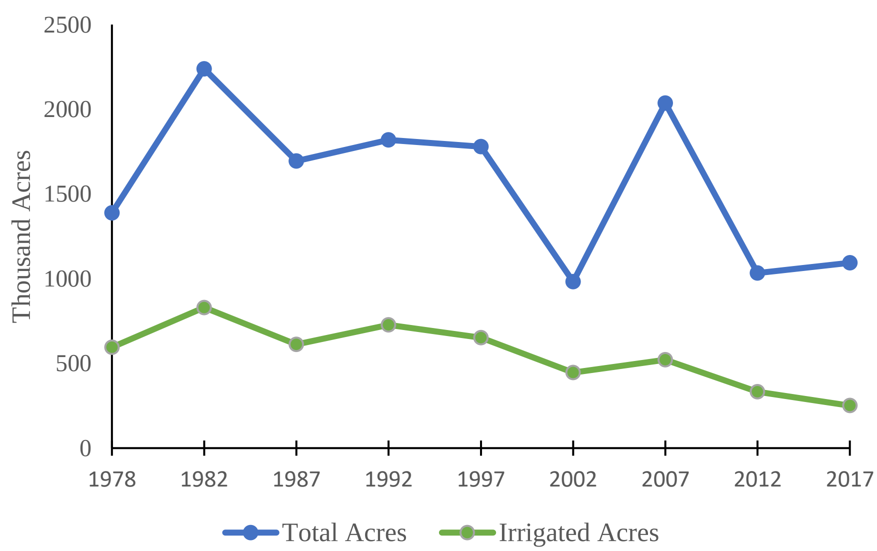

Figure 36. Total and irrigated wheat harvested area for grain (in thousand acres) in the Texas High Plains, 1978-2017.

Table 19. Total and irrigated wheat harvested for grain – acres, number of farms, and acres per farm in the Texas High Plains, 1978-2017.

	Irrigated and Non-irrigated			Irrigated		
Year	**Acres**	**Farms**	**Acres per Farm**	**Acres**	**Farms**	**Acres per Farm**
1978	1,388,038	5,252	264	595,775	3,030	197
1982	2,238,543	6,849	327	830,066	3,751	221
1987	1,693,982	6,204	273	611,863	3,335	183
1992	1,818,932	5,262	346	727,149	2,936	248
1997	1,778,713	4,706	378	652,464	2,442	267
2002	982,103	2,754	357	446,344	1,508	296
2007	2,036,189	3,561	572	521,690	1,558	335
2012	1,032,542	2,095	493	332,986	1,107	301
2017	1,094,511	1,970	556	250,723	683	367

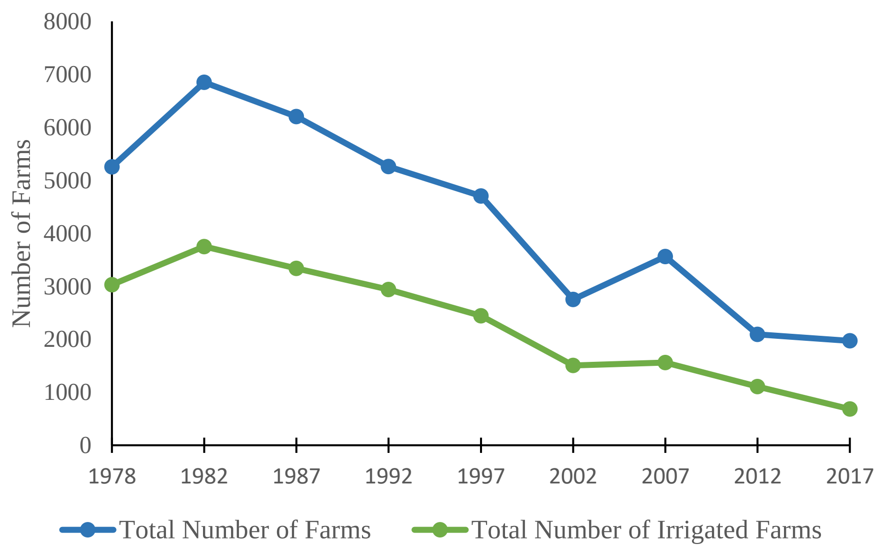

Figure 37. Number of farms with total wheat harvested for grain and number of farms with irrigated wheat harvested for grain in the Texas High Plains, 1978-2017.

Maps of total and irrigated acres of wheat harvested for grain are illustrated in Figure 38 and Figure 39, respectively. Overall, wheat production was concentrated in the northern part of the region. Focusing on total wheat acreage, Ochiltree had the largest number of acres in most census years. During the census year 1992, Ochiltree was considered wheat-dense (having acres of wheat harvested more than 150,000 acres). In the most recent census year, Deaf Smith was the county with the largest wheat acreage in the area. Similar patterns are observed when considering irrigated wheat acreage.

Figure 38. Irrigated and non-irrigated wheat harvested area for grain (in thousand acres) by county, 1978-2017.

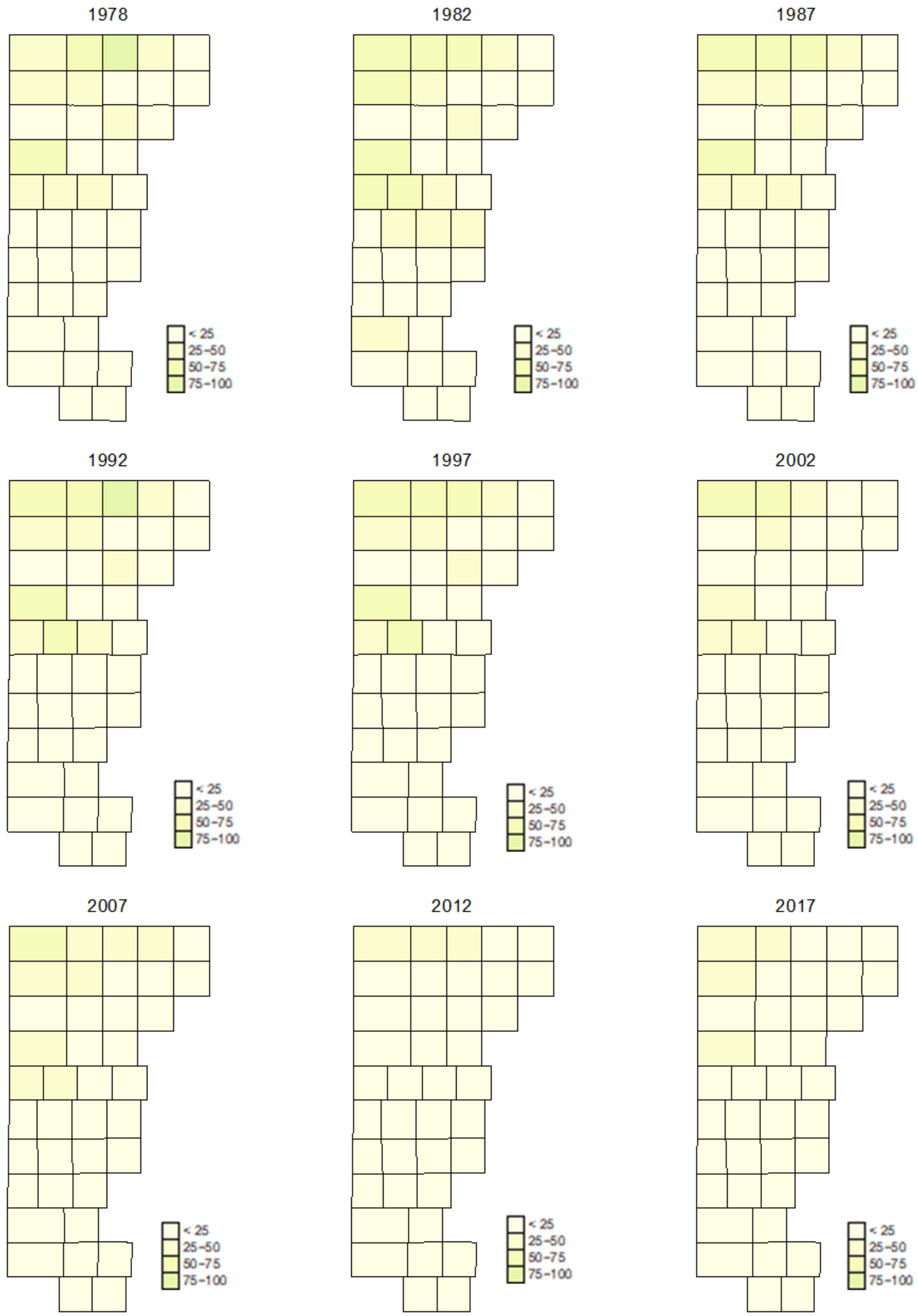

Figure 39. Irrigated wheat harvested area for grain (in thousand acres) by county, 1978-2017.

Table 20. Estimated Gini coefficients for total and irrigated wheat harvested for grain acres, 1978-2017.

Year	Total	Irrigated
1978	0.542	0.647
1982	0.485	0.586
1987	0.527	0.624
1992	0.522	0.632
1997	0.535	0.643
2002	0.488	0.619
2007	0.535	0.622
2012	0.539	0.570
2017	0.554	0.616

Estimated Gini coefficients for total and irrigated acres of wheat harvested for grain are reported in Table 20. For total wheat acreage, the Gini coefficient value ranges between 0.488 and 0.554. For irrigated wheat acreage, the Gini coefficient varies between 0.570 and 0.647. Similar to the other three crops, the results suggest that wheat acreage was concentrated in a small number of counties. As the Gini coefficient values for the case of irrigated acres were higher than those for the case of total acres, irrigated wheat farms were more concentrated in fewer counties than irrigated and non-irrigated wheat farms.

Spatial changes in geographical concentration of total and irrigated acres of wheat harvested for grain are shown in Figure 40 and Figure 41, respectively. As can be seen from Figure 40 and Table 21, the fewest number of counties with 25 percent of total wheat acres were two to four counties, depending on the census years. In 1978, the top three counties were Ochiltree, Deaf Smith, and Hansford. During the census years 1982 and 2017, these six counties covered more than 25 percent of harvested wheat acreage: Ochiltree, Deaf Smith, Hansford, Randall, Dallam, and Sherman. These counties, however, covered less than 15 percent of total land area. Similar patterns are observed when focusing on the case of irrigated wheat acreage (Figure 41 and Table 22). Overall, wheat acreage was concentrated in the northern part of the region.

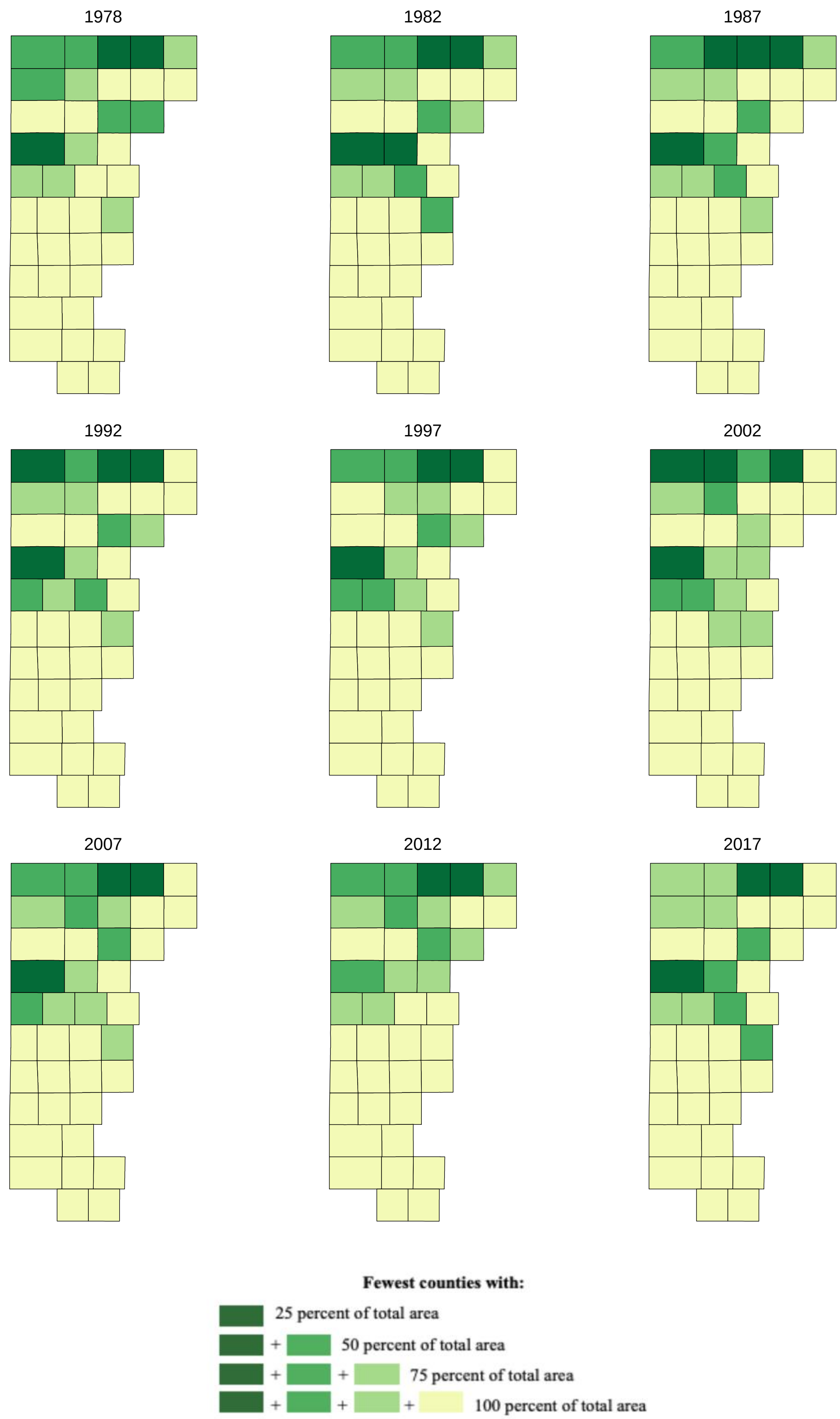

Figure 40. Concentration of irrigated and non-irrigated wheat harvested area for grain in thousand acres) by county, 1978-2017.

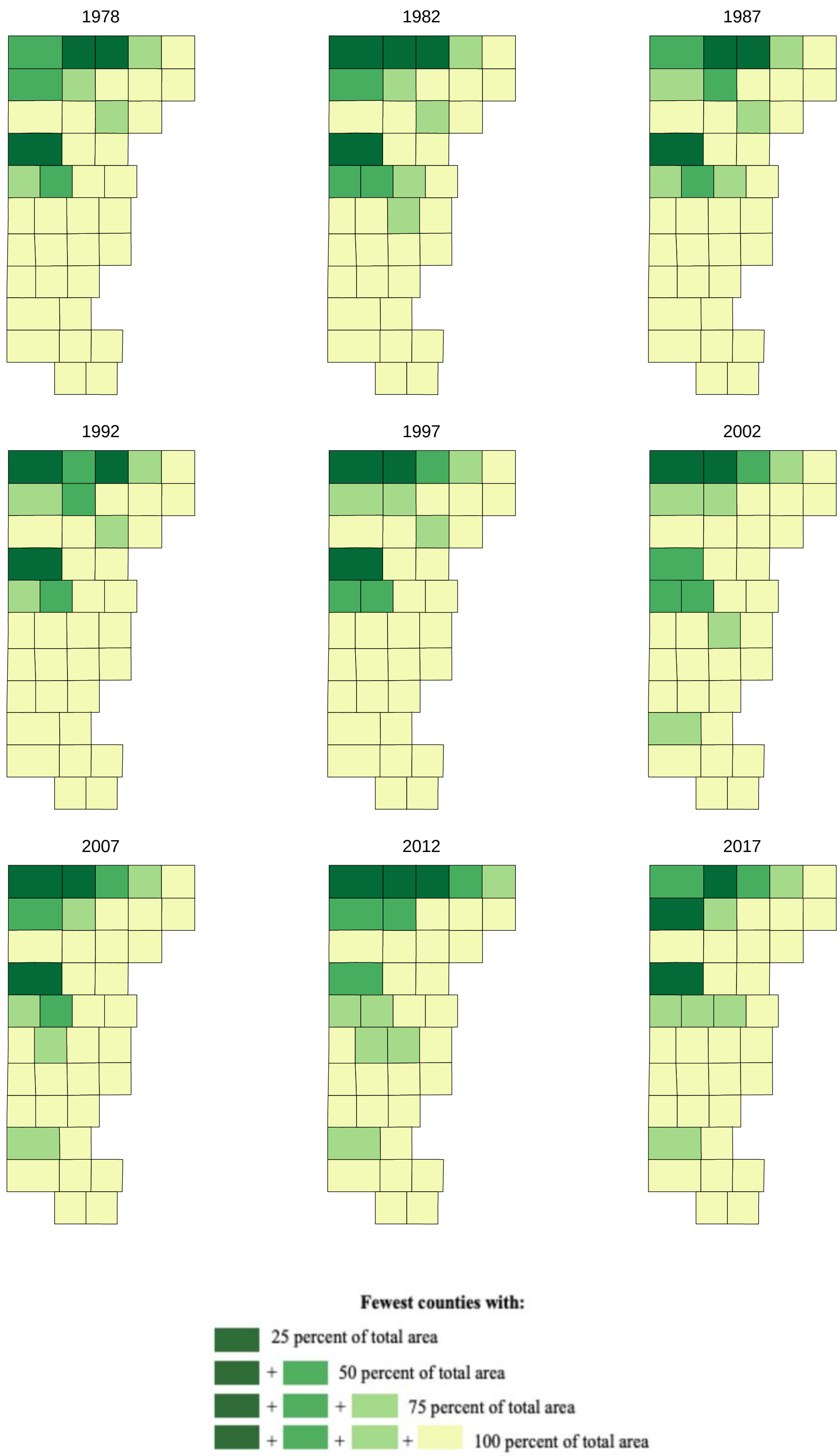

Figure 41. Concentration of irrigated wheat harvested area for grain (in thousand acres) by county, 1978-2017.

Table 21. Total wheat harvested for grain – number of counties, land area, and land area over the Ogallala Aquifer in the areas of greatest concentration.

	1978	1982	1987	1992	1997	2002	2007	2012	2017
Concentration level:	**Number of Counties**								
25% of total harvested cropland area	3	4	4	4	3	4	3	2	3
50% of total harvested cropland area	8	9	8	8	8	8	8	7	7
75% of total harvested cropland area	14	15	14	14	14	15	14	15	13
100% of total harvested cropland area	39	39	39	39	39	39	39	39	39
Concentration level:	**Land Area in Square Miles**								
25% of total harvested cropland area	3,337	4,259	4,260	4,842	3,337	4,845	3,337	1,839	3,337
50% of total harvested cropland area	9,082	9,506	8,513	8,476	8,474	8,460	8,485	7,599	7,077
75% of total harvested cropland area	14,624	15,525	14,595	14,592	14,024	15,582	14,558	15,440	13,663
100% of total harvested cropland area	38,945	38,945	38,945	38,945	38,945	38,945	38,945	38,945	38,945
Concentration level:	**Land Area over the Ogallala Aquifer in Square Miles**								
25% of total harvested cropland area	3,270	4,159	4,191	4,775	3,270	4,779	3,270	1,831	3,270
50% of total harvested cropland area	8,935	9,321	8,397	8,387	8,387	8,317	8,329	7,450	6,895
75% of total harvested cropland area	14,301	15,201	14,298	14,269	13,562	14,991	14,083	14,714	13,366
100% of total harvested cropland area	34,375	34,375	34,375	34,375	34,375	34,375	34,375	34,375	34,375

Table 22. Irrigated wheat harvested for grain – number of counties, land area, and land area over the Ogallala Aquifer in the areas of greatest concentration.

	1978	1982	1987	1992	1997	2002	2007	2012	2017
Concentration level:	**Number of Counties**								
25% of total harvested cropland area	3	4	3	3	3	2	3	3	3
50% of total harvested cropland area	6	7	6	6	6	6	6	7	5
75% of total harvested cropland area	10	12	11	10	10	11	11	13	11
100% of total harvested cropland area	39	39	39	39	39	39	39	39	39
Concentration level:	**Land Area in Square Miles**								
25% of total harvested cropland area	3,342	4,847	3,342	3,924	3,927	2,429	3,927	3,349	3,885
50% of total harvested cropland area	7,210	8,095	6,657	6,657	6,632	6,632	7,210	8,139	6,311
75% of total harvested cropland area	10,847	12,753	11,748	10,847	10,847	12,431	12,444	14,381	12,327
100% of total harvested cropland area	38,945	38,945	38,945	38,945	38,945	38,945	38,945	38,945	38,945
Concentration level:	**Land Area over the Ogallala Aquifer in Square Miles**								
25% of total harvested cropland area	3,277	4,782	3,277	3,861	3,865	2,426	3,865	3,343	3,784
50% of total harvested cropland area	7,106	7,985	6,524	6,524	6,561	6,561	7,106	7,962	6,206
75% of total harvested cropland area	10,653	12,558	11,553	10,653	10,653	12,247	12,260	14,197	12,142
100% of total harvested cropland area	34,375	34,375	34,375	34,375	34,375	34,375	34,375	34,375	34,375

Spatiotemporal changes of irrigated acres of wheat harvested for grain as percent of total wheat acreage are presented in Figure 42. In most years, all counties have some wheat acreage. During the census years 1978 to 2012, none of the counties irrigated more than 80 percent of total wheat acreage. In 2012 (2017), the two (three) counties that irrigated more than 80 percent of total wheat acreage are Dawson and Hemphill (Hemphill, Lubbock, and Midland). Overall, most counties irrigated less than 40 percent of their wheat acreage.

Figure 42. Irrigated wheat harvested area for grain as percent of total wheat harvested area for grain by county, 1978-2017.

Total acres of wheat harvested for grain as percent of total harvested cropland acreage are presented in Figure 43. It is apparent that the total wheat acres were mainly concentrated in the northern part of Texas High Plains. In 1978, seven counties had more than half of their total harvested cropland acres planted with wheat. The number of counties with more than 50 percent of their harvested cropland area planted with wheat increased from seven counties in 1978 to 13 counties in 1997. After that, however, there had been a decline in the proportion of wheat harvested relative to total harvested cropland acreage. In 2017, only four counties – Oldham, Potter, Randall, and Armstrong – had more than 50 percent of total harvested cropland area planted with wheat.

Irrigated acres of wheat harvested for grain as percent of irrigated harvested cropland acres are displayed in Figure 44. It is apparent that there had been a decrease in the proportion of irrigated wheat acres relative to irrigated cropland acres during the past 40 years. While at least 15 counties had at least 30 percent of their irrigated cropland acreage planted with wheat during 1978 to 1992, most counties had less than 10 percent of their irrigated cropland acreage planted with wheat during the last three census years. On the other hand, during the study period there was an increase in non-irrigated wheat acres. From 1978 to 2017 non-irrigated wheat acres increased by 6.5 percent. Increase in non-irrigated wheat acres and a decrease in irrigated wheat acres in the same time period suggests that irrigation water is a barrier for irrigated wheat production. Therefore, policy makers should invest more in developing drought tolerant varieties of wheat.

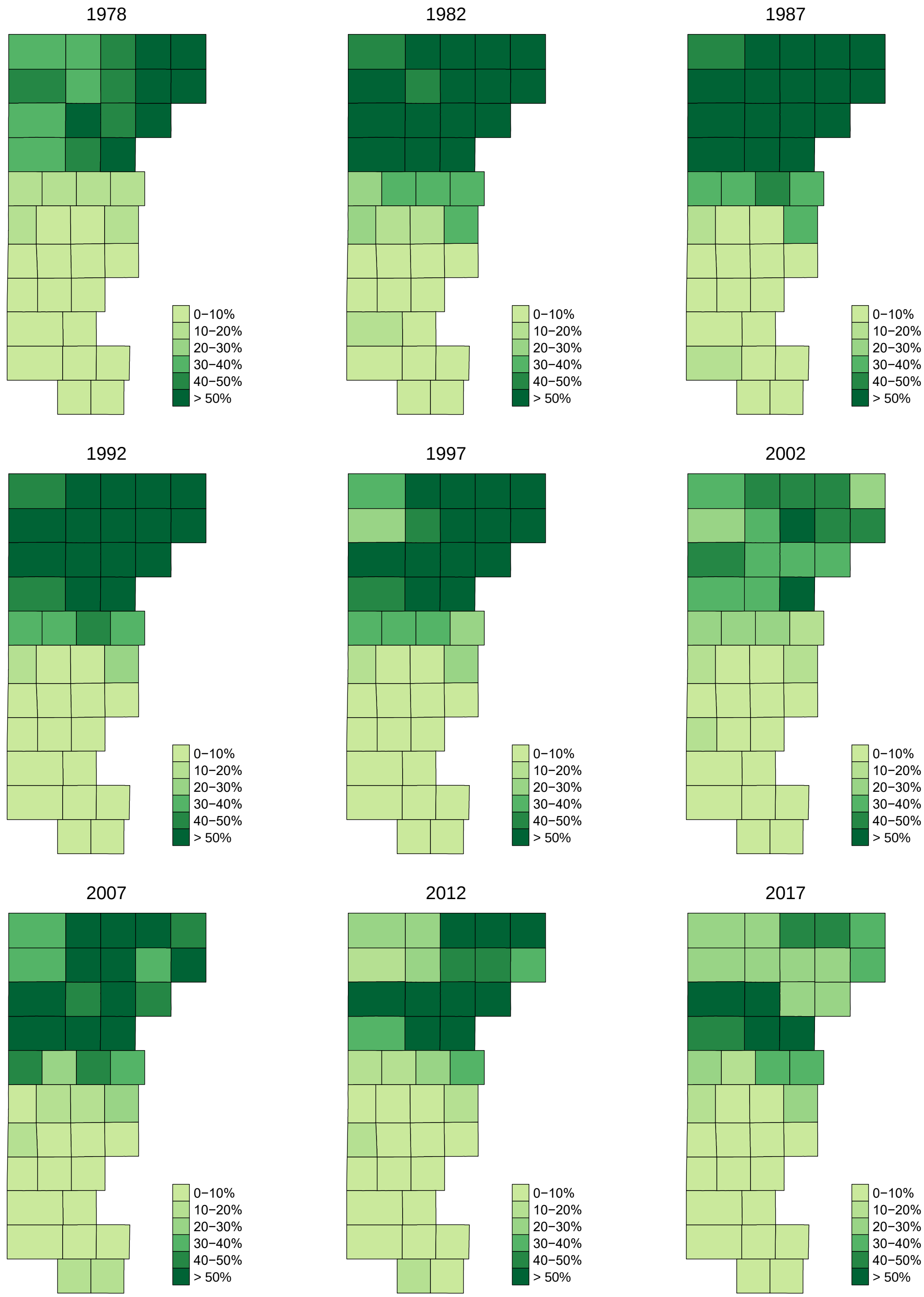

Figure 43. Total wheat harvested area for grain as percent of total harvested cropland area by county, 1978-2017.

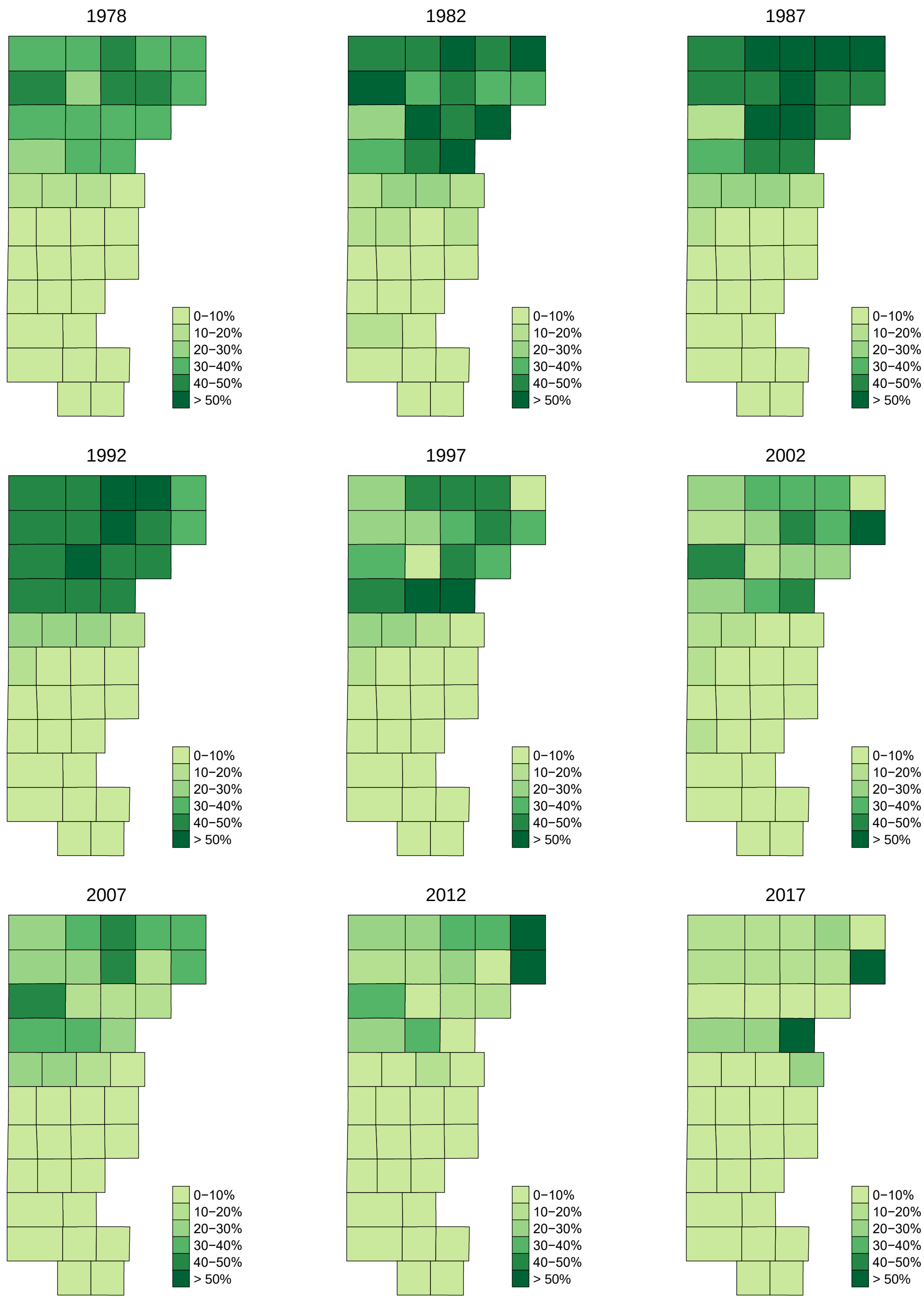

Figure 44. Irrigated wheat harvested area for grain as percent of irrigated harvested cropland area by county, 1978-2017.

Spatial autocorrelation

To assess spatial autocorrelation, or dependence in crop choices among neighboring counties, Moran's I statistics are calculated to test whether the relative proportion of each crop harvested was randomly distributed across counties. The test results for total acreage and irrigated acreage are reported in Tables 23 and 24, respectively. Overall, the Moran's I statistics are positive and statistically significant at the 5 percent significance level, indicating existence of spatial dependence.

Table 23. Estimated Moran's I statistics for relative proportion of each crop (irrigated and non-irrigated), 1978-2017.

Year	Corn	Cotton	Sorghum	Wheat
1978	0.551*	0.919*	0.830*	0.917*
1982	0.486*	0.486*	0.634*	0.753*
1987	0.518*	0.769*	0.534*	0.835*
1992	0.590*	0.917*	0.580*	0.922*
1997	0.625*	0.896*	0.611*	0.676*
2002	0.670*	0.880*	0.382*	0.518*
2007	0.638*	0.462*	0.240*	0.677*
2012	0.653*	0.794*	0.161*	0.170*
2017	0.421*	0.540*	0.175*	-0.005

*Denotes a rejection of the null hypothesis of no spatial autocorrelation at the 5 percent significance level.

Table 24. Estimated Moran's I statistics for relative proportion of each crop (irrigated only), 1978-2017.

Year	Corn	Cotton	Sorghum	Wheat
1978	0.503*	0.915*	0.611*	0.904*
1982	0.448*	0.918*	0.481*	0.907*
1987	0.491*	0.879*	0.410*	0.920*
1992	0.543*	0.899*	0.561*	0.919*
1997	0.599*	0.936*	0.513*	0.903*
2002	0.690*	0.897*	0.255*	0.824*
2007	0.581*	0.902*	0.391*	0.821*
2012	0.605*	0.860*	0.167*	0.754*
2017	0.621*	0.812*	0.235*	0.744*

*Denotes a rejection of the null hypothesis of no spatial autocorrelation at the 5 percent significance level.

For corn, the Moran's I statistics are relatively stable over time. The test statistic ranges from 0.421 to 0.670 when considering both irrigated and non-irrigated cropland area and from 0.448 to 0.690 when considering only irrigated cropland area. For cotton, the Moran's I statistics are very high in most census years. Specifically, Moran's I statistics vary between 0.486 and 0.919 for total cropland area and between 0.812 to 0.936 for irrigated cropland area. This indicates that there was strong spatial dependence in the crop choice across neighboring counties. With respect to sorghum, the Moran's I statistics have clearly declined over time, regardless of whether total or irrigated figures are being considered. This indicates that the relative proportion of sorghum becomes more and more randomly distributed across counties over time. For wheat, it's clear that the Moran's I statistics have also declined over time when considering the proportion of wheat relative to the total cropland area. In fact, the null hypothesis of no spatial autocorrelation cannot be rejected for the census year 2017. Nevertheless, when considering only irrigated cropland, the Moran's I statistics are consistently high for the case of wheat, indicating strong autocorrelation across neighboring counties. Overall, the spatial autocorrelation results are in line with the exploratory data analysis results presented in the previous sections.

CHAPTER V
SUMMARY AND CONCLUSION

This study examined temporal changes in county-level spatial patterns of crop production in the Texas High Plains. Historical agricultural census data on acres of harvested cropland, number of farms with harvested cropland, acres of corn harvested for grain, number of farms with acres of corn harvested for grain, acres of cotton harvested, number of farms with acres of cotton harvested, acres of sorghum harvested for grain, number of farms with acres of sorghum harvested for grain, acres of wheat, and number of farms with acres of wheat harvested for the census years 1978, 1982, 1987, 1992, 1997, 2002, 2007, 2012, and 2017 were considered in the analysis. Both total and irrigated figures were analyzed. Non-irrigated maps are attached in the appendix section.

The study analyzed spatial and temporal changes in cropland acreage as well as corn, cotton, sorghum, and wheat acres in the Texas High Plains from the standpoint of geographical concentration and spatial dependence. Maps were generated for each variable of interest to examine how much cropland acreage in the Texas High Plains has changed over time. To analyze the overall change in geographical concentration and spatiotemporal changes the Gini coefficient and the quantiles of size distributions, respectively were computed for all variables of interest. Finally, Moran's I statistic was calculated to examine spatial autocorrelation or dependence in the crop choices across the 39 Texas High Plains counties.

The main findings are as follows. First, temporal analysis of total and irrigated harvested acres trends showed a downward trend for almost all the variables of interest from 1978 to 2017. During the study period, total harvested cropland acres had been more volatile than the irrigated harvested cropland acres. For both total and irrigated harvested cropland, the total number of farms decreased, while the average acres per farm increased over the past 40 years of the study period. Total and irrigated harvested corn, cotton, sorghum, and wheat acres trends also showed a similar downward trend throughout the study period. Maps for both total and irrigated harvested acres of cropland show that counties in the center of Texas High Plains have the largest share of harvested acres which visualize the change of county-level harvested cropland over time. Further investigation on why the counties in the center of Texas High Plains have largest share of harvested acres shows that 88 percent of the total land area of the study region is situated over the Ogallala Aquifer. Besides, the counties in center region of the Texas High Plains have lower saturated thickness of Ogallala Aquifer than the northern part (Figure 45). Therefore, only the center counties of the Texas High Plains cannot be impacted by the Ogallala Aquifer. Some other factors such as weather variables, soil quality might have some correlations which warrant further investigation.

During the study period, irrigated harvested cropland area decreased by 35 percent while non-irrigated harvested cropland area increased by 8 percent which shows a shift of crop production from irrigated to non-irrigated. Non-irrigated cropland area increased but not comparable to the decrease of irrigated cropland areas. The reason of not increasing non-irrigated cropland areas might be the low yields of non-irrigated crops and weather variability.

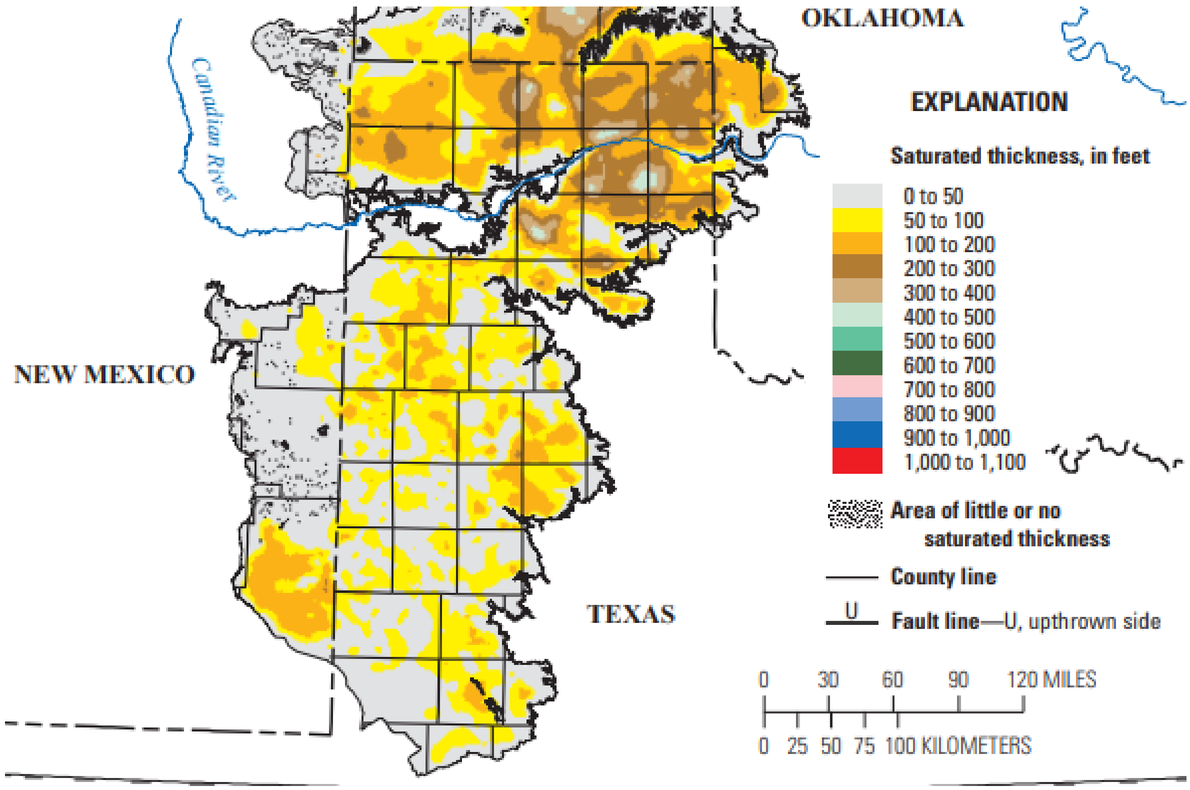

Figure 45. Saturated thickness of Ogallala Aquifer by county in the Texas High plains, 2012. Reproduced from McGuire et al., 2012.

Second, the Gini coefficient of relative share of total and irrigated harvested cropland acres as well as for four other crops in each county were estimated during the census years from 1978 to 2017. The Gini coefficient for total harvested cropland was (low-ranging from 0.305 to 0.380) relatively stable over time indicating that acres were nearly uniformly distributed across the 39 counties whereas irrigated harvested cropland acres were concentrated in a smaller number of counties. The high value of Gini coefficients of corn grain and cotton indicate that both total and irrigated corn acreages were consistently concentrated in a smaller number of counties over time. Gini coefficient values for the case of sorghum are relatively smaller than those for the cases of corn and cotton. This suggests that sorghum production was more uniformly distributed across the 39 counties than corn and cotton production. Similar to the other three crops, wheat acreage was also concentrated in a small number of counties while irrigated wheat farms were more concentrated than total wheat farms.

Third, for quantiles of size distribution, total (irrigated and non-irrigated) and irrigated harvested acres of cropland, corn, cotton, sorghum, and wheat were ranked from largest to smallest and the minimum number of counties with 25 percent, 50 percent, and 75 percent of total acres harvested were identified at the county level through the study period. There was almost no change in the number of fewest counties with 25 percent of total and irrigated harvested cropland acres concentration over the study period whereas there was a small change in the geographical concentration of total corn acreage where only two to three counties covered a quarter of total acres of corn harvested for grain. In 1978, a quarter of the total harvested cotton acres were concentrated in Gaines, Lubbock, and Dawson whereas the top three counties in 2017 were Lynn, Lubbock, and Dawson that covered at least 25 percent of total cotton production. A total of four or five counties such as Yoakum, Dallam, Sherman, Ochiltree, and Deaf Smith covered at least 25 percent of harvested sorghum acreage during the study period. However, wheat production was concentrated in the northern part of the region. The saturated thickness of Ogallala Aquifer in the northern part of the Texas High Plains is higher (up to 500 ft, Figure 45) than southern or center part (up to 200 ft, Figure 45) which might drive high concentration of wheat production in the northern region.

The relative area of four major harvested crops in the Texas High Plains was also examined by plotting the share of each of the crops relative to the total cropland. Most counties had more than 50 percent of its harvested cropland area planted with cotton throughout the study period. There was a decline in the share of sorghum and wheat production in the Texas High Plains during the study period. Number of counties with more than 50 percent of its harvested cropland area planted with wheat reduced from 7 in 1978 to 4 in 2017. Spatiotemporal changes in the proportion of irrigated harvested areas relative to total harvested area for each crop were also examined. Since corn is mostly an irrigated crop, most counties had more than 80 percent of total corn acreage irrigated in the Texas High Plains. In 2017, Lipscomb was the only county that irrigated more than 80 percent of its total cotton acreage and other counties started to harvest cotton in the more recent census years. This increase can be driven by the technical improvements in how growers produce cotton, government program changes and a resurgence of cotton demand after 1990 (Glade et al., 1996).

Finally, the spatial dependence in the production of major crops across 39 counties of Texas High Plains by applying the Moran's I test to see spatial autocorrelation among nearby locations was investigated. The test statistics range from 0.421 to 0.670 when considering total (irrigated and non-irrigated) cropland area and range from 0.448 to 0.690 when considering only irrigated cropland area which indicates that spatial dependence existed in the production of crops in this region.

Considering the spatiotemporal change of cropping pattern in the Texas High Plains, policy makers should promote and support the non-irrigated varieties of crops to reduce the dependence on irrigation water from Ogallala Aquifer. Although non-irrigated cropland area increased by 8 percent during the study period, it is not enough to compensate the 35 percent reduction in irrigated harvested cropland. Sorghum production needs more attention from the policy makers as both irrigated and non-irrigated harvested cropland for sorghum reduced by 86 percent and 38 percent, respectively, during the 40 years of the study period.

Some other topics of interest that were not covered in this study such as silage of corn, sorghum, and wheat harvested acres and correlation with the weather variables. These factors can be helpful to choose the location for dairy and cattle industries. Therefore, further research needs to look at the correlation between cropland allocation and weather variables (precipitation and temperature) in the Texas High Plains.

REFERENCES

Aalders, H. I., Aitkenhead, J. M. 2006. "Agricultural census data and land use modelling." Computers, Environment and Urban Systems. Vol. 30, Issue 6, Pages 799-814.

Beddow, J. M. and Pardey, P. G. 2015. "Moving matters: The effect of location on crop production." *The Journal of Economic History*, Vol. 75, No. 1, Pages 219-249.

Benavidez, J., Guerrero, B., Dudensing, R., Jones, D., Reynolds, S. 2019. "The impact of agribusiness in the High Plains trade area". Agriculture Council of Amarillo Chamber of Commerce. (Accessed February 25, 2021). Available at: https://amarillo.tamu.edu/files/2019/12/Impact-of-AgriBusiness.pdf.

Cullis, J., and B. Van Koppen. 2007. "Applying the Gini coefficient to measure inequality of water use in the Olifants River Water Management Area, South Africa." International Water Management Institute. Vol. 113.

Franczyk, J., and Chang, H. 2009. "Spatial analysis of water uses in Oregon, USA, 1985 to 2005." Water Resources Management. Vol. 23, Pages 755–774.

Glade, J., Edward, H., Leslie, M., and Harold, S. 1996. "The cotton industry in the United States." No. 1473-2017-3846.

Guerrero, B., Owens, R., Amosson, S., Sukcharoen, K., Richeson, J., Almas, L. 2019. “Assessing economic changes due to an expanding dairy industry in the Texas High Plains.” *Journal of American Water Resources Association*. Pages 1-10.

Haggett, P., A.D. Cliff, and A. Frey. 1977. “Locational analysis in human geography.” *Journal of Economic and Human Geography.* Vol. 68 (6), Pages 363–67.

Hicke, J.A., Lobell, D.B., and Asner, G.P. 2004. “Cropland area and net primary production computed from 30 years of USDA agricultural harvest data”. Earth Interactions. Vol. 8, Issue 10.

Hornbeck, R., and Keskin, P. 2014. “The historically evolving Impact of the Ogallala Aquifer: Agricultural adaptation to groundwater and drought.” *American Economic Journal: Applied Economics.* Vol. 6, No. 1, Pages 190-219.

Howell, T.A., Evett, S. R, Tolk, J.A, Schneider, A.D, and Steiner, J. L. 1996. “Evapotranspiration of corn Southern High Plains. In: Evapotranspiration and Irrigation Scheduling, C.R. Camp, E.J. Sadler, and R.E. Yoder (Eds.).” Proceedings of the International Conference, Nov. 3-6, 1996, San Antonio, TX, ASAE, St. Joseph, MI, Pages. 158-166.

Howell, T., Yazar, A., Schneider, A., Dusek, D., and Copeland, K. 1995. “Yield and water use efficiency of corn in response to LEPA irrigation.” Transactions of the American Society of Agricultural Engineers 38: 1737-1747.

Krugman, P. 1991. “Increasing returns and economic geography.” *Journal of Political Economy*. Vol. 99(3), Pages 483-499.

Laingen, C. 2015. "A spatiotemporal analysis of sorghum in the United States." Papers in Applied Geography. Vol. 1, Issue 4, Pages 307- 311.

Liu, H., Jia, Y., Niu, C., and Gan, Y. 2019. "Spatial pattern analysis of regional water use profile based on the Gini coefficient and location quotient." *American Water Resource Association.* Vol. 55, Issue5, Pages 1349-1366.

Lobell, B.D., Hicke, A.J., Asner, P. G., Field, B. C., Tucker, J. C., and Los, O. S. 2002. "Satellite estimates of productivity and light use efficiency in United States agriculture, 1982–1998." Global Change Biology. Vol. 8, Issue. 8, Pages 1–15.

Martinez- Casasnovas, A. J., Martin- Montero, A., Casterad, A.M. 2005. "Mapping multi- year cropping patterns in small irrigation districts from time- series analysis of Landsat TM images." *European Journal of Agronomy.* Vol. 23, Issue 2. Pages 159-169.

McBride, D.W. 1997. "Change in U.S. livestock production, 1969-92." Rural Economy Decision, Economic Research Services, U.S. Department of Agriculture. Agricultural economic report No. 754.

McCullough, L.R. 2016. "Water use and the regional economic impact of the cotton industry on the southern Ogallala Aquifer." Published Thesis. West Texas A&M University, Canyon Texas.

McGuire, L.V., Fischer, B.C., and Stanton, C.P. 1999. "Water-level changes, 1980 to 1997, and saturated thickness, 1996-97, in the High Plains aquifer." US Geological Survey. No. 124-99. Available at: https://pubs.usgs.gov/sir/2012/5177/sir12-5177.pdf.

McGuire, L. V., Johnson, R. M., Schieffer, L. R., Stanton, S. J., Sebree, K. S., and Verstraeten, M. I. 2003. "Water in storage and approaches to groundwater management, High Plains Aquifer, 2000." U.S. Geological Survey circular: 1243.

McGuire, V. L., Lund, D. K., and Densmore, K.B. (2012)." Saturated thickness and water in storage in the High Plains aquifer, 2009, and water-level changes and changes in water in storage in the High Plains aquifer, 1980 to 1995, 1995 to 2000, 2000 to 2005, and 2005 to 2009." USGS Sci. Invest. Rep. 5177, Page 6.

Moran, P.A. 1950. "Notes on continuous stochastic phenomena." Biometrika. Vol. 37, No. 1/2. Pages. 17-23.

Peng, J., Liu, Y., Liu, Z., and Yang, Y. 2017. "Mapping spatial non-stationarity of human-natural factors associated with agricultural landscape multifunctionality in Beijing–Tianjin–Hebei region, China." Agriculture, Ecosystem and Environment. Vol. 246. Pages 221-233.

Perrin, K. R., Fulginiti, E. L., Garcia, F. 2018. "Agricultural production from the High Plains Aquifer is worth over $3 billion per year." Cornhusker Economics. *983*. Available at: https://digitalcommons.unl.edu/agecon_cornhusker/983.

Prince, D. S., J. Haskett, J., Steininger, M., Strand, H., and Wright, R. 2001. "Net primary production of U.S. Midwest croplands from agricultural harvest yield data." Ecological Applications. Vol. 11, Issue 4, Pages 1194-1205.

PRISM Climate Group. 2020. *PRISM Data Explorer*. Oregon State University. (Accessed September 24, 2020). Available at: https://prism.oregonstate.edu/explorer/.

Sukcharoen, K., Golden, B., Vestal, M., Guerrero, B. 2020. "Do crop price expectation matter? An analysis of groundwater pumping decisions in western Kansas." Agricultural Water Management. Vol. 231, 106021.

Terrell, L. B., Johnson, N. P., and Segarra, E. 2002. "Ogallala Aquifer depletion: economic impact on the Texas High Plains." *Water Policy*. Vol. 4, Issue 1, Pages 33-46.

Texas Water Development Board. 1996. "Surveys of irrigation in Texas 1958, 1964, 1969, 1974, 1979, 1984, 1989, and 1994." Report No. 347. Austin, TX: Texas Water Development Board.

Thayer, A. 2018. "Climate, water, water markets, and Texas agriculture: three essays." Published Thesis. Texas A & M University.

United States Department of Agriculture, National Agricultural Statistics Service. 1978. Census of Agriculture. (Accessed June 20, 2020). Available at: http://libusda05.serverfarm.cornell.edu/usda/AgCensusImages/1978/01/43/181/Table-01.pdf.

United States Department of Agriculture, National Agricultural Statistics Service. 2017. Census of Agriculture. (Accessed June 25, 2020). Available at: https://www.nass.usda.gov/Publications/AgCensus/2017/Full_Report/Volume_1,_Chapter_1_State_Level/Texas/st48_1_0001_0001.pdf.

United States Department of Agriculture, National Agricultural Statistics Service, 2017 Census of Agriculture Methodology. Appendix A. (Accessed January 20, 2021). Available at:

https://www.nass.usda.gov/Publications/AgCensus/2017/Full_Report/Volume_1,_Chapter_1_US/usappxa.pdf.

United States Department of Agriculture, National Agricultural Statistics Service, 2019. U.S. Census of Agriculture for 2017. USDA National Agricultural Statistical Service. (Accessed September 24, 2020). Available at: https://www.nass.usda.gov/Publications/AgCensus/2017/index.php.

Wallander, S., Claassen. R., Nickerson, C. 2012. "The ethanol decade: An expansion of U.S. corn production." USDA-ERS Economic Information Bulletin. No. 79, Pages 22.

Xiao, J., Shen, Y., Ge, J., Tateishi, R., Tang, C., Liang, C., and Huang, Z. 2006. "Evaluating urban expansion and land use change in Shijiazhuang, China, by using GIS and remote sensing." Landscape and urban Planning. Vol. 15, Issues 1-2, Pages 69-80.

Xue, Q., Marek, H. T., Xu, W., and Bell, J. 2017. "Irrigated corn production and management in the Texas High Plains." *Journal of Contemporary Water Research & Education.* Vol. 162, Issue 1, Pages 31-41.

Yunda, L., and Lianjun, T. 2020. "Spatio-temporal pattern and driving Forces of comprehensive agricultural productivity in Jilin Province, China." Chinese Geographical Science. Vol. 30, Pages 493-504.

Zipper, C. S., Qiu, J., and Kucharik, J. C. 2016. "Drought effects on U.S. maize and soybean production: spatiotemporal patterns and historical changes." Environmental Research Letters. Vol.11, No. 9.

APPENDIX A

Table A 1. Total acres of harvested cropland in the Texas High Plains by county, 1978-2017.

County	1978	1982	1987	1992	1997	2002	2007	2012	2017
Andrews	28,525	39,679	43,368	25,175	28,624	12,620	21,385	15,626	16,287
Armstrong	73,120	100,434	81,576	74,910	70,345	57,597	79,703	51,313	49,012
Bailey	249,446	230,760	136,346	161,662	165,550	131,703	149,234	91,494	144,940
Briscoe	104,911	83,014	64,764	62,941	79,185	54,199	75,248	47,810	80,680
Carson	146,423	191,154	154,361	172,506	171,917	105,259	181,185	126,938	205,318
Castro	316,227	276,577	213,925	241,361	291,272	227,906	287,048	212,938	188,310
Cochran	239,999	219,133	121,506	155,162	181,629	155,239	177,981	102,687	205,484
Crosby	238,632	213,320	188,703	220,798	272,070	214,709	210,808	178,483	193,401
Dallam	250,252	261,412	203,239	230,710	297,475	250,350	317,249	215,276	193,223
Dawson	322,422	278,169	225,620	256,111	324,684	262,706	315,220	191,481	293,818
Deaf Smith	315,001	332,085	260,624	244,776	308,018	195,943	303,570	185,075	290,800
Floyd	342,748	314,848	246,634	258,546	284,854	220,235	265,211	163,278	283,399
Gaines	434,997	421,054	287,568	328,179	380,156	316,324	384,435	321,335	361,120
Glasscock	53,202	71,915	63,954	70,637	96,043	88,011	106,493	58,384	138,004
Gray	102,060	105,053	77,615	92,719	95,851	58,177	82,596	71,918	69,670
Hale	457,424	419,856	280,454	333,146	372,956	345,270	315,912	247,399	291,830
Hansford	203,143	203,607	169,195	203,150	212,399	127,477	249,487	222,287	226,938
Hartley	132,816	157,962	115,245	140,626	152,776	159,433	241,558	186,954	201,178
Hemphill	34,926	44,703	33,748	29,505	26,881	16,331	23,043	20,874	10,840
Hockley	315,786	317,976	237,592	270,301	294,552	289,009	256,545	185,701	245,331
Howard	102,251	98,569	88,008	100,878	108,740	92,487	122,496	22,643	76,613
Hutchinson	61,551	60,335	55,412	74,740	87,425	44,584	97,920	59,259	53,059
Lamb	380,877	353,804	226,556	270,290	293,937	299,230	319,949	228,993	272,704
Lipscomb	81,877	89,262	72,648	75,212	68,003	46,422	60,283	42,431	50,903
Lubbock	372,975	301,709	231,814	293,169	333,727	311,542	301,279	248,737	325,991
Lynn	297,699	267,741	212,326	268,598	300,615	289,420	290,889	232,325	339,939
Martin	137,066	157,866	121,713	125,469	159,460	112,709	154,688	48,251	170,206
Midland	35,806	41,571	33,449	29,128	31,822	15,195	35,971	19,586	19,108
Moore	148,631	169,202	133,869	162,528	177,071	147,854	219,086	166,594	146,514
Ochiltree	212,118	267,989	214,199	233,663	233,892	128,502	263,068	172,086	199,320
Oldham	58,713	72,739	57,818	60,996	46,500	14,541	55,996	16,591	35,678
Parmer	350,288	321,588	214,679	258,960	309,629	226,271	279,077	202,947	214,242
Potter	27,491	21,878	23,234	21,925	24,288	18,696	27,884	9,630	15,971
Randall	112,746	161,471	130,238	120,833	130,451	71,410	106,682	61,691	99,305
Roberts	29,309	24,906	23,399	25,999	23,958	15,535	28,223	17,813	15,212
Sherman	207,680	194,465	168,821	181,527	218,933	186,873	240,804	166,946	242,778
Swisher	252,240	277,549	190,036	189,631	201,823	145,315	196,010	108,343	189,546
Terry	331,643	337,626	243,400	253,815	277,241	245,693	268,372	217,045	269,179
Yoakum	207,480	175,900	132,185	148,510	167,464	134,425	187,210	124,907	169,756
Total	7,770,501	7,678,881	5,779,840	6,468,792	7,302,216	5,835,202	7,299,798	5,064,068	6,595,607

Table A 2. Irrigated acres of harvested cropland in the Texas High Plains by county, 1978-2017.

County	1978	1982	1987	1992	1997	2002	2007	2012	2017
Andrews	5,813	1,999	4,712	3,913	4,075	4,111	5,781	3,885	12,236
Armstrong	12,146	10,618	7,633	6,956	7,251	3,068	3,523	3,510	2,868
Bailey	115,010	105,618	59,069	57,144	62,058	53,363	57,428	44,057	50,045
Briscoe	45,997	32,911	26,993	23,026	27,625	27,204	27,923	21,383	21,171
Carson	81,914	78,801	61,387	80,239	72,844	44,230	40,741	48,997	63,578
Castro	288,530	230,973	172,623	198,566	220,088	187,670	200,956	153,144	117,308
Cochran	91,836	58,844	34,442	43,571	68,341	82,543	81,074	64,184	104,068
Crosby	150,525	81,641	83,225	105,859	161,337	115,685	108,149	108,260	86,043
Dallam	143,454	141,332	125,353	164,175	217,852	210,323	215,689	170,758	136,472
Dawson	35,078	18,846	18,324	30,197	63,651	51,613	76,429	59,094	53,121
Deaf Smith	196,483	186,688	148,901	151,900	159,797	123,559	118,208	111,097	120,555
Floyd	225,112	204,224	140,527	151,540	167,631	129,092	128,464	94,226	139,933
Gaines	223,334	195,722	152,981	196,755	230,241	202,353	236,195	217,472	186,661
Glasscock	29,534	29,584	26,304	34,967	52,160	27,542	29,395	24,934	50,428
Gray	24,039	19,038	16,475	21,126	21,747	15,866	22,594	30,439	25,230
Hale	390,964	353,091	232,649	285,489	301,352	280,717	234,871	196,146	181,441
Hansford	172,698	136,003	112,370	130,371	122,216	74,483	93,681	96,867	92,757
Hartley	84,815	110,724	75,651	105,726	121,169	117,565	167,182	149,707	149,980
Hemphill	3,818	2,894	3,013	2,883	3,651	1,701	1,992	2,792	1,508
Hockley	161,076	96,293	74,628	100,188	140,751	138,346	125,847	100,152	104,671
Howard	1,181	876	826	948	2,991	2,093	2,301	4,065	11,768
Hutchinson	47,828	37,924	30,048	38,800	52,287	27,830	30,812	28,851	22,102
Lamb	286,173	252,225	165,152	206,708	213,573	224,033	226,165	165,536	165,787
Lipscomb	22,032	11,942	9,606	13,294	17,500	22,598	16,574	20,544	20,360
Lubbock	257,833	166,926	121,091	142,573	208,430	171,425	156,273	150,512	161,177
Lynn	65,123	33,406	27,965	43,217	73,237	75,395	72,339	68,148	82,638
Martin	15,568	13,796	11,228	7,021	11,320	9,414	16,506	14,670	44,277
Midland	16,370	12,093	9,083	9,437	10,129	6,399	6,977	9,145	4,475
Moore	121,117	129,342	93,791	119,752	150,308	110,021	100,273	117,972	88,772
Ochiltree	82,358	75,515	61,210	82,345	71,058	48,315	82,084	48,247	47,814
Oldham	14,604	13,921	11,680	13,227	11,617	5,639	18,021	3,371	6,202
Parmer	315,354	265,721	167,079	201,279	206,279	173,575	160,728	152,332	103,909
Potter	8,209	5,026	5,635	3,492	4,457	4,369	6,943	2,696	2,232
Randall	60,487	39,812	28,629	29,342	35,855	24,030	18,204	15,632	14,032
Roberts	7,964	5,207	5,164	6,017	6,756	4,947	7,458	7,283	5,321
Sherman	163,437	132,864	111,875	125,122	149,388	137,598	154,118	122,775	180,408
Swisher	207,709	183,102	111,259	112,086	110,963	90,012	77,750	60,229	90,156
Terry	146,436	93,801	80,297	107,461	134,176	136,153	136,185	93,922	98,955
Yoakum	71,298	53,976	49,187	62,893	81,737	89,241	100,392	86,256	90,428
Total	4,393,257	3,623,319	2,678,064	3,219,604	3,777,898	3,254,121	3,366,225	2,873,289	2,940,888

Table A 3. Non-irrigated acres of harvested cropland in the Texas High Plains by county, 1978-2017.

County	1978	1982	1987	1992	1997	2002	2007	2012	2017
Andrews	22,712	37,680	38,656	21,262	24,549	8,509	15,604	11,741	4,051
Armstrong	60,974	89,816	73,943	67,954	63,094	54,529	76,180	47,803	46,144
Bailey	134,436	125,142	77,277	104,518	103,492	78,340	91,806	47,437	94,895
Briscoe	58,914	50,103	37,771	39,915	51,560	26,995	47,325	26,427	59,509
Carson	64,509	112,353	92,974	92,267	99,073	61,029	140,444	77,941	141,740
Castro	27,697	45,604	41,302	42,795	71,184	40,236	86,092	59,794	71,002
Cochran	148,163	160,289	87,064	111,591	113,288	72,696	96,907	38,503	101,416
Crosby	88,107	131,679	105,478	114,939	110,733	99,024	102,659	70,223	107,358
Dallam	106,798	120,080	77,886	66,535	79,623	40,027	101,560	44,518	56,751
Dawson	287,344	259,323	207,296	225,914	261,033	211,093	238,791	132,387	240,697
Deaf Smith	118,518	145,397	111,723	92,876	148,221	72,384	185,362	73,978	170,245
Floyd	117,636	110,624	106,107	107,006	117,223	91,143	136,747	69,052	143,466
Gaines	211,663	225,332	134,587	131,424	149,915	113,971	148,240	103,863	174,459
Glasscock	23,668	42,331	37,650	35,670	43,883	60,469	77,098	33,449	87,576
Gray	78,021	86,015	61,140	71,593	74,104	42,311	60,002	41,479	44,440
Hale	66,460	66,765	47,805	47,657	71,604	64,553	81,041	51,253	110,389
Hansford	30,445	67,604	56,825	72,779	90,183	52,994	155,806	125,420	134,181
Hartley	48,001	47,238	39,594	34,900	31,607	41,868	74,376	37,247	51,198
Hemphill	31,108	41,809	30,735	26,622	23,230	14,630	21,051	18,082	9,332
Hockley	154,710	221,683	162,964	170,113	153,801	150,663	130,698	85,549	140,660
Howard	101,070	97,693	87,182	99,930	105,749	90,394	120,195	18,578	64,845
Hutchinson	13,723	22,411	25,364	35,940	35,138	16,754	67,108	30,408	30,957
Lamb	94,704	101,579	61,404	63,582	80,364	75,197	93,784	63,457	106,917
Lipscomb	59,845	77,320	63,042	61,918	50,503	23,824	43,709	21,887	30,543
Lubbock	115,142	134,783	110,723	150,596	125,297	140,117	145,006	98,225	164,814
Lynn	232,576	234,335	184,361	225,381	227,378	214,025	218,550	164,177	257,301
Martin	121,498	144,070	110,485	118,448	148,140	103,295	138,182	33,581	125,929
Midland	19,436	29,478	24,366	19,691	21,693	8,796	28,994	10,441	14,633
Moore	27,514	39,860	40,078	42,776	26,763	37,833	118,813	48,622	57,742
Ochiltree	129,760	192,474	152,989	151,318	162,834	80,187	180,984	123,839	151,506
Oldham	44,109	58,818	46,138	47,769	34,883	8,902	37,975	13,220	29,476
Parmer	34,934	55,867	47,600	57,681	103,350	52,696	118,349	50,615	110,333
Potter	19,282	16,852	17,599	18,433	19,831	14,327	20,941	6,934	13,739
Randall	52,259	121,659	101,609	91,491	94,596	47,380	88,478	46,059	85,273
Roberts	21,345	19,699	18,235	19,982	17,202	10,588	20,765	10,530	9,891
Sherman	44,243	61,601	56,946	56,405	69,545	49,275	86,686	44,171	62,370
Swisher	44,531	94,447	78,777	77,545	90,860	55,303	118,260	48,114	99,390
Terry	185,207	243,825	163,103	146,354	143,065	109,540	132,187	123,123	170,224
Yoakum	136,182	121,924	82,998	85,617	85,727	45,184	86,818	38,651	79,328
Total	3,377,244	4,055,562	3,101,776	3,249,188	3,524,318	2,581,081	3,933,572	2,190,779	3,654,719

Table A 4. Total acres of harvested corn-grain in the Texas High Plains by county, 1978-2017.

County	**1978**	**1982**	**1987**	**1992**	**1997**	**2002**	**2007**	**2012**	**2017**
Andrews	0	0	0	0	0	0	175	375	0
Armstrong	627	62	137	1,513	945	626	549	720	3,790
Bailey	29,431	18,934	14,420	10,760	8,071	3,561	3,883	1,284	8,683
Briscoe	1,791	791	2,026	3,738	2,807	0	885	0	349
Carson	15,562	3,808	2,243	9,799	14,735	11,105	20,908	15,145	30,309
Castro	116,015	79,704	55,895	75,451	87,536	48,034	98,414	72,485	44,464
Cochran	2,670	0	0	0	0	0	62	0	20,842
Crosby	1,862	62	201	1,319	1,280	0	1,087	496	2,498
Dallam	37,549	34,752	45,443	70,554	134,140	134,820	150,097	101,516	83,958
Dawson	86	75	349	0	175	0	0	375	0
Deaf Smith	74,019	26,856	17,375	28,568	31,885	14,573	27,231	25,630	31,879
Floyd	19,622	11,790	9,884	16,901	15,108	3,953	7,506	8,781	12,016
Gaines	868	362	175	0	942	349	375	740	5,100
Glasscock	0	112	249	62	135	0	868	0	627
Gray	2,329	1,542	815	3,435	5,820	5,986	6,066	6,199	5,117
Hale	83,198	78,841	58,550	80,005	57,161	15,553	36,597	22,715	32,612
Hansford	19,308	3,677	11,599	30,866	39,813	28,096	46,483	48,330	56,399
Hartley	16,988	19,590	23,635	43,932	77,308	89,285	107,623	80,275	67,135
Hemphill	0	62	62	237	500	1	0	0	375
Hockley	416	13	87	549	75	0	210	124	12,398
Howard	0	0	0	0	0	0	62	0	0
Hutchinson	5,468	1,235	3,982	10,615	18,231	10,842	16,844	14,168	9,354
Lamb	84,154	57,368	34,224	54,343	46,328	24,027	49,632	34,623	35,043
Lipscomb	700	0	0	0	4,458	3,458	6,821	10,080	10,221
Lubbock	8,320	1,409	1,395	1,597	949	448	2,538	686	17,986
Lynn	311	2,491	337	0	375	62	62	0	10,248
Martin	0	275	0	0	0	0	0	0	0
Midland	0	0	263	0	0	25	62	0	2,176
Moore	27,266	20,435	24,546	52,975	57,096	66,582	54,317	53,118	46,530
Ochiltree	3,811	1,553	3,105	22,138	32,347	10,526	23,527	15,820	22,857
Oldham	2,341	312	0	562	410	175	375	175	124
Parmer	182,760	107,111	58,787	85,586	76,307	28,576	62,580	49,550	24,624
Potter	1,661	62	0	13	187	400	225	187	175
Randall	4,439	462	175	1,753	2,777	1,463	991	1,181	4,118
Roberts	1,052	0	250	500	1,875	2,850	4,748	2,038	1,175
Sherman	23,421	8,469	20,361	41,872	60,227	70,989	78,869	63,614	105,588
Swisher	28,151	29,047	17,963	20,596	21,775	6,676	14,230	7,438	6,182
Terry	0	62	0	0	434	192	375	0	3,997
Yoakum	2606	1115	250	674.5	805	62	300	0	7373
Total	798802.4	512437.5	408781	670912.5	803015.5	583294	825574.5	637866.5	726320.5

Table A 5. Irrigated acres of harvested corn-grain in the Texas High Plains by county, 1978-2017.

County	1978	1982	1987	1992	1997	2002	2007	2012	2017
Andrews	0	0	0	0	0	0	0	0	0
Armstrong	343	48	105	931	945	306	258	346	2,520
Bailey	29,131	18,789	14,220	10,129	6,163	3,106	3,559	1,174	3,013
Briscoe	1,772	791	2,026	3,663	2,807	0	569	0	205
Carson	15,194	3,566	2,243	9,799	14,735	10,775	17,674	14,363	23,132
Castro	115,261	79,504	53,484	74,461	84,736	46,985	81,206	56,964	38,010
Cochran	2,670	0	0	0	0	0	0	0	7,723
Crosby	1,862	0	0	0	1,040	0	1,087	496	2,230
Dallam	3,711	34,414	44,840	70,288	134,140	130,798	135,061	96,158	72,336
Dawson	0	0	0	0	0	0	0	0	0
Deaf Smith	69,170	25,988	17,246	28,123	31,885	13,618	20,603	24,124	29,393
Floyd	19,483	11,708	9,683	16,251	15,048	3,816	5,841	7,474	9,742
Gaines	868	362	173	0	942	302	312	630	3,877
Glasscock	0	0	0	0	0	0	0	0	0
Gray	2,101	1,460	698	3,362	5,820	5,986	5,562	5,811	4,283
Hale	82,512	78,541	57,352	79,452	56,952	14,473	33,903	16,678	22,394
Hansford	19,168	3,437	10,493	30,392	39,813	26,076	40,113	42,962	47,003
Hartley	16,294	19,011	23,285	43,414	77,308	80,248	95,633	74,550	55,795
Hemphill	0	0	0	0	0	0	0	0	0
Hockley	219	9	64	399	55	0	130	78	5,721
Howard	0	0	0	0	0	0	0	0	0
Hutchinson	5,468	1,235	3,982	10,615	18,231	10,742	14,624	12,576	8,969
Lamb	83,720	57,179	34,124	54,235	41,193	19,912	48,548	29,424	25,918
Lipscomb	700	0	0	0	4,458	3,428	6,821	10,080	9,126
Lubbock	7,844	1,409	1,395	1,597	949	340	2,026	686	7,083
Lynn	0	0	0	0	0	0	0	0	2,396
Martin	0	0	0	0	0	0	0	0	0
Midland	0	0	0	0	0	0	0	0	0
Moore	27,265	20,355	21,513	47,971	57,096	64,076	47,464	48,447	37,339
Ochiltree	3,232	1,486	3,105	18,176	17,357	8,472	21,376	14,968	19,310
Oldham	2,116	312	0	562	410	151	312	149	94
Parmer	181,584	106,909	58,405	85,313	76,307	28,090	53,788	43,790	19,656
Potter	1,661	62	0	13	187	346	187	159	133
Randall	4,252	462	173	1,503	2,777	962	627	764	2,378
Roberts	1,052	0	250	493	1,875	2,850	4,748	2,038	1,049
Sherman	23,275	8,291	20,226	41,600	60,227	67,823	76,104	53,402	91,795
Swisher	27,838	28,901	17,963	20,502	21,775	5,314	12,056	6,098	4,635
Terry	0	0	0	0	434	0	0	0	1,776
Yoakum	1,680	1,014	226	600	805	0	300	0	2,680
Total	751,446	505,243	397,273	653,844	776,470	548,995	730,492	564,389	561,714

Table A 6. Non-irrigated acres of harvested corn-grain in the Texas High Plains by county, 1978-2017.

County	1978	1982	1987	1992	1997	2002	2007	2012	2017
Andrews	0	0	0	0	0	0	175	375	0
Armstrong	284	14	32	582	0	320	291	374	1,270
Bailey	300	145	200	631	1,908	455	324	110	5,670
Briscoe	19	0	0	75	0	0	316	0	144
Carson	368	242	0	0	0	330	3,234	782	7,177
Castro	754	200	2,411	990	2,800	1,049	17,208	15,521	6,454
Cochran	0	0	0	0	0	0	62	0	13,119
Crosby	0	62	201	1,319	240	0	0	0	268
Dallam	33,838	338	603	266	0	4,022	15,036	5,358	11,622
Dawson	86	75	349	0	175	0	0	375	0
Deaf Smith	4,849	868	129	445	0	955	6,628	1,506	2,486
Floyd	139	82	201	650	60	137	1,665	1,307	2,274
Gaines	0	0	1	0	0	47	63	110	1,223
Glasscock	0	112	249	62	135	0	868	0	627
Gray	228	82	117	73	0	0	504	388	834
Hale	686	300	1,198	553	209	1,080	2,694	6,037	10,218
Hansford	140	240	1,106	474	0	2,020	6,370	5,368	9,396
Hartley	694	579	350	518	0	9,037	11,990	5,725	11,340
Hemphill	0	62	62	237	500	1	0	0	375
Hockley	197	3	23	150	19	0	80	46	6,677
Howard	0	0	0	0	0	0	62	0	0
Hutchinson	0	0	0	0	0	100	2,220	1,592	385
Lamb	434	189	100	108	5,135	4,115	1,084	5,199	9,125
Lipscomb	0	0	0	0	0	30	0	0	1,095
Lubbock	476	0	0	0	0	108	512	0	10,903
Lynn	311	2,491	337	0	375	62	62	0	7,852
Martin	0	275	0	0	0	0	0	0	0
Midland	0	0	263	0	0	25	62	0	2,176
Moore	1	80	3,033	5,004	0	2,506	6,853	4,671	9,191
Ochiltree	579	67	0	3,962	14,990	2,054	2,151	852	3,548
Oldham	225	0	0	0	0	23	63	26	30
Parmer	1,176	202	382	273	0	486	8,792	5,760	4,968
Potter	0	0	0	0	0	54	38	28	42
Randall	187	0	1	250	0	501	364	417	1,740
Roberts	0	0	0	7	0	0	0	0	126
Sherman	146	178	135	272	0	3,166	2,765	10,212	13,793
Swisher	313	146	0	94	0	1,362	2,174	1,340	1,547
Terry	0	62	0	0	0	192	375	0	2,221
Yoakum	926	101	24	74	0	62	0	0	4,693
Total	47,356	7,195	11,508	17,069	26,545	34,299	95,083	73,477	164,607

Table A 7. Total acres of harvested cotton in the Texas High Plains by county, 1978-2017.

County	1978	1982	1987	1992	1997	2002	2007	2012	2017
Andrews	25,635	28,047	7,208	16,693	20,772	7,804	16,507	8,248	11,314
Armstrong	1,493	1,738	549	717	361	175	2,094	387	5,878
Bailey	125,619	32,959	57,332	6,814	73,651	50,223	41,507	25,812	77,145
Briscoe	65,591	21,404	23,022	13,000	35,485	26,432	28,576	21,447	35,180
Carson	472	175	0	0	62	5,280	19,365	28,362	83,179
Castro	62,410	41,536	39,222	21,411	58,330	74,422	30,484	41,768	48,683
Cochran	147,170	52,692	81,652	30,725	116,568	100,224	124,177	68,720	124,080
Crosby	198,469	127,760	145,560	71,622	233,538	190,947	171,616	161,033	177,589
Dallam	0	425	0	0	0	1,124	1,994	6,908	23,513
Dawson	319,517	264,190	201,771	184,300	274,472	215,421	281,712	172,113	259,949
Deaf Smith	3,484	4,000	4,047	2,734	10,706	35,529	12,125	13,598	40,008
Floyd	205,085	76,708	120,399	33,006	148,345	114,094	129,753	115,893	193,793
Gaines	378,644	305,213	223,950	233,410	278,940	187,676	262,094	210,931	241,339
Glasscock	45,674	56,959	56,324	59,037	84,156	66,509	84,993	54,509	128,853
Gray	1,677	1,084	374	375	500	883	8,827	13,158	28,185
Hale	221,905	142,936	151,555	36,188	207,674	221,719	164,297	157,254	211,914
Hansford	493	349	0	0	0	0	2,183	13,683	62,209
Hartley	1,459	250	575	0	1,062	1,124	2,709	9,056	25,288
Hemphill	346	175	237	175	175	0	0	375	375
Hockley	262,443	116,914	180,572	102,209	221,358	221,843	218,069	157,987	152,495
Howard	99,898	93,760	78,408	59,001	102,389	71,966	106,887	20,886	70,458
Hutchinson	0	0	0	0	0	0	3,203	8,750	22,744
Lamb	225,511	115,890	123,008	25,574	175,894	201,741	121,319	112,847	156,911
Lipscomb	0	0	0	0	0	0	750	349	2,615
Lubbock	321,638	177,160	195,699	78,771	279,205	240,871	242,656	205,581	264,305
Lynn	284,080	145,087	187,282	165,600	270,283	270,872	269,262	213,912	297,817
Martin	134,663	146,755	110,974	93,823	147,605	69,084	143,739	43,987	148,810
Midland	30,656	33,619	25,953	24,109	27,352	10,052	22,234	11,216	11,344
Moore	0	187	0	0	0	750	7,399	21,803	33,846
Ochiltree	0	0	0	0	13	0	4,144	8,185	44,115
Oldham	0	237	62	175	349	260	175	237	1,161
Parmer	57,170	32,886	38,110	8,865	61,293	78,488	24,496	41,514	52,217
Potter	709	0	0	0	0	812	397	736	175
Randall	0	365	124	0	124	2,222	1,552	2,472	8,060
Roberts	0	250	0	0	0	0	563	934	1,499
Sherman	0	0	0	62	62	0	16,906	24,395	40,929
Swisher	70,395	58,890	42,454	11,816	55,056	72,755	55,766	54,355	100,398
Terry	265,597	238,103	203,150	141,853	220,240	173,335	204,646	157,694	209,724
Yoakum	94,133	106,595	88,382	98,244	125,427	76,478	116,260	84,304	98,050
Total	3,652,036	2,425,296	2,387,953	1,520,308	3,231,446	2,791,114	2,945,435	2,295,398	3,496,146

Table A 8. Irrigated acre of harvested cotton in the Texas High Plains by county, 1978-2017.

County	**1978**	**1982**	**1987**	**1992**	**1997**	**2002**	**2007**	**2012**	**2017**
Andrews	5,471	946	3,990	2,432	2,447	2,212	8,514	1,973	1,954
Armstrong	809	972	515	599	361	175	844	210	2,960
Bailey	52,706	16,551	22,614	1,909	25,753	24,907	13,427	14,466	29,892
Briscoe	29,611	6,107	13,234	3,400	16,553	19,328	16,985	18,358	17,108
Carson	0	0	0	0	0	3,361	7,113	18,298	29,002
Castro	58,665	39,184	37,125	20,980	50,946	69,045	24,965	33,689	31,590
Cochran	76,986	32,373	32,896	6,010	51,468	65,644	61,627	48,321	73,296
Crosby	121,888	42,989	85,167	25,437	145,005	110,083	96,812	103,384	79,967
Dallam	0	0	0	0	0	0	1,494	5,037	16,872
Dawson	34,916	17,961	17,056	21,186	40,169	37,267	62,144	48,744	36,437
Deaf Smith	2,963	3,837	3,610	2,312	9,636	30,643	10,300	9,222	22,560
Floyd	143,340	50,748	87,436	22,361	103,806	79,311	78,141	71,320	102,151
Gaines	186,439	119,930	111,185	143,099	159,846	121,920	149,486	140,666	115,259
Glasscock	28,499	28,616	24,750	33,065	50,463	26,486	27,824	23,483	36,919
Gray	59	186	108	0	0	323	2,717	5,270	5,551
Hale	175,688	116,667	124,300	27,977	170,085	189,331	134,114	131,648	141,736
Hansford	0	0	0	0	0	0	536	8,764	27,683
Hartley	0	0	0	0	0	0	2,128	5,925	18,773
Hemphill	0	0	0	0	0	0	0	0	0
Hockley	147,544	48,734	63,720	35,659	107,422	113,591	112,384	91,054	86,876
Howard	1,007	2,298	1,259	644	2,572	1,439	7,459	3,829	4,976
Hutchinson	0	0	0	0	0	0	2,457	8,400	11,818
Lamb	152,077	85,124	91,565	18,690	125,247	154,356	82,117	84,472	110,313
Lipscomb	0	0	0	0	0	0	0	0	2,615
Lubbock	222,848	111,450	107,223	30,736	177,922	140,337	132,440	130,907	143,858
Lynn	62,373	15,722	26,793	18,096	66,753	70,960	68,150	64,161	73,484
Martin	14,767	4,007	4,269	6,184	8,065	7,747	13,329	11,283	9,218
Midland	12,673	8,934	6,307	7,567	8,571	4,661	5,342	6,486	3,369
Moore	0	0	0	0	0	685	3,927	15,572	21,142
Ochiltree	0	0	0	0	0	0	1,499	6,305	22,441
Oldham	0	0	0	0	0	260	168	237	838
Parmer	52,750	31,597	35,903	8,680	48,740	70,549	22,052	33,834	33,833
Potter	375	0	0	0	0	0	290	366	63
Randall	0	315	0	0	0	2,044	1,240	2,472	2,316
Roberts	0	0	0	0	0	0	305	681	789
Sherman	0	0	0	0	0	0	13,243	20,817	31,020
Swisher	60,794	48,778	35,765	7,602	39,869	58,896	38,538	37,831	54,688
Terry	134,975	70,879	70,505	58,172	103,902	96,710	96,924	68,425	67,740
Yoakum	51,196	38,990	35,206	38,836	60,875	55,081	53,964	56,412	49,751
Total	1,831,419	943,895	1,042,501	541,633	1,576,476	1,557,352	1,354,999	1,332,321	1,520,857

Table A 9. Non-irrigated acres of harvested cotton in the Texas High Plains by county, 1978-2017.

County	1978	1982	1987	1992	1997	2002	2007	2012	2017
Andrews	20,164	27,101	3,218	14,261	18,325	5,592	7,993	6,275	9,360
Armstrong	684	766	33	118	0	0	1,250	177	2,918
Bailey	72,913	16,408	34,718	4,905	47,898	25,316	28,080	11,346	47,253
Briscoe	35,980	15,297	9,788	9,600	18,932	7,104	11,591	3,089	18,072
Carson	472	175	0	0	62	1,919	12,252	10,064	54,177
Castro	3,745	2,352	2,097	431	7,384	5,377	5,519	8,079	17,093
Cochran	70,184	20,319	48,756	24,715	65,100	34,580	62,550	20,399	50,784
Crosby	76,581	84,771	60,393	46,185	88,533	80,864	74,804	57,649	97,622
Dallam	0	425	0	0	0	1,124	500	1,871	6,641
Dawson	284,601	246,229	184,715	163,114	234,303	178,154	219,568	123,369	223,512
Deaf Smith	521	163	437	422	1,070	4,886	1,825	4,376	17,448
Floyd	61,745	25,960	32,963	10,645	44,539	34,783	51,612	44,573	91,642
Gaines	192,205	185,283	112,765	90,311	119,094	65,756	112,608	70,265	126,080
Glasscock	17,175	28,343	31,574	25,972	33,693	40,023	57,169	31,026	91,934
Gray	1,618	898	266	375	500	560	6,110	7,888	22,634
Hale	46,217	26,269	27,255	8,211	37,589	32,388	30,183	25,606	70,178
Hansford	493	349	0	0	0	0	1,647	4,919	34,526
Hartley	1,459	250	575	0	1,062	1,124	581	3,131	6,515
Hemphill	346	175	237	175	175	0	0	375	375
Hockley	114,899	68,180	116,852	66,550	113,936	108,252	105,685	66,933	65,619
Howard	98,891	91,462	77,149	58,357	99,817	70,527	99,428	17,057	65,482
Hutchinson	0	0	0	0	0	0	746	350	10,926
Lamb	73,434	30,766	31,443	6,884	50,647	47,385	39,202	28,375	46,598
Lipscomb	0	0	0	0	0	0	750	349	0
Lubbock	98,790	65,710	88,476	48,035	101,283	100,534	110,216	74,674	120,447
Lynn	221,707	129,365	160,489	147,504	203,530	199,912	201,112	149,751	224,333
Martin	119,896	142,748	106,705	87,639	139,540	61,337	130,410	32,704	139,592
Midland	17,983	24,685	19,646	16,542	18,781	5,391	16,892	4,730	7,975
Moore	0	187	0	0	0	65	3,472	6,231	12,704
Ochiltree	0	0	0	0	13	0	2,645	1,880	21,674
Oldham	0	237	62	175	349	0	7	0	323
Parmer	4,420	1,289	2,207	185	12,553	7,939	2,444	7,680	18,384
Potter	334	0	0	0	0	812	107	370	112
Randall	0	50	124	0	124	178	312	0	5,744
Roberts	0	250	0	0	0	0	258	253	710
Sherman	0	0	0	62	62	0	3,663	3,578	9,909
Swisher	9,601	10,112	6,689	4,214	15,187	13,859	17,228	16,524	45,710
Terry	130,622	167,224	132,645	83,681	116,338	76,625	107,722	89,269	141,984
Yoakum	42,937	67,605	53,176	59,408	64,552	21,397	62,296	27,892	48,299
Total	1,820,617	1,481,401	1,345,453	978,674	1,654,970	1,233,763	1,590,436	963,077	1,975,289

Table A 10. Total acres of harvested sorghum-grain in the Texas High Plains by county, 1978-2017.

County	1978	1982	1987	1992	1997	2002	2007	2012	2017
Andrews	2,360	9,047	8,972	7,021	4,154	0	375	3,856	0
Armstrong	25,500	25,034	22,908	23,910	25,136	21,500	13,292	13,021	7,194
Bailey	41,597	102,970	29,975	95,198	37,676	36,947	44,790	23,479	17,078
Briscoe	9,610	16,163	6,715	15,774	8,619	5,396	9,555	3,372	3,574
Carson	57,289	67,094	50,167	59,973	57,907	44,000	39,424	15,995	34,031
Castro	33,364	27,770	19,828	19,973	21,600	15,889	24,212	19,788	9,714
Cochran	75,846	143,761	34,188	113,189	39,278	30,982	23,697	5,599	31,180
Crosby	23,641	33,692	22,112	118,945	19,188	7,296	20,891	8,272	6,187
Dallam	92,951	98,152	49,943	31,523	35,232	14,673	21,374	13,544	14,457
Dawson	1,994	7,467	17,763	63,316	21,418	24,914	16,102	5,779	3,681
Deaf Smith	78,693	94,021	70,791	64,718	77,120	46,317	50,491	30,491	41,104
Floyd	42,902	41,656	25,335	105,332	40,001	46,404	52,566	10,364	7,751
Gaines	31,046	59,068	21,262	44,766	14,992	23,068	13,113	18,579	13,945
Glasscock	5,641	6,814	7,453	5,817	2,903	5,050	6,360	549	961
Gray	27,652	21,555	16,098	19,427	25,800	22,380	14,681	4,518	3,743
Hale	55,911	41,803	20,643	109,093	46,187	50,134	43,394	27,395	15,373
Hansford	70,676	68,203	44,758	31,050	23,441	39,180	19,618	7,091	7,662
Hartley	41,280	37,840	19,249	17,175	19,349	10,553	24,897	21,270	8,972
Hemphill	8,543	5,544	4,378	3,292	2,871	347	456	0	0
Hockley	38,284	163,411	42,895	155,358	52,224	35,587	21,811	19,654	0
Howard	613	1,721	2,327	27,931	25	3,469	8,495	0	349
Hutchinson	21,219	18,985	11,859	10,707	11,972	742	5,775	3,419	2,863
Lamb	27,998	71,476	28,707	107,805	18,248	19,227	64,711	26,616	36,096
Lipscomb	10,547	6,295	5,263	3,285	11,170	11,714	11,417	4,460	11,595
Lubbock	25,745	79,692	21,242	166,796	23,744	39,803	25,606	28,614	23,354
Lynn	9,238	82,383	14,365	89,527	11,549	5,959	9,390	11,616	22,224
Martin	162	4,407	3,340	16,115	2,503	28,435	1,965	0	5,570
Midland	681	839	516	62	408	474	1,200	75	0
Moore	56,172	59,057	32,906	22,138	32,347	26,792	28,747	44,617	20,873
Ochiltree	53,463	49,380	36,983	35,406	48,351	46,862	43,033	20,527	41,040
Oldham	31,591	18,703	13,113	13,108	12,191	4,888	14,797	4,995	6,321
Parmer	26,637	50,067	26,175	40,280	41,402	30,118	39,859	17,652	22,413
Potter	9,343	4,847	5,110	3,461	5,435	6,693	4,892	879	1,217
Randall	47,731	32,428	26,001	24,603	28,983	16,920	16,411	13,573	12,414
Roberts	4,541	2,437	1,400	2,052	2,985	3,421	5,346	1,337	750
Sherman	81,494	69,590	34,705	21,128	27,961	26,578	16,939	17,410	24,168
Swisher	72,275	43,255	25,229	46,367	38,059	19,099	26,655	8,810	18,019
Terry	58,984	79,191	30,011	97,638	26,442	21,895	18,604	25,410	9,083
Yoakum	100,014	59,105	34,464	38,114	21,913	16,044	19,745	4,099	18,866
Total	1,403,228	1,804,923	889,149	1,871,373	940,784	809,750	824,686	486,725	503,822

Table A 11. Irrigated acres of harvested sorghum-grain in the Texas High Plains by county, 1978-2017.

County	1978	1982	1987	1992	1997	2002	2007	2012	2017
Andrews	0	0	0	0	0	0	0	0	0
Armstrong	4,810	4,176	3,359	2,355	2,233	1,073	474	1,987	596
Bailey	8,654	26,485	4,902	22,887	8,434	3,751	11,757	5,369	2,581
Briscoe	6,274	8,775	4,060	9,540	3,530	2,989	4,516	624	0
Carson	33,195	37,922	26,428	28,581	21,896	10,327	6,235	4,828	2,910
Castro	27,544	22,553	13,635	15,282	12,740	8,163	13,668	7,328	4,739
Cochran	10,841	24,584	5,811	34,256	8,243	2,686	7,161	2,538	4,046
Crosby	20,838	16,170	12,612	63,012	11,122	2,632	6,908	2,391	1,681
Dallam	35,462	34,441	17,317	8,946	4,972	5,849	7,336	7,261	6,679
Dawson	0	214	539	7,274	4,188	1,833	4,837	1,320	457
Deaf Smith	41,336	54,678	40,916	31,076	28,349	23,793	12,823	9,878	7,855
Floyd	40,318	33,159	19,232	67,503	21,415	25,077	26,604	6,178	1,008
Gaines	14,644	31,334	7,250	11,595	4,962	2,567	7,917	2,236	3,808
Glasscock	642	290	1,001	957	407	0	418	48	0
Gray	11,397	7,652	6,378	5,324	4,628	3,493	3,646	864	0
Hale	52,123	31,469	14,609	87,862	33,790	36,586	27,898	21,687	3,086
Hansford	61,803	56,040	38,289	23,103	11,558	10,371	5,434	4,961	1,323
Hartley	26,013	26,877	11,502	9,384	6,851	2,360	9,733	13,546	3,736
Hemphill	930	475	366	861	767	0	0	0	0
Hockley	10,272	38,139	7,463	60,407	25,561	8,198	5,186	4,274	0
Howard	0	0	0	0	0	0	0	0	0
Hutchinson	18,321	16,485	8,179	7,020	7,131	338	1,321	3,114	1,435
Lamb	17,767	27,643	9,090	58,669	12,861	9,526	41,436	9,823	6,124
Lipscomb	6,024	1,930	685	874	4,520	1,605	1,578	1,265	1,786
Lubbock	17,125	30,595	6,881	82,408	13,206	18,938	14,025	12,782	1,947
Lynn	1,533	11,208	1,716	22,263	2,356	408	2,615	1,585	4,832
Martin	0	0	0	0	0	0	0	0	0
Midland	127	0	0	0	0	0	0	0	0
Moore	43,169	53,987	29,305	18,176	17,357	14,215	13,576	30,197	9,935
Ochiltree	43,169	36,396	26,124	25,358	17,665	11,839	9,593	6,163	4,170
Oldham	5,262	3,763	1,489	2,448	2,511	1,608	7,981	1,119	268
Parmer	20,038	40,743	18,688	29,313	16,176	16,990	22,437	10,694	2,365
Potter	3,115	2,120	2,051	717	623	399	478	201	151
Randall	25,420	15,236	11,714	10,333	8,378	4,330	1,997	2,832	1,406
Roberts	2,906	1,791	16	1,574	1,010	884	540	179	0
Sherman	67,069	53,397	25,042	16,028	15,705	12,539	10,686	12,738	14,425
Swisher	58,974	31,413	18,590	32,561	21,327	9,705	13,269	4,270	3,398
Terry	8,386	14,526	5,427	41,695	7,378	1,874	6,958	2,450	519
Yoakum	10,620	8,340	7,264	14,416	4,682	1,545	7,707	2,015	5,838
Total	756,121	805,006	407,930	854,058	368,532	258,491	318,748	198,745	103,104

Table A 12. Non-irrigated acres of harvested sorghum-grain in the Texas High Plains by county, 1978-2017.

County	1978	1982	1987	1992	1997	2002	2007	2012	2017
Andrews	2,360	9,047	8,972	7,021	4,154	0	375	3,856	0
Armstrong	20,690	20,858	19,549	21,555	22,903	20,427	12,818	11,034	6,598
Bailey	32,943	76,485	25,073	72,311	29,242	33,196	33,033	18,110	14,497
Briscoe	3,336	7,388	2,655	6,234	5,089	2,407	5,039	2,748	3,574
Carson	24,094	29,172	23,739	31,392	36,011	33,673	33,189	11,167	31,121
Castro	5,820	5,217	6,193	4,691	8,860	7,726	10,544	12,460	4,975
Cochran	65,005	119,177	28,377	78,933	31,035	28,296	16,536	3,061	27,134
Crosby	2,803	17,522	9,500	55,933	8,066	4,664	13,983	5,881	4,506
Dallam	57,489	63,711	32,626	22,577	30,260	8,824	14,038	6,283	7,778
Dawson	1,994	7,253	17,224	56,042	17,230	23,081	11,265	4,459	3,224
Deaf Smith	37,357	39,343	29,875	33,642	48,771	22,524	37,668	20,613	33,249
Floyd	2,584	8,497	6,103	37,829	18,586	21,327	25,962	4,186	6,743
Gaines	16,402	27,734	14,012	33,171	10,030	20,501	5,196	16,343	10,137
Glasscock	4,999	6,524	6,452	4,860	2,496	5,050	5,942	501	961
Gray	16,255	13,903	9,720	14,103	21,172	18,887	11,035	3,654	3,743
Hale	3,788	10,334	6,034	21,231	12,397	13,548	15,496	5,708	12,287
Hansford	8,873	12,163	6,469	7,947	11,883	28,809	14,184	2,130	6,339
Hartley	15,267	10,963	7,747	7,791	12,498	8,193	15,164	7,724	5,236
Hemphill	7,613	5,069	4,012	2,431	2,104	347	456	0	0
Hockley	28,012	125,272	35,432	94,951	26,663	27,389	16,625	15,380	0
Howard	613	1,721	2,327	27,931	25	3,469	8,495	0	349
Hutchinson	2,898	2,500	3,680	3,687	4,841	404	4,454	305	1,428
Lamb	10,231	43,833	19,617	49,136	5,387	9,701	23,275	16,793	29,972
Lipscomb	4,523	4,365	4,578	2,411	6,650	10,109	9,839	3,195	9,809
Lubbock	8,620	49,097	14,361	84,388	10,538	20,865	11,581	15,832	21,407
Lynn	7,705	71,175	12,649	67,264	9,193	5,551	6,775	10,031	17,392
Martin	162	4,407	3,340	16,115	2,503	28,435	1,965	0	5,570
Midland	554	839	516	62	408	474	1,200	75	0
Moore	13,003	5,070	3,601	3,962	14,990	12,577	15,171	14,420	10,938
Ochiltree	10,294	12,984	10,859	10,048	30,686	35,023	33,440	14,364	36,870
Oldham	26,329	14,940	11,624	10,660	9,680	3,280	6,816	3,876	6,053
Parmer	6,599	9,324	7,487	10,967	25,226	13,128	17,422	6,958	20,048
Potter	6,228	2,727	3,059	2,744	4,812	6,294	4,414	678	1,066
Randall	22,311	17,192	14,287	14,270	20,605	12,590	14,414	10,741	11,008
Roberts	1,635	646	1,384	478	1,975	2,537	4,806	1,158	750
Sherman	14,425	16,193	9,663	5,100	12,256	14,039	6,253	4,672	9,743
Swisher	13,301	11,842	6,639	13,806	16,732	9,394	13,386	4,540	14,621
Terry	50,598	64,665	24,584	55,943	19,064	20,021	11,646	22,960	8,564
Yoakum	89,394	50,765	27,200	23,698	17,231	14,499	12,038	2,084	13,028
Total	647,107	999,917	481,219	1,017,315	572,252	551,259	505,937	287,980	400,718

Table A 13. Total acres of harvested wheat in the Texas High Plains by county, 1978-2017.

County	1978	1982	1987	1992	1997	2002	2007	2012	2017
Andrews	0	425	5,481	887	149	0	749	25	1,500
Armstrong	38,084	69,364	54,491	44,836	40,432	29,160	54,677	35,907	30,403
Bailey	30,976	47,986	22,448	30,377	23,719	24,999	0	8,620	14,610
Briscoe	16,089	26,267	22,708	21,396	23,526	9,852	24,935	18,523	31,572
Carson	72,279	115,461	95,359	98,952	89,448	33,611	97,671	66,453	59,821
Castro	56,950	91,014	71,215	84,680	100,977	55,498	84,940	29,904	33,632
Cochran	13,702	21,605	3,906	8,831	7,485	7,678	17,885	16,407	9,276
Crosby	8,732	20,494	12,538	13,817	12,027	9,578	11,171	5,337	6,745
Dallam	95,409	116,493	97,114	112,955	106,645	84,154	125,054	60,836	48,193
Dawson	139	1,728	1,710	1,827	2,930	3,616	9,247	4,860	3,255
Deaf Smith	114,148	175,187	133,307	116,964	150,404	73,628	169,092	56,081	122,363
Floyd	58,650	95,910	78,249	64,487	62,841	39,091	70,000	24,808	71,830
Gaines	3,848	42,532	15,720	14,822	22,192	27,026	28,596	18,451	10,368
Glasscock	619	963	4,360	3,364	6,331	8,519	13,359	1,263	3,298
Gray	65,361	73,780	54,269	64,252	56,199	21,638	41,033	38,454	16,791
Hale	23,133	56,116	26,069	28,206	37,124	30,581	43,768	20,177	20,707
Hansford	99,838	125,695	106,326	138,323	136,871	51,932	175,355	141,459	93,942
Hartley	63,642	89,157	65,990	71,541	44,779	43,768	84,300	36,977	40,420
Hemphill	18,299	30,267	19,576	18,205	14,840	7,220	12,832	6,461	3,784
Hockley	10,189	25,957	8,505	7,664	8,650	6,800	6,504	2,896	1,477
Howard	580	500	867	840	1,989	1,233	3,232	0	499
Hutchinson	30,636	36,273	36,310	51,124	53,380	23,319	70,012	29,129	15,655
Lamb	15,152	49,172	17,581	24,691	22,911	19,178	40,047	19,484	13,349
Lipscomb	57,039	78,694	61,825	61,483	42,059	11,060	28,452	29,804	19,445
Lubbock	6,304	8,234	4,562	11,930	6,838	6,970	16,289	4,273	2,185
Lynn	1,192	7,836	1,966	5,898	4,747	5,293	4,967	3,741	5,894
Martin	0	3,025	488	1,258	2,653	4,180	3,138	1,077	375
Midland	0	2,837	474	217	323	741	3,878	3,380	310
Moore	52,849	83,528	70,228	81,552	84,035	48,910	118,441	39,697	40,034
Ochiltree	147,985	210,815	168,662	184,060	160,674	57,358	190,570	121,155	89,498
Oldham	21,527	50,549	39,990	41,559	31,031	6,940	35,437	9,660	22,721
Parmer	54,485	93,109	72,119	86,427	104,345	53,410	113,470	33,702	54,087
Potter	14,798	15,589	15,332	16,786	15,637	7,254	13,473	5,604	11,278
Randall	47,430	117,182	87,526	80,028	81,010	28,147	64,194	35,078	55,943
Roberts	20,257	19,433	18,949	20,169	15,232	6,338	10,666	8,718	4,239
Sherman	82,354	103,833	101,244	105,483	121,942	79,114	123,056	46,509	53,131
Swisher	41,121	109,974	86,798	87,532	67,693	32,839	94,340	28,748	67,437
Terry	3,006	14,140	5,421	8,284	6,644	7,425	19,643	8,977	10,620
Yoakum	1,236	7,419	4,299	3,225	8,001	14,045	11,716	9,907	3,825
Total	1,388,038	2,238,543	1,693,982	1,818,932	1,778,713	982,103	2,036,189	1,032,542	1,094,511

Table A 14. Irrigated acres of harvested wheat in the Texas High Plains by county, 1978-2017.

County	**1978**	**1982**	**1987**	**1992**	**1997**	**2002**	**2007**	**2012**	**2017**
Andrews	0	0	0	0	0	0	0	0	320
Armstrong	3,753	5,502	3,535	3,395	3,679	1,420	851	260	2,160
Bailey	6,029	18,705	7,068	9,724	8,798	10,636	0	1,723	1,318
Briscoe	3,932	4,756	4,074	3,952	2,478	2,198	1,284	1,974	5,713
Carson	32,311	34,717	30,798	38,621	30,959	10,119	7,176	9,177	5,946
Castro	42,181	53,323	42,048	52,854	53,605	37,213	40,830	11,114	8,883
Cochran	1,909	1,655	416	1,070	1,664	2,125	3,766	4,042	3,738
Crosby	1,228	1,374	1,727	3,326	1,070	1,402	1,607	700	1,502
Dallam	48,664	62,549	54,778	70,311	61,836	60,513	60,036	37,145	25,098
Dawson	3	350	376	427	809	2,417	2,656	4,195	2,236
Deaf Smith	52,610	73,462	57,517	64,247	71,919	33,249	42,925	24,306	32,360
Floyd	7,635	27,991	14,022	12,137	11,143	6,746	11,559	6,735	6,536
Gaines	1,882	31,447	11,745	9,613	11,087	17,314	20,175	12,582	7,323
Glasscock	119	90	443	362	673	1,631	382	70	310
Gray	8,441	9,547	8,174	9,727	7,704	3,774	3,880	4,529	1,233
Hale	10,068	32,629	16,873	16,295	19,388	17,118	17,305	12,275	3,757
Hansford	79,957	70,452	60,132	75,522	60,911	28,167	42,877	36,262	17,989
Hartley	36,332	56,041	35,844	46,148	29,525	17,143	38,677	20,250	28,591
Hemphill	1,151	1,092	1,336	1,138	1,358	1,190	790	6,461	3,784
Hockley	1,527	4,689	1,491	1,349	1,750	1,647	1,484	1,278	352
Howard	0	0	0	0	0	0	0	0	0
Hutchinson	20,994	17,092	15,897	19,814	19,966	13,518	12,681	8,370	2,583
Lamb	5,526	29,336	11,975	18,804	12,350	9,968	20,754	10,394	5,685
Lipscomb	6,826	9,360	7,130	5,313	1,432	1,638	5,094	12,283	1,878
Lubbock	1,418	2,045	494	2,215	1,501	1,680	3,441	2,072	1,799
Lynn	20	161	105	204	157	1,524	430	1,687	987
Martin	0	0	0	0	0	0	0	0	0
Midland	0	424	77	0	0	61	204	152	310
Moore	35,810	49,155	39,074	49,540	41,980	26,473	25,063	17,834	13,345
Ochiltree	31,378	35,795	30,722	43,908	33,547	18,782	27,625	17,960	11,737
Oldham	5,431	3,957	2,184	5,874	3,592	2,290	7,473	1,088	321
Parmer	34,996	50,481	38,620	45,212	42,694	29,893	32,581	12,607	10,276
Potter	2,555	3,218	3,580	1,756	237	865	1,027	42	144
Randall	23,575	18,206	13,694	13,671	18,193	7,487	6,006	5,023	3,232
Roberts	3,671	1,671	2,283	2,608	3,211	1,835	1,139	719	594
Sherman	56,166	62,368	58,908	61,407	66,206	53,024	49,145	26,063	25,311
Swisher	25,514	45,098	29,778	31,726	19,885	8,930	11,529	8,496	7,593
Terry	1,946	6,697	2,217	3,605	3,676	3,311	11,662	5,463	3,862
Yoakum	217	4,631	2,728	1,274	3,481	9,043	7,576	7,655	1,919
Total	595,775	830,066	611,863	727,149	652,464	446,344	521,690	332,986	250,723

Table A 15. Non-irrigated acres of harvested wheat in the Texas High Plains by county, 1978-2017.

County	1978	1982	1987	1992	1997	2002	2007	2012	2017
Andrews	0	425	5,481	887	149	0	749	25	1,180
Armstrong	34,331	63,862	50,956	41,441	36,753	27,740	53,826	35,647	28,243
Bailey	24,947	29,281	15,380	20,653	14,921	14,363	0	6,897	13,292
Briscoe	12,157	21,511	18,634	17,444	21,048	7,654	23,651	16,549	25,859
Carson	39,968	80,744	64,561	60,331	58,489	23,492	90,495	57,276	53,875
Castro	14,769	37,691	29,167	31,826	47,372	18,285	44,110	18,790	24,749
Cochran	11,793	19,950	3,490	7,761	5,821	5,553	14,119	12,365	5,538
Crosby	7,504	19,120	10,811	10,491	10,957	8,176	9,564	4,637	5,243
Dallam	46,745	53,944	42,336	42,644	44,809	23,641	65,018	23,691	23,095
Dawson	136	1,378	1,334	1,400	2,121	1,199	6,591	665	1,019
Deaf Smith	61,538	101,725	75,790	52,717	78,485	40,379	126,167	31,775	90,003
Floyd	51,015	67,919	64,227	52,350	51,698	32,345	58,441	18,073	65,294
Gaines	1,966	11,085	3,975	5,209	11,105	9,712	8,421	5,869	3,045
Glasscock	500	873	3,917	3,002	5,658	6,888	12,977	1,193	2,988
Gray	56,920	64,233	46,095	54,525	48,495	17,864	37,153	33,925	15,558
Hale	13,065	23,487	9,196	11,911	17,736	13,463	26,463	7,902	16,950
Hansford	19,881	55,243	46,194	62,801	75,960	23,765	132,478	105,197	75,953
Hartley	27,310	33,116	30,146	25,393	15,254	26,625	45,623	16,727	11,829
Hemphill	17,148	29,175	18,240	17,067	13,482	6,030	12,042	0	0
Hockley	8,662	21,268	7,014	6,315	6,900	5,153	5,020	1,618	1,125
Howard	580	500	867	840	1,989	1,233	3,232	0	499
Hutchinson	9,642	19,181	20,413	31,310	33,414	9,801	57,331	20,759	13,072
Lamb	9,626	19,836	5,606	5,887	10,561	9,210	19,293	9,090	7,664
Lipscomb	50,213	69,334	54,695	56,170	40,627	9,422	23,358	17,521	17,567
Lubbock	4,886	6,189	4,068	9,715	5,337	5,290	12,848	2,201	386
Lynn	1,172	7,675	1,861	5,694	4,590	3,769	4,537	2,054	4,907
Martin	0	3,025	488	1,258	2,653	4,180	3,138	1,077	375
Midland	0	2,413	397	217	323	680	3,674	3,228	0
Moore	17,039	34,373	31,154	32,012	42,055	22,437	93,378	21,863	26,689
Ochiltree	116,607	175,020	137,940	140,152	127,127	38,576	162,945	103,195	77,761
Oldham	16,096	46,592	37,806	35,685	27,439	4,650	27,964	8,572	22,400
Parmer	19,489	42,628	33,499	41,215	61,651	23,517	80,889	21,095	43,811
Potter	12,243	12,371	11,752	15,030	15,400	6,389	12,446	5,562	11,134
Randall	23,855	98,976	73,832	66,357	62,817	20,660	58,188	30,055	52,711
Roberts	16,586	17,762	16,666	17,561	12,021	4,503	9,527	7,999	3,645
Sherman	26,188	41,465	42,336	44,076	55,736	26,090	73,911	20,446	27,820
Swisher	15,607	64,876	57,020	55,806	47,808	23,909	82,811	20,252	59,844
Terry	1,060	7,443	3,204	4,679	2,968	4,114	7,981	3,514	6,758
Yoakum	1,019	2,788	1,571	1,951	4,520	5,002	4,140	2,252	1,906
Total	792,263	1,408,476	1,082,118	1,091,783	1,126,249	535,759	1,514,499	699,556	843,788

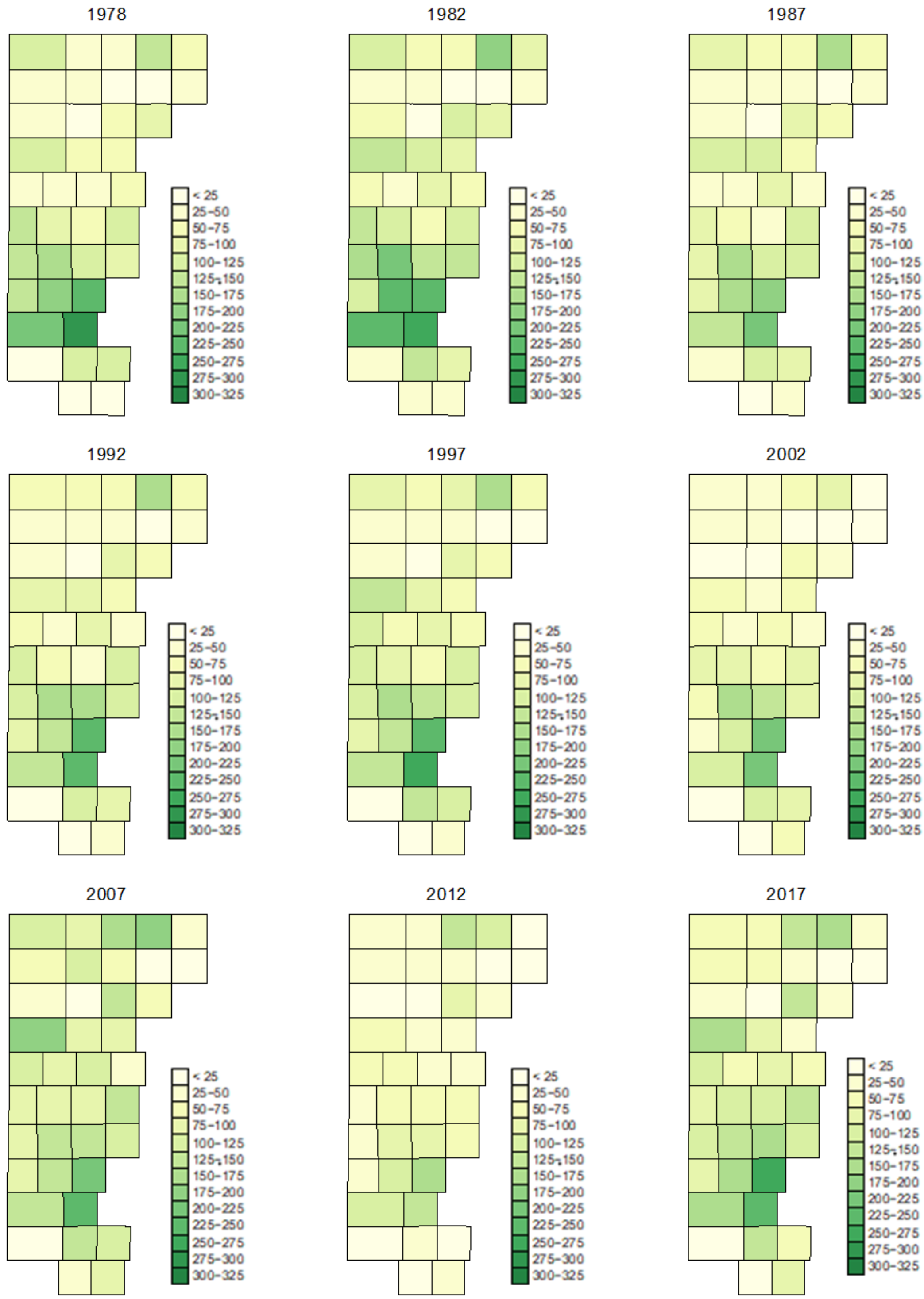

Figure A 1. Non-irrigated harvested cropland acres (in thousand acres) by county, 1978-2017.

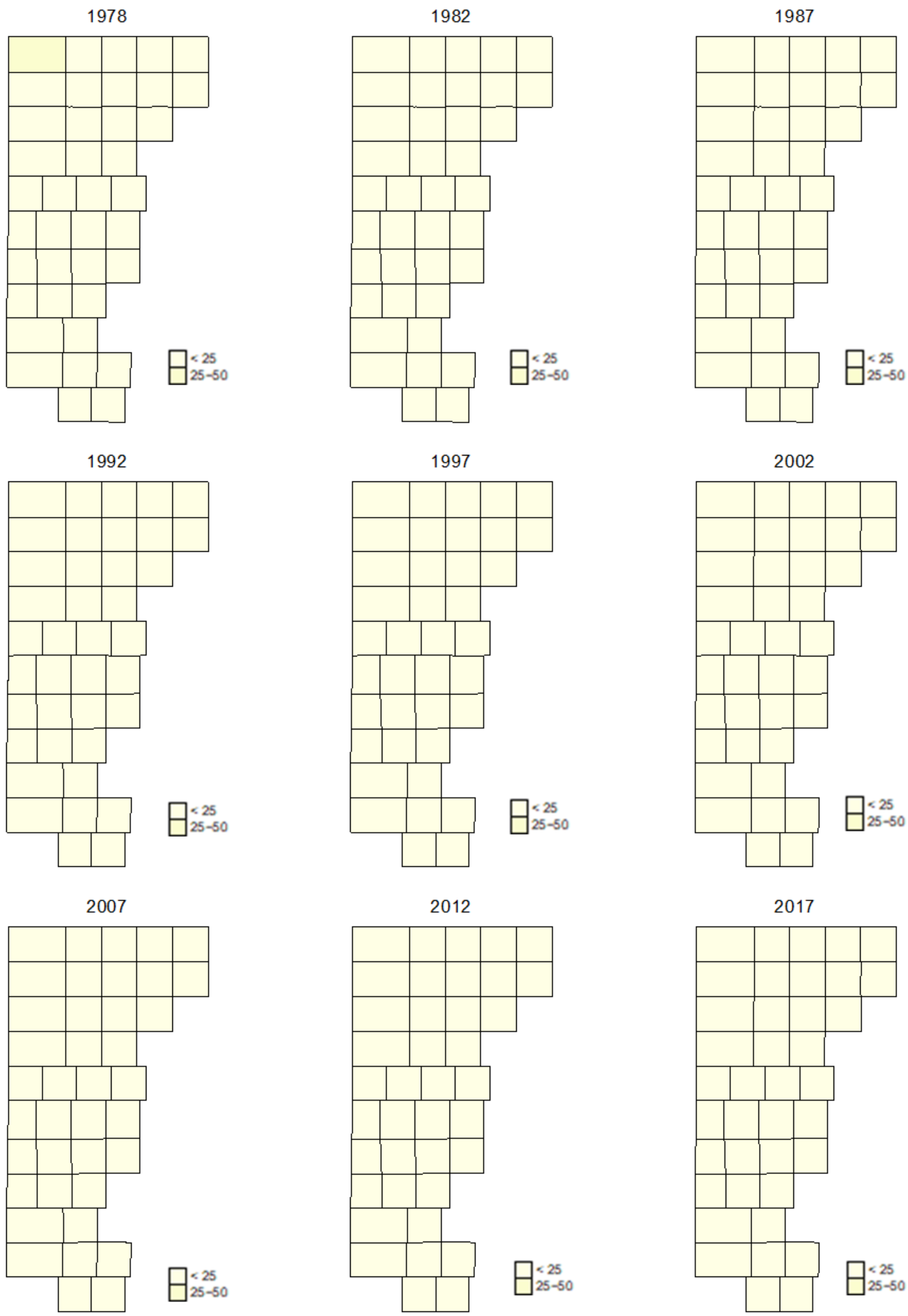

Figure A 2. Non-irrigated acres of corn harvested for grain (in thousand acres) by county, 1978-2017.

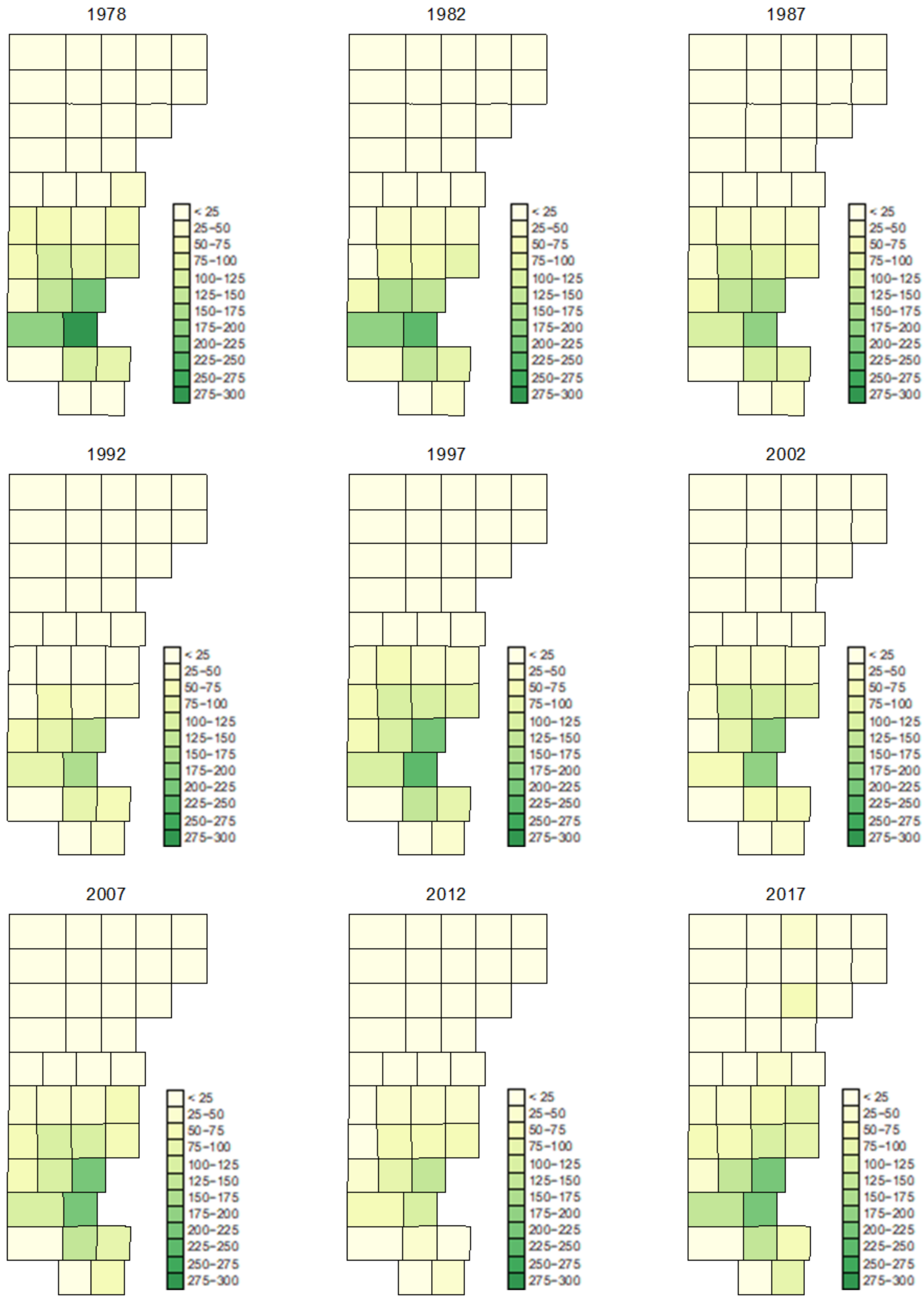

Figure A 3. Non-irrigated acres of cotton harvested (in thousand acres) by county, 1978-2017.

Figure A 4. Non-irrigated acres of sorghum harvested for grain (in thousand acres) by county, 1978-2017.

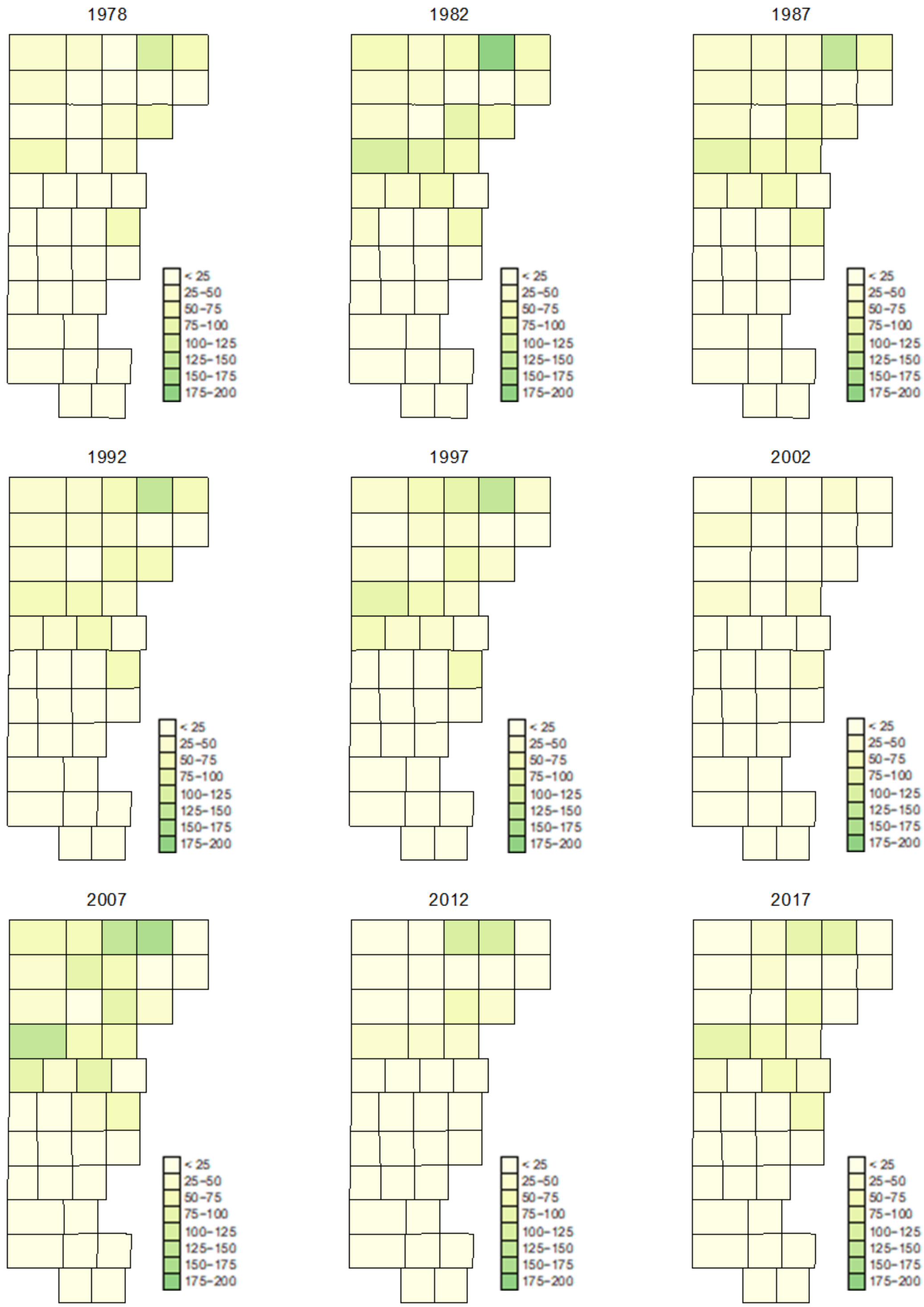

Figure A 5. Non-irrigated acres of wheat harvested for grain (in thousand acres) by county, 1978-2017.