THE EVOLUTION OF IRRIGATED ACRES IN GEORGIA AND IRRIGATION WITHDRAWAL RATES SEEN IN THE LOWER FLINT RIVER BASIN

by

MEAGAN SZYDZIK

(Under the Direction of Jeffrey Mullen)

ABSTRACT

The demand for irrigation is particularly concentrated in the Lower Flint River basin, where agriculture is heavily focused in Georgia. A need exists to understand irrigation trends at a farm, county, and watershed level to make predictions, so that availability of water resources can be ensured for future generations. The evolution of irrigated acres in Georgia over the past 12 years is analyzed alongside past irrigation projections to make implications about irrigation trends. Simulated crop production models are performed in DSSAT to analyze impacts in total water demand in the Lower Flint River basin. The findings suggest that irrigated lands have been increasing since 2008, with cotton expanding the most. Simulated crop models suggest that increased irrigation yields higher profits.

INDEX WORDS: Lower Flint River basin, Georgia, Irrigation, DSSAT, Irrigated acres, ArcGIS, CropScape, Withdrawals, Profits, Simulated crop models, Projections, Trends, Water Demand, Agriculture, Corn, Cotton, Peanuts, Soybeans, Crops

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MEAGAN SZYDZIK

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by

MEAGAN SZYDZIK

Major Professor: Jeffrey Mullen
Committee: Mark Masters
John Bergstrom

Electronic Version Approved:

Ron Walcott
Vice Provost for Graduate Education and Dean of the Graduate School
The University of Georgia
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DEDICATION

This work is dedicated to my family, especially my parents, for unconditionally supporting me through my endeavors and motivating me to always be ‘brilliant.’ Also, to Weston for encouraging me to never give up and continue trying even when things seem impossible.

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Chapter 1: Introduction

1.1 Background

Georgia's State Water Plan defines four main steps for managing water resources in a sustainable and economical manner (Georgia Water Council, 2008). The first component involves the creation of consumptive use assessments by the Environmental Protection Division (EPD), which determine how much water can be consumed without causing negative impacts. Consumptive use includes water withdrawals that are not returned to the watershed from which they are removed plus waters that are contaminated to the point where the water is unusable. As such, EPD must determine the amount of waste and stormwater that can enter streams without negatively affecting water quality, which is defined as assimilative capacity. Second, the regional planning councils develop forecasts of future water needs to compare with the assessments by the EPD to identify any areas of concern. Currently, there are 11 water planning regions that are divided based on jurisdictional, economical, and hydrological boundaries to address local water issues. Of the water planning regions, 10 councils are formed under the State Water Plan, while separately the Metropolitan North Georgia Water Planning District is formed by the General Assembly (O.C.G.A. § 12-5-571, 2001). Thirdly, plans are constructed for each region jointly, by the EPD and the regional water planning councils, to identify best water management practices for current and future consumptive needs and assimilative capacity. The last step involves implementation of the adopted plans and water permitting by the EPD. These steps can be seen as a management cycle that goes back and forth between asking what gaps there are between forecasted future water resource needs and the expected available water resources in terms of information, water quality, and water quantity. The overall goal is to fill these gaps through the development of proper management practices at the local level.

Agricultural irrigation predictions are a crucial factor in policy planning, serving as an attempt to answer questions surrounding water withdrawals and demand in upcoming years. The demand for irrigation is particularly concentrated in the south of the state, known as the Coastal Plain region, and even more so in the Flint River basin. The Chattahoochee-Flint River basin has the most water withdrawals for the purpose of irrigation in the entire state, stressing the basin's water balance beyond Georgia's borders and into Alabama and Florida (Painter, 2019). Currently there are over 25,000 farm irrigation permits issued statewide by the Environmental Protection Division of GA, with the Flint River basin comprising the most permits for agricultural water withdrawals (Manganiello, 2017; Watershed Protection Branch, 2020). Considering the state's expansive agricultural sector, the need arises to understand irrigation trends at a farm, county, and watershed level and to make agricultural water use projections as accurate as possible to facilitate water management now and into the future.

Many agricultural analysts are faced with questions about irrigation demand, attempting to address complex issues related to crop and water management. Agricultural demand projections present insight on irrigation predictions for specific crops in GA, which can be used in future policy decisions. These comprised county-level irrigated acreage forecasts developed for the 2010 and 2016 water planning councils. Forecasts are helpful since they can provide an estimate of predicted water demand and withdrawal needs in the next few decades.

Those in the agricultural sector can take advantage of crop simulation models to decide on the scheduling and quantity of water use for a growing season. The Decision Support System for Agrotechnology Transfer (DSSAT) v4.7.5 does just that and has been used to aid in problem solving since 1982. This is a simulation-based model that uses various site-specific inputs such as historical weather data, soil type, and crop genotypes to produce crop performance outputs (Hoogenboom et al., 2019). Not only is harvested yield reported for the simulated year of farming, but also the number of irrigation applications and total amount of water used, among many other outputs. Irrigation treatments also allow for user defined conditions to water when soil moisture drops below a certain threshold or on specific days throughout the season. The model requires a minimum set of data for the ability to supply reliable estimations, but with detailed inputs, can provide important answers to the what-if's surrounding crop management choices.

Irrigation projections benefit from a history of crop data to visually identify how and where irrigated lands have either contracted to expanded in past years. CropScape is a Cropland Data Layer Program created by the USDA, National Agricultural Statistics Service that uses satellite imagery to provide georeferenced cropland cover data for the United States. The map layers are available for download by state and year classifications in the form of raster images, allowing for GA’s cropland history to be easily accessible and analyzed. The imagery datasets are generally reliable, with row crop identification being 85-95% accurate (USDA, 2021). In addition to CropScape, ArcGIS is a geographic information system framework designed to analyze and organize data spatially (Esri, 2021). Geospatial layers from CropScape can be processed with ArcGIS tools to obtain shapefile layers that reveal agricultural fields by county and crop type in GA.

1.2 Definition of Terms

A few key terms are used throughout this paper to distinguish between different geospatial layers of interest in ArcGIS. When referring to all lands in GA that are irrigatable, the term “potential lands” will be used. Of these potential lands, only those fields that are determined to be under irrigation will be referred to as “wetted lands.” This paper also concentrates on four main crops considered the “focus crops,” which are corn, cotton, peanuts, and soybeans. Irrigated fields that only contain one crop type will be referred to as “single four,” since there are four crops of interest. Likewise, all fields containing any acres of focus crops will be considered the “big four” layers in ArcGIS. Data outputs obtained from DSSAT models will be referred to as “DSSAT data.”

1.3 Research Objectives

The main objective of this study is to use CropScape and ArcGIS to demonstrate the evolution of irrigated acres in GA over the past 12 years and use DSSAT data to estimate water use by agricultural producers. The following specific objectives will be addressed:

1. Estimate the amount of irrigated land, by county and crop, for GA from 2008 through 2020 using ArcGIS and CropScape geospatial layers.

2. Compare the amount of irrigated land in 2020, by county and crop, estimated using ArcGIS and CropScape geospatial layers to the 2020 projections developed for the 2010 and 2016 water planning councils.
3. Compare the total amount of irrigated land for the big four in GA from 2012 and 2017, to the amount reported in the USDA 2017 Census of Agriculture.
4. Compare the potential lands available for 2010, 2016, and 2021 to identify differences over time across the state.
5. Simulate average irrigation withdrawals per year in the Lower Flint region using DSSAT, for the focus crops and years 2016-2020.
6. Identify the profit maximizing irrigation strategy by county and crop using DSSAT.

The Study Area 1.4

The focus area for this research is displayed in figure 1, where 16 counties in the southwest corner of GA represent the Lower Flint River basin (LFRB) counties. The first four objectives listed above examine changes across the whole state as well as the LFRB study area, but objectives 5-6 are focused specifically on the LFRB. Agricultural irrigation is the highest use of water withdrawals in the study are, making up to 90% of the water usage during the growing seasons (Couch and McDowell, 2006). The predominant land cover is row crops, such as corn, cotton, and peanut and also pastureland (Lower Flint-Ochlockonee Water Planning Council, 2017).

In order to populate the study area with historical weather data to be used in DSSAT modelling, the Automated Environmental Monitoring Network (AEMN) of GA was used. This is a network of automated weather stations with the purpose of collecting detailed weather data at various stations across GA, all representing unique climate and soil conditions (Hoogenboom et al., 2003). Information such as precipitation and maximum and minimum temperature can be obtained through the Georgia AEMN website at www.georgiaweather.net for any station's current or historically generated weather data. There are currently 86 weather stations across the state, of which, 14 are found within the LFRB study area as seen in figure 1.

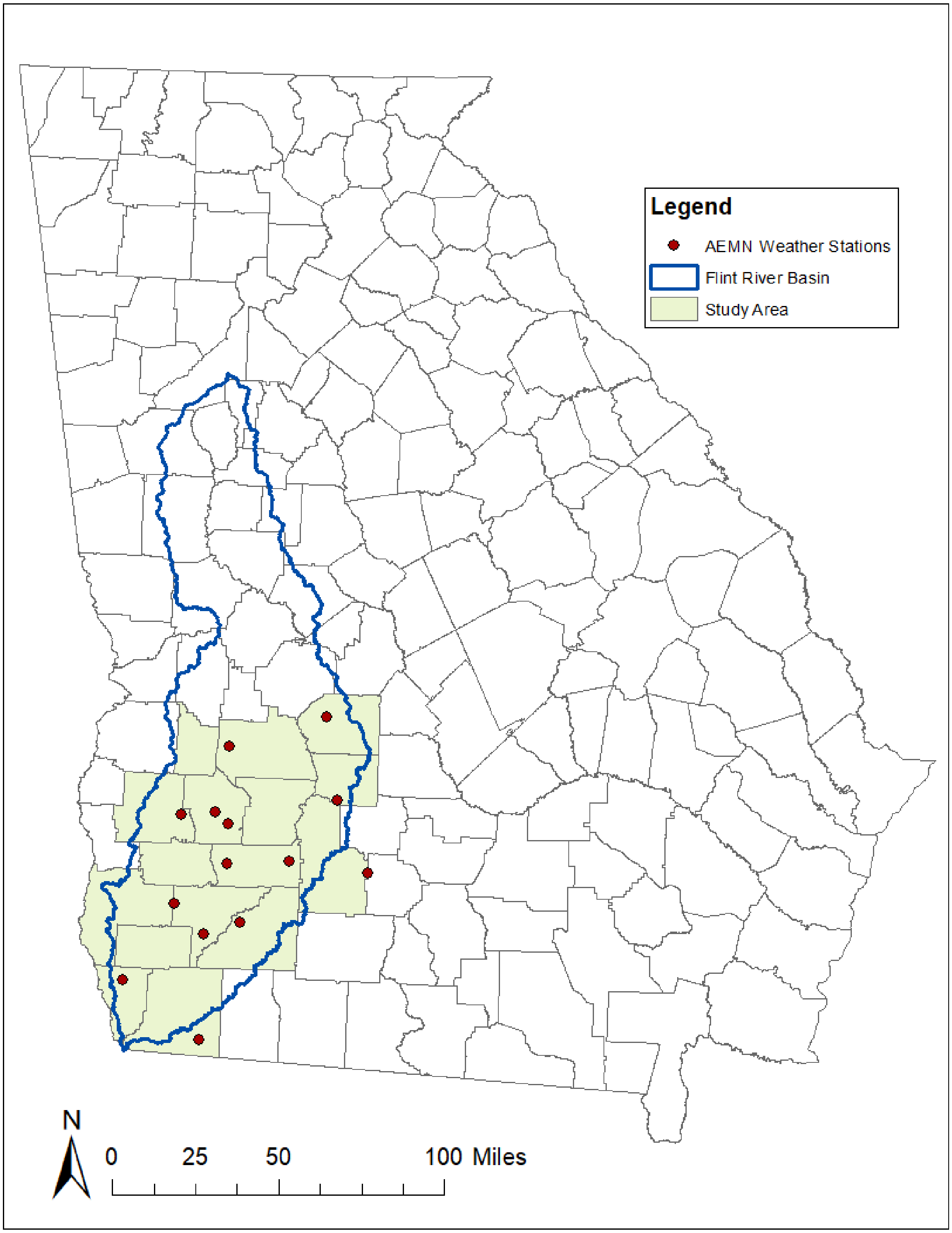

Figure 1: Map of Lower Flint River Basin Study Area

Thesis Organization 1.5

This thesis is organized into 5 chapters. The first chapter covers the introduction for the study. Chapter two will present the literature review for recent works in irrigation predictions, after which, the third chapter will go over the methodology for this thesis, discussing data sources and model specifications. Chapter 4 will cover the findings of the research and Chapter 5 will conclude with a summary and recommendations.

Chapter 2: Literature Review

Introduction 2.1

The review of literature for this paper will examine the recent works expanding upon the multi-output profit function used in Mullen et al. (2009). The constrained optimization problem yields optimal land allocations for each crop, product supply functions and a water demand function. Elasticities with respect to crop price as well as water price were estimated from the land allocation model and a short-run water demand model. The main objective of this study was to analyze the impact of water costs on irrigation consumption and crop management for irrigators in GA. These impacts would then aid in understanding water demand in the future in the face of agricultural water policy. Georgia operates with the doctrine of riparian water rights, stating that water belongs to those who own the land it happens to run onto, and own the right to consume the water under reasonable use as to not interfere with the use by the next owner (O.C.G.A. §§ 44-8-1; 51-9-7). Because water cost is not explicitly valued in GA, a proxy for water price is estimated from groundwater pumping costs (Mullen et al., 2009). The pumping cost of agricultural irrigation will also be used in this thesis to calculate variable irrigation costs used in the estimation of farm-level profits.

Recent Literature 2.2

A recent study by Kornelis and Norris (2020), looking at the Great Lakes Region, employ the use of a similar multi-output profit function for corn, soybean, and potatoes, which includes the allocation of irrigated lands with crop and water management decisions. Their optimization is a function of crop prices, the cost of irrigation water, the land constraint, and other exogenous environmental variables such as climate, weather, and soil quality. Unlike Mullen et al., Kornelis and Norris do not take into account the input prices other than water. Their proxy for the cost of irrigation water was a firm-level average cost calculated by using total annual energy expenditures for pumping and dividing by the total amount of acre-inches applied. Kornelis and Norris found that firms do respond to the price of water through application rates at an intensive margin, which dominates the extensive crop allocation response. They also found evidence that extreme heat has an impact on irrigation water demand, where increasing summer temperatures from climate change are expected to increase the water demand in the Great Lakes Region. Their water-price irrigation demand elasticities range from –0.26 to –0.29, showing a similar but somewhat larger price elasticity for irrigation water compared to Mullen et al. Another result showed that, unexpectedly, increasing water cost caused a substitute toward potato production, a water intensive crop. This was a similar finding where the impact of higher water price led to a larger corn area, even given the high-water rates needed for corn production (Mullen et al., 2009).

Sukcharoen et al. (2020) also use the multi-crop profit function based on crop prices, variable input prices, the number of irrigated acres planted to crop, the total number of irrigated acres, and other exogenous variables including precipitation, land quality, and irrigation technology. Using the normalized quadratic profit function from Lau (1978) and Huffman (1988), the maximization problem yields an estimation for ground water pumping decisions for a specific crop. They test whether farmer's management of irrigation is aligned with the idea of profit maximization, by testing whether crop price expectations have a positive effect on the consumption of agricultural water. For identifying a farmer's yearly changes in per-acre of groundwater pumped in response to yearly expected crop price changes, a reduced form fixed-effects equation is used for each crop, which isolates the effects of expected crop prices. Sukcharoen et al. uses six different proxies for crop price expectations: (1) an average of monthly crop prices from the preceding year; (2) an average of monthly crop prices from the preceding three years; (3) and (4) a three-month average of previous year pre- and post-harvest prices, respectively; and (5) and (6) a three-year average of pre- and post-harvest prices, respectively. The results show farmers' groundwater pumping decisions are not actually consistent with the profit maximization framework, specifically that producers do not vary the amount of irrigation applications per acre in response to higher expected own crop price. Sukcharoen et al. concludes that this is possible if farmers are viewing water as a fixed input and not reacting to a change in expected crop price if they do not have the capacity to pump more water.

Silva et al. (2019) analyze the aggregate county-level effect of groundwater withdrawals for irrigation, climate variables, and energy price changes on the High Plains Aquifer. This is done through a water balance equation, a short-run water demand function, and a long-run demand for acres under irrigation. The water balance is estimated using intensive and extensive margin effects of irrigation and the effects of precipitation. Precipitation represents the recharging of groundwater, while irrigation represents depletion by water applied per acre irrigated (intensive margin) and the proportion of the county area irrigated (extensive margin). A restricted profit function is then used to represent farm technology and irrigation decisions, to represent the maximum profit per acre of land. Elasticities are also measured for the effect of price on groundwater. They find a statistically significant, negative own-price elasticities of water demand at the intensive and extensive margin at –0.367 and –0.378 respectively. They also estimate that a 10% increase the irrigated surface area would result in a 1.5-inch annual decline in the water table.

Given the need for irrigation projections, an understanding of irrigation consumption in GA will be presented in this paper. This thesis will employ ideas from recent literature to conceptualize how farmers in GA are managing their irrigation usage in heavily agricultural regions of the state.

Chapter 3: Methodology

3.1 Introduction

This chapter outlines the data sources and processing done to geospatial layers from CropScape in ArcGIS to visually display irrigated acreage in GA at the county-level. Methods used to compare the CropScape layers with the USDA reported acres, the irrigation shapefiles for GA, as well as the agricultural irrigation projections are explained in detail. Also described, are the inputs for crop simulation models in DSSAT for the LFRB region.

3.2 ArcGIS Data and Specifications

Data layers used for analyses done in ArcGIS were from CropScape - National Agricultural Statistics Service Cropland Data Layer (2021). The raster images for the state of GA from 2008 to 2020 were downloaded and imported into ArcGIS and transformed into vector data shapefiles. A shapefile stores the location, shape, and attributes of geographic features in a vector format that uses points, lines, or polygons to represent features (Esri, 2021). This is opposed to the original raster data that uses cell data or pixels to represent features. The shapefile from CropScape displays all crop type and land cover for the entire state. Attributes from the original CropScape layer were used to populate irrigation fields with crop types where the spatial location of the two align.

The irrigation field data is obtained from shapefile layers filled with polygons generally in the shape of circular center pivot irrigation fields. These were available for the years 2010, 2016, and 2021. The irrigated areas were originally produced with GIS tools from aerial imagery using fields that were determined as irrigated by farmers, the EPD's Agricultural Meter Program, the Georgia Soil and Water Conservation Commission's (SWCC) Agricultural Meter Program, and by UGA's Ag Water Demand GIS efforts (Hook et al., 2010). The shapefiles were used previously to form the baseline for irrigated acreage in GA from which future projections were made in estimating the Ag Water Demand for water planning councils. Although GA requires Agricultural Water Withdrawal Permits by the EPD, the record of permits only list the irrigated acreage that are permitted rather than actual irrigated acres. Of these permitted acres, only around 25 to 35% of land is actively irrigated, thus, the effort for irrigation mapping began (Hook et al., 2010). The attributes for these layers contained information about the acreage of the fields and assigned an identifier to each polygon. Irrigation polygons, as mentioned before, were laid over top the CropScape shapefile and processed with a spatial join, to assign the fields with crop information. The 2010 shapefile was used for the CropScape years 2008-2015. The 2016 shapefile was used for 2016-2019 and, lastly, the 2021 shapefile was used for the year 2020. These constitute a set of three layers labeled as potential lands used to identify overall acreage differences over time in this study.

The irrigation field shapefiles show which fields have irrigation systems on them. Instances occur where the irrigation field polygons have been assigned a crop type and are not classified as 'wetted lands' under irrigation. These include areas on the

CropScape layer where the crop type is labeled as part of the background map, barren land, clover or wildflowers, forests, developed land and open space, fallow or idle cropland, grass or pastureland, wetlands, open water, other tree crops, shrubland, triticale, winter wheat, or woody wetlands. In a given year, all irrigation field polygons with the aforementioned crop types were assumed to be unirrigated and taken out of the analysis. The resulting layer is considered the wetted lands.

The focus crops of this paper are corn, cotton, peanuts, and soybeans. Irrigation field polygons identified to only contain these focus crops were selected and exported as an individual layer for analysis which was called 'big four'. To determine the acres irrigated for each crop on each field, the proportion of the crop acreage to the entire polygon acreage was calculated and then multiplied by the polygon acres. This gives irrigated acres for all crops within a field.

A subset of the irrigation field polygons – those containing only one crop – was also identified and labeled as the 'single four' layers. Single-crop fields were found by selecting all polygons that had equal to or greater than 90% of their area listed as one crop type.

Four sets of county maps were generated for the focus crops from 2008 to 2020. The first set shows the total irrigated acreage for all focus crops aggregated at the county level. The second set shows total irrigated acreage for each focus crop individually, aggregated at the county level. The third set shows the single-crop field acreage for each focus crop individually, aggregated at the county level. The fourth set shows the total irrigated acreage for the single-crop fields, aggregated at the county level. These county maps can be used to identify systematic differences and trends throughout the state involving irrigated lands for corn, cotton, peanuts, and soybeans.

A fifth set of maps was also generated by grouping all crops (including the focus crops) that were identified in CropScape as part of wetted lands, to give all irrigated acres in the state. The crops in this dataset include: alfalfa, apples, barley, blueberries, broccoli, cabbage, cranberries, canola, cantaloupes, canola, carrots, celery, citrus, corn, cotton, cucumbers, dry beans, eggplants, grapes, greens, herbs, millet, miscellaneous fruits and vegetables, oats, onions, oranges, other crops, other hay or non-alfalfa, peaches, peanuts, peas, pecans, peppers, popcorn, potatoes, rye, sod or grass seed, sorghum, soybeans, spring wheat, squash, strawberries, sugarcane, sunflowers, sweet corn, sweet potatoes, tobacco, tomatoes, and watermelons.

To aid in explaining changes over time with irrigated acres, a graph of farm-level crop prices for each focus crop was plotted against time from 2008-2020. Historical prices were obtained from the USDA/NASS QuickStats Database for corn, cotton, and soybeans. This is an online database providing published estimates from U.S. agricultural production (USDA NASS, 2017). Prices received by farmers were annual, national marketing year prices. A marketing year refers to a one-year period starting at harvest of a commodity and ending at the same time the following year (USDA NASS, 2014). Prices received in this case refer to the weighted average for the marketing year. Weights are determined by the sale price for each commodity per state (USDA NASS, 2011). Historical peanut farm-level prices received were obtained from the Food and Agricultural Policy Research Institute at the University of Missouri in their 2021 U.S. Agricultural Market Outlook (FAPRI-MU, 2021). Their price data excel workbooks provide past annual, national prices received for peanuts based on a September-August year.

The ArcGIS and CropScape geospatial layers created for 2020 were then compared with the 2020 projections developed for the 2010 and 2016 water planning councils. These forecasts were estimated in 2009 and 2015 and include information on 2020's projected irrigated acreage in GA at a county-level for corn, cotton, peanuts, and soybeans (Mullen, 2009, 2015). These datasets were imported into ArcGIS and joined with a map layer of GA's counties to display the aggregated irrigated acres per county. This is done for each crop separately for both the 2009 and 2015 data. These maps are then visually compared to the big four map sets from 2020 to identify differences between the projected acres and CropScape acres. Also, the three sets of data were plotted on a bar graph separated by crop type and compares the total statewide irrigated acreage between the different datasets. The statewide comparisons between the two projections and CropScape were then calculated using the percent differences. The percent difference from the 2009 projection to the CropScape irrigated acres was calculated as well as the percent difference from the 2015 projection the CropScape acreage.

To compare the overall potential irrigated acreage changes between the three irrigation field shapefiles (2010, 2016, and 2021), the percent differences from 2010 to 2016 and 2016 to 2021 were calculated. This involves aggregating all acres with an irrigation polygon field, whether actually irrigated or not, at the county level. The difference between the county-level potential irrigated acreage in the older shapefile and the newer shapefile is then divided by the older shapefile acreage and multiplied by 100

(Eq.1). The entire shapefile is used with all fields and crop types because the object is to observe what happens between each shapefile year in terms of expanding or contracting acreage with an irrigation system.

$$\text{Percent Difference: } \frac{New\ Shapefile\ Acres - Old\ Shapefile\ Acres}{Old\ Shapefile\ Acres} * 100 \qquad \text{(Eq. 1)}$$

Percent differences were also calculated for the comparison between big four from CropScape, to the corn, cotton, peanut, and soybean irrigated acres reported in the 2017 Census of Agriculture by the USDA NASS (2019). Similarly, the total irrigated acres for each county from the Census was compared with that of the CropScape wetted lands, total irrigated acres. The Census counts farms in their data if $1,000 or more of agricultural products were sold or produced during the year of the census and the collected data is directly from farm and ranch operators (USDA NASS, 2019). The census lists irrigated acres by state and county for field crops as well as all irrigated acres in the state. Irrigated lands are defined by the USDA as all land watered by artificial or controlled means, such as through the use of sprinklers, flooding, furrows, subirrigation, and spreader dikes, as well as supplemental and preplant irrigation (USDA National Agricultural Statistics Service, 2019). The “Irrigated land” category was used from the 2017 Census of Agriculture to supply county level irrigated acreage data for the years 2012 and 2017 in Georgia. This was then compared to the CropScape acreage for the years 2012 and 2017. The percent difference calculation used for the USDA and CropScape comparison is show in Eq 2.

$$\text{Percent Difference: } \frac{USDA\ Irrigated\ Acres - Shapefile\ Irrigated\ Acres}{Shapefile\ Irrigated\ Acres} * 100 \qquad \text{(Eq. 2)}$$

3.3 DSSAT Data and Model Specifications

The LFRB study area includes 14 weather stations from the AEMN, which are used to specify the site locations for the crop simulation models in DSSAT. DSSAT requires a set of minimum data inputs to run a simulation including historical weather such as daily maximum and minimum temperature, rainfall, and solar radiation. The AEMN website provides the historical weather data for each station in terms of temperature and rainfall. This information was downloaded as daily output for each year and weather station within the study area from 2016 to 2020. Daily solar radiation from 2016 to 2020 was obtained from the NASA POWER Data Access Viewer, which outputs the All-Sky Insolation Incident on a Horizontal Surface (MJ/m^2/day) for a specific latitude and longitude (NASA, 2021). Elevations were also needed in DSSAT for site information; thus, the U.S. Geological Survey TMN Elevation tool was used with the station coordinates to identify elevations for each of the 14 sites (U.S. Geological Survey, 2021).

The DSSAT model then requires information about the crop cultivar, soil type, irrigation strategy, fertilizer applications, and planting date. A total of 280 crop-site-year combinations were developed for the LFRB: 4 crops (corn, cotton, peanuts, and soybeans) at 14 weather stations over 5 years (2016-2020). A nearest neighbor analysis was done in ArcGIS to determine the closest weather station to the centroid of each county in the LFRB; the simulation results of the nearest neighbor weather station were assigned to each county.

Tifton Sandy Loam (TSL) was the soil type chosen to be used for all sites, as it is the predominant soil in the study area. The model specifications are explained in further detail below for each crop. After all the inputs were entered into DSSAT's FileX model building system, the simulation ran and produced output summaries for the growing season. Irrigation amounts (mm/ha) and harvested yield (kg/ha) were the outputs of interest.

Seven automatic irrigation strategies were specified for each crop and planting date. DSSAT was set up to automatically irrigate the top 30 cm of soil any time the soil moisture drops below a certain threshold. The seven strategies were thresholds of 10%, 20%. 30%, 40%, 50%, 60%, and 70%. The agricultural water demand projections made in 2010, 2016, and 2020 to support state water planning were based on the conservative assumption that farmers use 70% soil moisture as a threshold for irrigation applications, i.e., when the soil moisture falls below 70%, they initiate an application. Comparing the DSSAT output across the different thresholds is a way to understand how different irrigation management strategies would affect water withdrawals.

The following information includes DSSAT input specifications modeled after the simulations done by Alhassan (2010) in his thesis, Valuing weather information in irrigated agriculture. The DSSAT planting dates used for corn are March 1, March 15, March 30, April 15, April 30, May 15, and May 30. The planting method includes the PIO31G98 corn cultivar and dry seed in rows with a plant population of 7.2/m^2. Row spacing is 61 cm while planting depth is at 7 cm. Fertilizer was first applied in two doses and was broadcast incorporated at a depth of 5 cm. The first application was at the start of the planting in a dose of 70 kg/ha Urea and a second dose one month later of 90 kg/ha. Table 1 show the model specifications in DSSAT for corn.

The DSSAT set up for cotton includes the DP 555 BG/RR cultivar and had five planting dates from April to May. The planting dates were April 1, April 15, April 30, May 15, and May 30. Ammonium Nitrate fertilizer was applied in three doses of 20 kg/ha for cotton with the same broadcast incorporated application method at a depth of 5 cm starting at the planting date. The planting method is dry seed in rows with a spacing of 90 cm and a depth of 4 cm. Plant population for this simulation of cotton is 14 plants/m^2. Once again, the specifications will be shown in table 2 below.

Peanut management in DSSAT includes the planting dates of April 10, April 20, April 30, May 10, and May 20. The peanut cultivar used was Georgia Green with a planting method of dry seed and rows with a spacing of 31 cm with a depth of 4 cm. The plant population used was 12.9/m^2. Fertilizer was applied in one dose on the planting date with 11 kg/ha of Diammonium phosphate. Peanut specifications are displayed in table 3.

Soybean management used five planting dates from May to June with the cultivar M Group 7. The planting dates were May 10, May 20, May 30, June 10, and June 20. The planting population was 20/m^2. Planting method used dry seed and rows spaced 60 cm and a depth of 3 cm. A single dose of fertilizer was applied at planting with 15 kg/ha of ammonium phosphate. The DSSAT model inputs are listed in table 4.

Table 1: Simulated Crop Management Data for Corn Production

Planting date	Corn Cultivar	Soil Moisture Threshold for Irrigation	Fertilizer Application		Soil type	Planting Method	Planting Distribution	Row Spacing (cm)	Planting Depth (cm)	Plant population / m^2
			Type	Amount /Time						
03/01	PIO31G98	10%, 20%, 30%, 40%, 50%, 60%, 70%	Urea	70kg/ha on 03/01 90kg/ha on 03/30	TLS	Dry seed	Row	61	7	7.2
03/15	PIO31G98	10%, 20%, 30%, 40%, 50%, 60%, 70%	Urea	70kg/ha on 03/15 90kg/ha on 04/15	TLS	Dry seed	Row	61	7	7.2
03/30	PIO31G98	10%, 20%, 30%, 40%, 50%, 60%, 70%	Urea	70kg/ha on 03/30 90kg/ha on 04/30	TLS	Dry seed	Row	61	7	7.2
04/15	PIO31G98	10%, 20%, 30%, 40%, 50%, 60%, 70%	Urea	70kg/ha on 04/15 90kg/ha on 05/15	TLS	Dry seed	Row	61	7	7.2
04/30	PIO31G98	10%, 20%, 30%, 40%, 50%, 60%, 70%	Urea	70kg/ha on 04/30 90kg/ha on 05/30	TLS	Dry seed	Row	61	7	7.2
05/15	PIO31G98	10%, 20%, 30%, 40%, 50%, 60%, 70%	Urea	70kg/ha on 05/15 90kg/ha on 06/15	TLS	Dry seed	Row	61	7	7.2
05/30	PIO31G98	10%, 20%, 30%, 40%, 50%, 60%, 70%	Urea	70kg/ha on 05/30 90kg/ha on 06/30	TLS	Dry seed	Row	61	7	7.2

Table 2: Simulated Crop Management Data for Cotton Production

Planting date	Cotton Cultivar	Soil Moisture Threshold for Irrigation	Fertilizer Application		Soil type	Planting Method	Planting Distribution	Row Spacing (cm)	Planting Depth (cm)	Plant population / m2
			Type	Amount /Time						
04/01	DP 555	10%, 20%, 30%, 40%, 50%, 60%, 70%	Ammonium Nitrate	20kg/ha on 04/01 20kg/ha on 04/24 20kg/ha on 05/24	TLS	Dry seed	Row	90	4	14
04/15	DP 555	10%, 20%, 30%, 40%, 50%, 60%, 70%	Ammonium Nitrate	20kg/ha on 04/15 20kg/ha on 05/06 20kg/ha on 06/06	TLS	Dry seed	Row	90	4	14
04/30	DP 555	10%, 20%, 30%, 40%, 50%, 60%, 70%	Ammonium Nitrate	20kg/ha on 04/30 20kg/ha on 05/21 20kg/ha on 06/21	TLS	Dry seed	Row	90	4	14
05/15	DP 555	10%, 20%, 30%, 40%, 50%, 60%, 70%	Ammonium Nitrate	20kg/ha on 05/15 20kg/ha on 06/05 20kg/ha on 07/05	TLS	Dry seed	Row	90	4	14
05/30	DP 555	10%, 20%, 30%, 40%, 50%, 60%, 70%	Ammonium Nitrate	20kg/ha on 05/30 20kg/ha on 06/21 20kg/ha on 07/21	TLS	Dry seed	Row	90	4	14

Table 3: Simulated Crop Management Data for Peanut Production

Planting date	Peanut cultivar	Soil Moisture Threshold for Irrigation	Fertilizer Application		Soil type	Planting Method	Planting Distribution	Row Spacing (cm)	Planting Depth (cm)	Plant population / m^2
			Type	Amount /Time						
04/10	Georgia green	10%, 20%, 30%, 40%, 50%, 60%, 70%	Diammonium phosphate	11kg/ha on 04/10	TLS	Dry seed	Row	31	4	12.9
04/20	Georgia green	10%, 20%, 30%, 40%, 50%, 60%, 70%	Diammonium phosphate	11kg/ha on 04/20	TLS	Dry seed	Row	31	4	12.9
04/30	Georgia green	10%, 20%, 30%, 40%, 50%, 60%, 70%	Diammonium phosphate	11kg/ha on 04/30	TLS	Dry seed	Row	31	4	12.9
05/10	Georgia green	10%, 20%, 30%, 40%, 50%, 60%, 70%	Diammonium phosphate	11kg/ha on 05/10	TLS	Dry seed	Row	31	4	12.9
05/20	Georgia green	10%, 20%, 30%, 40%, 50%, 60%, 70%	Diammonium phosphate	11kg/ha on 05/20	TLS	Dry seed	Row	31	4	12.9

Table 4: Simulated Crop Management Data for Soybean Production

Planting date	Soybeans Cultivar	Soil Moisture Threshold for Irrigation	Fertilizer Application		Soil type	Planting Method	Planting Distribution	Row Spacing (cm)	Planting Depth (cm)	Plant population / m^2
			Type	Amount /Time						
05/10	MG VII	10%, 20%, 30%, 40%, 50%, 60%, 70%	Ammonium Phosphate	15kg/ha on 05/10	TLS	Dry seed	Row	60	3	20
05/20	MG VII	10%, 20%, 30%, 40%, 50%, 60%, 70%	Ammonium Phosphate	15kg/ha on 05/20	TLS	Dry seed	Row	60	3	20
05/30	MG VII	10%, 20%, 30%, 40%, 50%, 60%, 70%	Ammonium Phosphate	15kg/ha on 06/30	TLS	Dry seed	Row	60	3	20
06/10	MG VII	10%, 20%, 30%, 40%, 50%, 60%, 70%	Ammonium Phosphate	15kg/ha on 06/10	TLS	Dry seed	Row	60	3	20
06/20	MG VII	10%, 20%, 30%, 40%, 50%, 60%, 70%	Ammonium Phosphate	15kg/ha on 06/20	TLS	Dry seed	Row	60	3	20

As previously mentioned, the DSSAT models ran for five years to simulate crop growing seasons from 2016 to 2020. There were four crop models that ran for each of the 14 weather station sites with seven different irrigation system strategies from 10% to 70%. The simulation runs were then replicated 10 times to produce an average for the final output. The summary output included irrigation applications recorded in mm/ha as well as harvested yield at the plant's maturity in kg. Cotton, peanuts, and soybeans, each had a total of 14 weather stations, 5 years modeled, with 7 irrigation strategies, and 5 planting dates for 2,450 simulations each. Corn had the same number of simulations except the model used 7 planting dates to give a total of 3,430 total simulations.

The yield from each simulation was multiplied by crop prices received by farmers to calculate the total revenue for each simulation. The crop prices, as previously stated were historical prices received by farmers annually, for each focus crop. These were obtained and compiled in excel using the data from USDA/NASS QuickStats Database and FAPRI-MU. All prices were converted to dollars per kilogram ($/kg) to be multiplied by the DSSAT harvested yield, which was in units of kilograms per hectare (kg/ha).

Georgia surface water rights are considered regulated riparian rights, while groundwater rights are considered correlative. Riparian water rights allow surface water to be used by those who own land along the water's edge – owning riparian land bestows this right. Regulated riparian rights require riparian landowners to secure a permit for their water withdrawals. Such a permit is required in Georgia for riparian landowners who have the capacity to withdraw more than 100,000 gallons per day for agricultural purposes. Similar to riparian rights, correlative rights give owners of land associated with groundwater a common right to reasonable use of the aquifer below their property. As with surface water, Georgia requires correlative landowners who withdraw more than 100,000 gallons per day for agricultural purposes to obtain a permit for those withdrawals. While these surface and groundwater withdrawals require permits, there is not a volumetric charge or volumetric limit assessed for withdrawals. The only volume-based cost to the farmer for their irrigation water is the cost to move it from the source to the field, i.e., the pumping costs.

In this paper, pumping costs of irrigation will serve as a proxy for water price, as suggested by the literature (Mullen et al., 2009). Pumping costs can be estimated by multiplying (1) the electricity rate for ag producers in GA ($/kWh); (2) the pumping fuel use required for lifting one acre-foot of water, one foot in height (kWh/acre-foot/foot); (3) the water use output from DSSAT (acre-feet); and (4) the distance of average well depth (feet) for each county in the study area. The electricity rate was obtained from GA Power's agricultural rates for farm service. The summer service rates were used because it aligns with the focus crop's growing season. Two energy charges were used to calculate an 'on-peak' and 'off-peak' pumping cost. These are 17.6052¢ per kWh and 5.7125¢ per kWh for the on- and off-peak rates, respectively (Georgia Power, 2021). A pumping fuel use of 1.551 kWh/ac-ft/ft was used to represent lifting one acre-foot of water, one foot in height (Rogers and Alam, 1999). Lastly, the distance of average well depth in feet was obtained from each county using groundwater in the Flint River basin. Average well depth was used, but in cases where it was unavailable, the singe well depth value was used. Most of the counties withdrew from the Floridan Aquifer, but a few did not provide the Floridan well depth so Clayton, Caliborne, or Providence sand well depth was used instead. These factors were all multiplied along with the irrigation amounts from DSSAT for each crop simulation model and resulted in the pumping cost of each irrigation strategy.

One of the objectives of the DSSAT analysis is to identify the irrigation strategy that maximizes net returns for each crop in each county in each year. Assuming the only difference across irrigation strategies in production costs, for a given crop in a given county in a year, are the pumping costs, then the strategy with the largest total revenue-pumping cost differential is also the most profitable strategy.

Lastly, descriptive statistics were performed in excel for each crop from the DSSAT data. The mean, variance, standard deviation, and 95% confidence intervals were calculated for each year (2016-2020) and irrigation strategy (10%-70%). Along with this, a two-way Anova with replication was also performed in excel to test the null hypothesis that there is no difference in means between the irrigation rates for each strategy and year. A two-way Anova uses two independent variables, in this case the irrigation strategy and year. The dependent variable is the irrigation rate from DSSAT. The ‘with replication’ means there is more than one observation for each combination of independent variables. The results produce a source of variation table. There are three different sources of variation that are tested for, including sample (year), columns (irrigation strategy), and interaction (the interactions between irrigation strategy and year). This table displays the p-value, which if less than the significance level of 0.05, are statistically significant and can reject the null hypothesis since there are substantial differences between the means. Another method uses the F-values in the source of variation table to determine if the null hypothesis can be rejected; the means are not all equal if the F-value is greater than the F-crit value. The Anova test cannot indicate where differences lie within the data though and analyzing the means can give some insight in this case.

Then, to determine if there is a locational component to the DSSAT irrigation demand, a one-way Anova was performed using the mean irrigation rate from a single irrigation strategy for each weather station across all years. Only one independent variable was used in this single-factor test and in this case were the 14 different weather sites. This was also done for each crop and tested the null hypothesis that the mean irrigation rate for a specific irrigation strategy is the same across each weather station.

Chapter 4: Findings and Results

4.1 Evolution of Irrigated Acres

In analyzing the past 12 years, CropScape shows Georgia having an overall increase in irrigated lands, especially in the Lower Flint River basin. All the representations of the LFRB are seen to mimic the trends statewide. This shows how the study area is shaping agricultural trends in southern GA as the main driving force behind crop production and irrigation use. The ArcGIS and CropScape geospatial layers for all sets of maps are shown in entirety in Appendix A. The maps show the relationship between aggregated county-level irrigated acres for each year and crop.

Figures 2 - 4 show how irrigated acres have trended over time from 2008 to 2020 using the wetted lands layer for the total acreage of all irrigated crops and the big four layer for the total per individual focus crop. All wetted lands in GA increased by nearly 460,000 acres statewide during the past 12 years. When looking at the LFRB specifically, acreage increased by around 161,000 irrigated acres. The highest concentration of wetted lands were counties in the southwestern corner of GA. Northern GA as well as the southeastern coastline were sparce in irrigated acreage. Cotton claimed the largest share of the big four irrigated acres in the state followed by peanuts, then corn and soybeans in order. While all corn, cotton, and peanut acres were seen to increase over the 12 years, soybean irrigated acres actually declined. This same trend is seen for the LFRB region. Cotton increased by an estimated 264,400 irrigated acres statewide and around 94,100 acres just in the LFRB region. Peanuts and Corn gained

210,700 and 143,600 acres respectively for the whole state, and 83,900 and 75,000 acres likewise for the study area. On the other hand, soybeans lost around 122,400 irrigated acres in GA and around 55,400 acres for the LFRB.

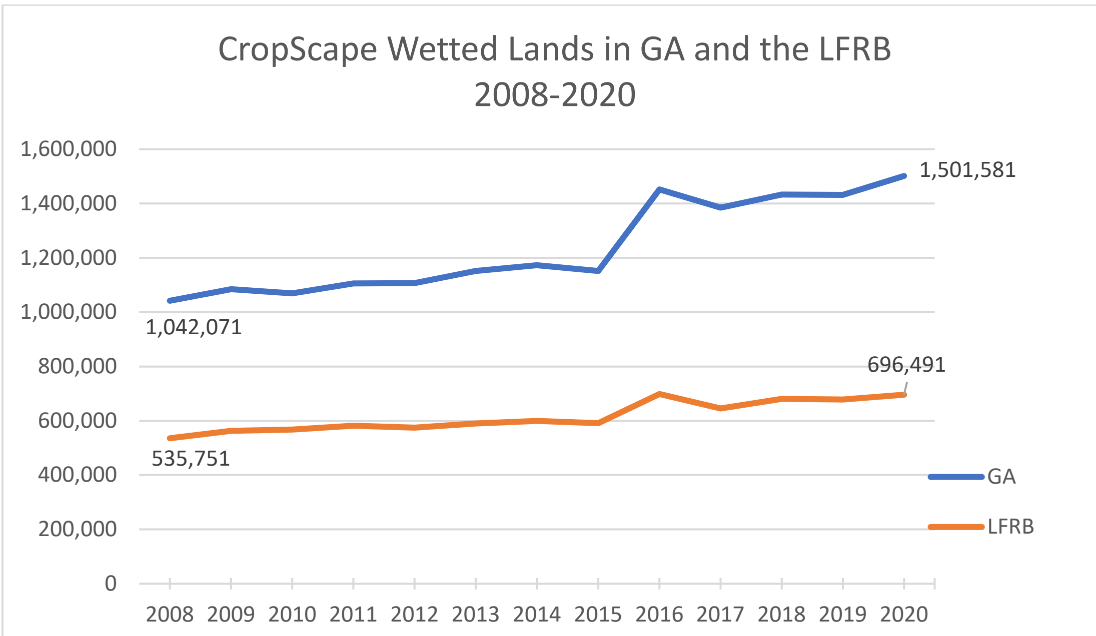

Figure 2: Wetted Lands in GA and the LFRB per year

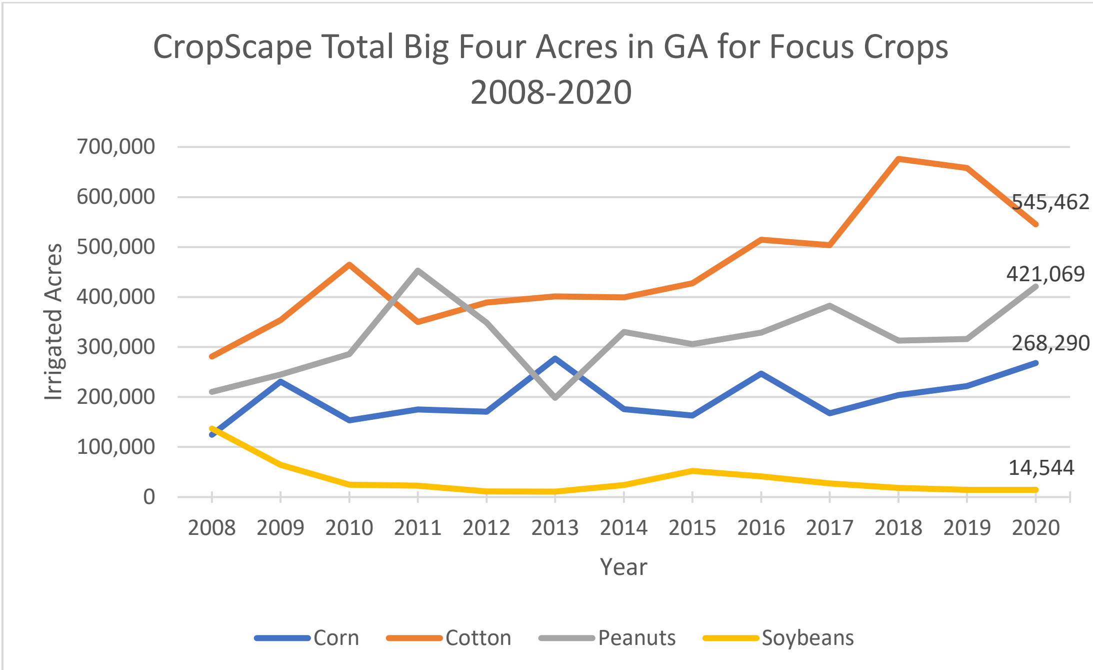

Figure 3: Big four acres in GA per year

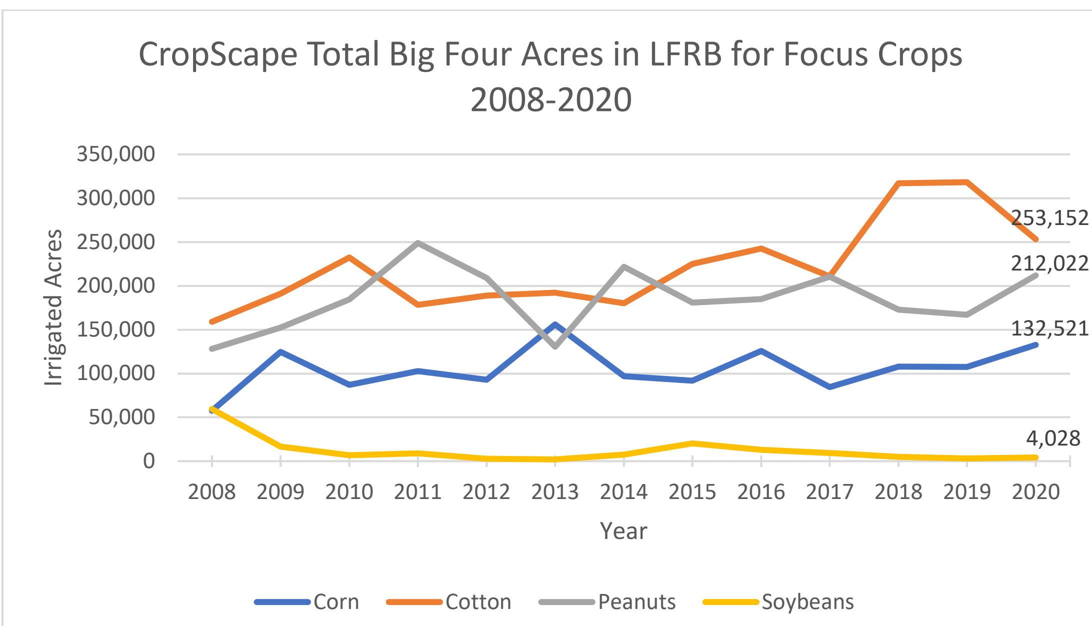

Figure 4: Big four acres in the LFRB region per year

For single-crop fields, the trends over the past 12 years are shown below in figures 5-7. The total amount of single four acres increased substantially by around 402,000 acres. Likewise, in the LFRB irrigated single four acres increased nearly 200,000. This implies that nearly half the state's total of single-crop fields occur within the 16 counties composing the LFRB region. The same trends from wetted lands and the big four above are seen in the relationship with the single four acres as well. Cotton shows the largest proportion of single four acres, followed by peanuts, corn, and soybeans in order. Soybeans are also seen to fall in irrigated acres. Cotton gained a total of around 201,000 irrigated acres in single-crop fields for the state and around 93,100 acres for the LFRB. Peanuts had an increase of around 127,800 and 66,800 irrigated acres for the state and LFRB region respectively. Corn increased by 103,200 acres in GA and 54,500 acres in the study area. Soybeans decreased by 30,200 and 15,500 irrigated acres in the state and then the LFRB.

With such a considerable development in single four acres, this suggests there has been an expansion of monoculture farming in GA. Monoculture is the practice of growing only one crop type on the majority of a farm. This can have negative impact on soil health, pest and disease resistance, and biodiversity (Shand, 1997). With genetic uniformity, future risk increases from the aforementioned impacts to a crop's health and leaves possibilities for economic loss and degradation to biodiversity from long-term monocropping.

While there are less single four fields than the big four in GA, similar systematic differences between the regions in the state can be concluded. The LFRB includes the highest contrast to the rest of the state in number of irrigated acres, while very little acreage is occurring in northern GA. Wetted lands seem to coincide with GA's Fall Line, signifying the Coastal Plain region of high crop productivity. In figures 8-11 below, the historical crop prices were graphed from 2008-2020 for each focus crop. The trends in irrigated acres for the focus crops can somewhat be explained by the prices received by farmers for the crop grown. All crop prices showed a spike around 2011 which can also be seen in the total irrigated acres for all crops. The prices fell shortly after 2011 remaining fairly steady until increasing in recent years. Although prices have been only slightly increasing, they do not explain the large jump in irrigated acres seen in cotton since 2017. Another explanation for some of the jumps in the graphs come from the use of a new shapefile. Since the three original shapefiles used for mapping in ArcGIS are from 2010, 2016, and 2021, once a new year is used as a baseline for irrigated acres, it corresponds to a jump in acreage for each of those years.

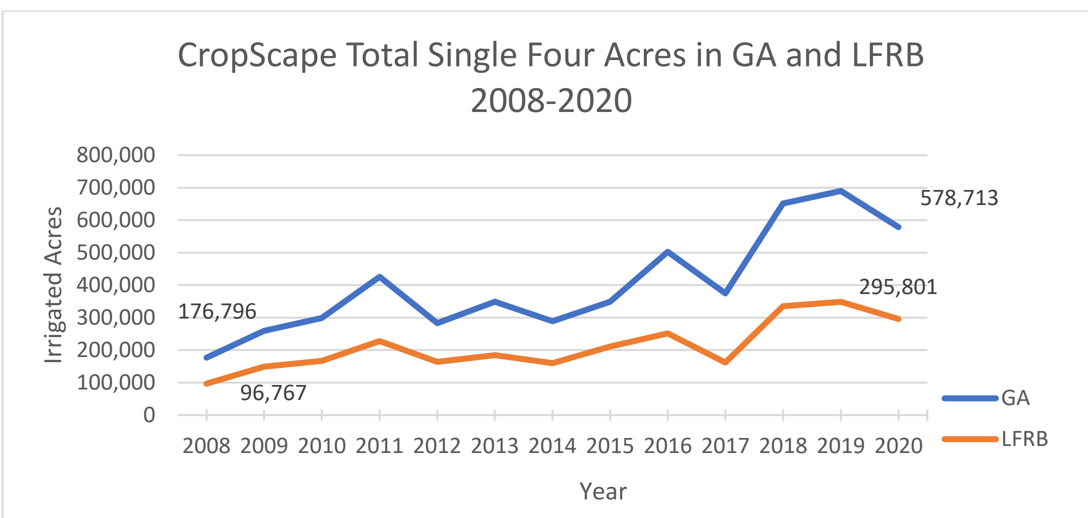

Figure 5: Single four acres in GA and the LFRB per year

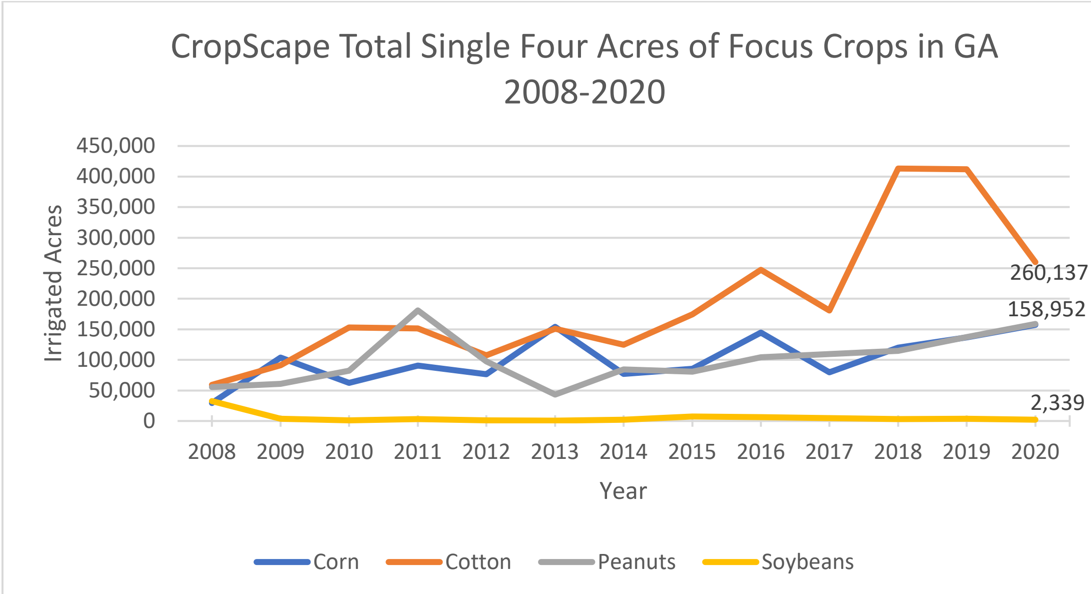

Figure 6: Single four acres in GA per year

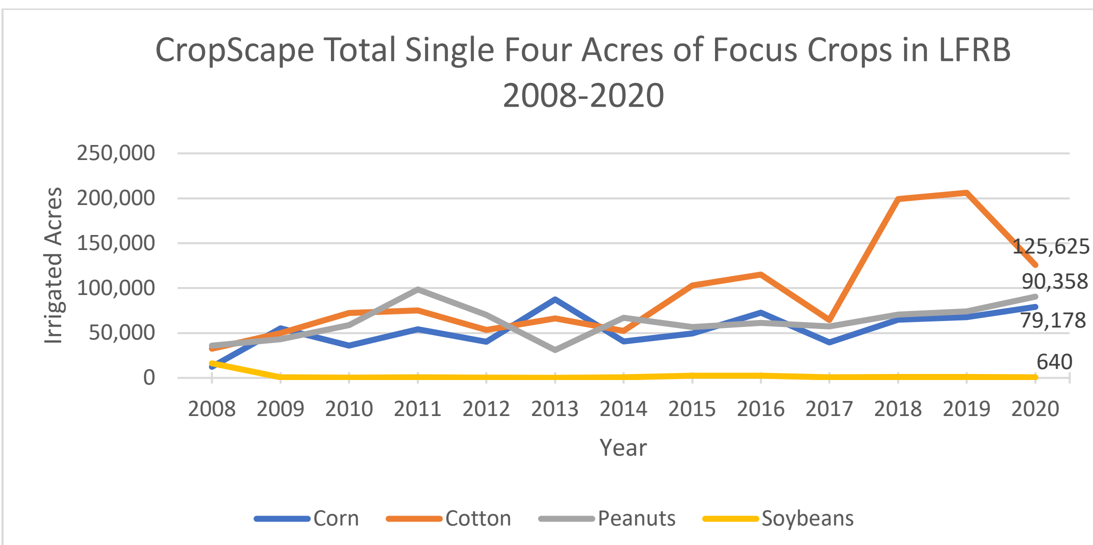

Figure 7: Single four acres in the LFRB region per year

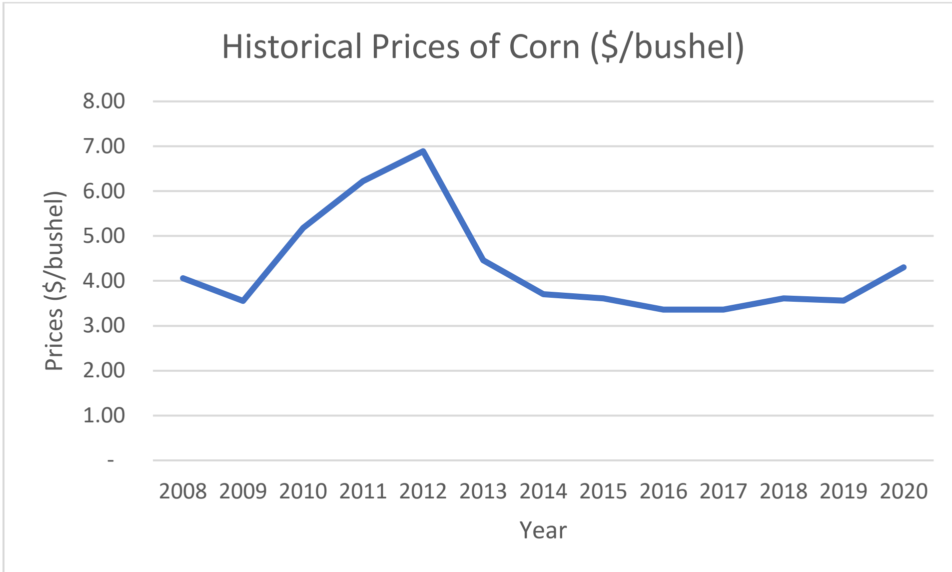

Figure 8: Historical farm-level prices received for corn

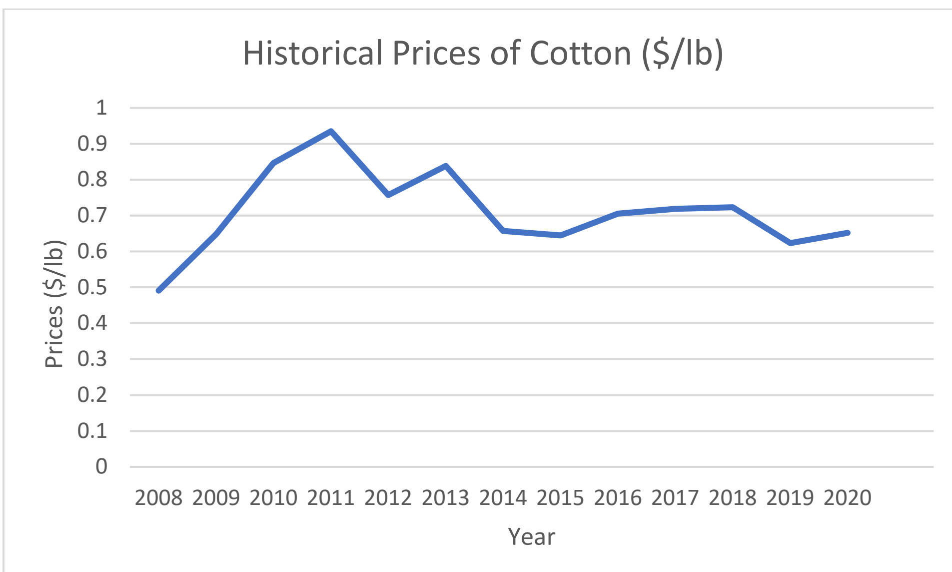

Figure 9: Historical farm-level prices received for cotton

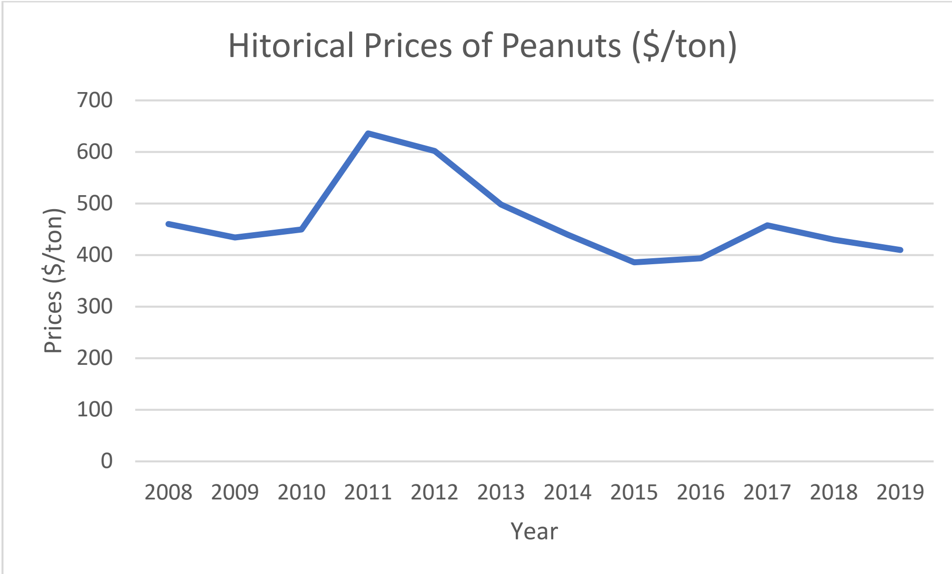

Figure 10: Historical farm-level prices received for peanuts

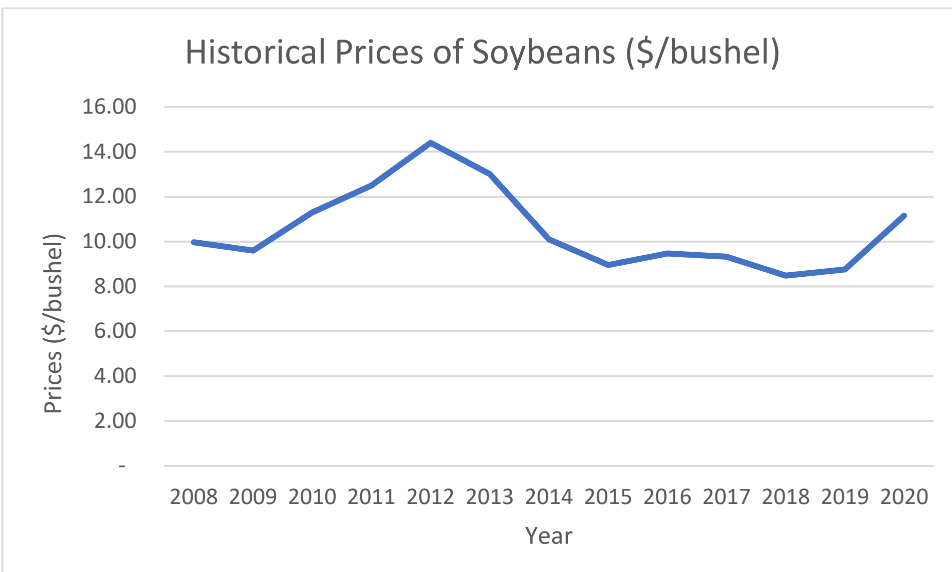

Figure 11: Historical farm-level prices received for soybeans

4.2 Projected Irrigated Acres for 2020

The CropScape and ArcGIS geospatial maps produced for the projected irrigated acreage in 2020 using 2009 and 2015 baseline acreage are presented in Appendix B for each focus crop. Figure 12 shows the acreage differences between the projections and CropScape's wetted lands and big four acres, while table 6 shows the percent differences. It is evident that differences are very small except in soybeans, where the projections exceed CropScape's acres. Generally, the 2015 projections show a slightly higher acreage for 2020 than the 2009 projection. In peanuts, the CropScape acres were greater than both projections. These results suggest that projections made for future decades should be able to accurately predict irrigated lands, especially in the statewide total and for cotton.

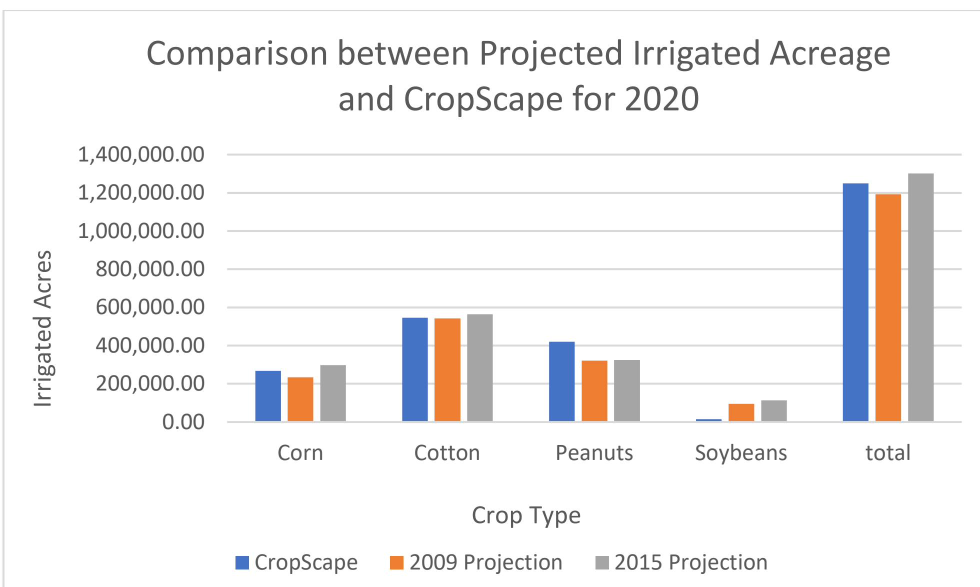

Figure 12: Irrigated acreage differences between the projections and CropScape's wetted lands and big four acres in 2020

Table 5: Percent differences between the 2009 and 2015 Projections for 2020 Irrigated Acres and CropScape (CS) 2020 Big Four Acres

Percent Differences between Projections and CropScape

Crop Type	2009 Projection & CS	2015 Projection & CS
Corn	-12.87	11.22
Cotton	-0.60	3.44
Peanuts	-23.63	-22.77
Soybeans	551.17	678.06
Total	-4.57	4.13

4.3 Evolution of Statewide Field Polygons

It is important to not only sense changes in the amount of estimated irrigated acres in GA, but also to analyze the total acreage of the field polygon shapefiles to grasp how potential lands are changing over time. These two maps are shown below in figure 13 and 14. The blue coloring indicates on the maps where irrigated acres are expanding, i.e., the percent change in acreage is increasing from one year to the next shapefile year. Likewise, the red coloring indicates where the potential irrigated acres a contracting, i.e., the percent change in acreage is decreasing from one shapefile year to the next.

From 2010 to 2016, contraction mostly occurred from 5-15% in the southwest corner of GA and a few counties in northern GA. The expansion of potential lands happened in northern GA and along the eastern coastline, especially in Floyd and Richmond County. This percent change is nearly 1000% for both counties. Although this is a considerable percent difference, the actual irrigated acreage in these northern counties is quite small. Generally, northern GA observed the most expansion compared to the other regions, most likely due to the south already being heavily developed agriculture. Another consideration affecting the lack of greater expansion in the south stems from the moratorium issued by the EPD on new permits for irrigation wells withdrawing from the Floridan aquifer in the Lower Flint River Basin. This was instated in 2012 to allow the EPD to study the impact of continued withdrawals in southwest GA on water resources and the possible consequences to existing users. Given these reasonings, the LFRB only sees an average of 4.67 percent difference from 2010 to 2016. The entire state on the other hand sees an average of 72.45 percent difference between the two shapefile years.

The comparison between 2016 to 2021 show much more subtle contracting and expanding differences in potential lands. The most significant expansion in lands was in Fulton and Banks County in northern GA by around a 100 and 560 percent change respectively. Less than 1 percent differences occurred mostly in northern GA, with one county, DeKalb, losing 43.8%. The entire state received an average percent difference of 13.63 between 2016 and 2021, a stark difference from the change seen from 2010 to 2016. The LFRB saw an average percent difference of 3.15, also smaller than the 2010-2016 trend.

Overall, it is noticeable that the state of GA has been growing in potential lands since 2010 and does not seem to be reducing any large amount of acreage under irrigation. The most rapid expansion of potential lands occurred during the six years after 2010. On the other hand, since 2016 there has only been a slight increase in irrigated acres uniformly across the whole state. This could be due to the quality of the 2010 versus the 2016 shapefile of potential lands. Looking at the huge jump in statewide acreage between the two shapefile years challenges the accuracy of the CropScape polygon data, but when assessing the relative stability in potential lands from 2016 to 2020 provides more assurance in the 2016 shapefile's data. This could be due to improved identification techniques in the satellite imagery for field polygons and GIS work since 2010.

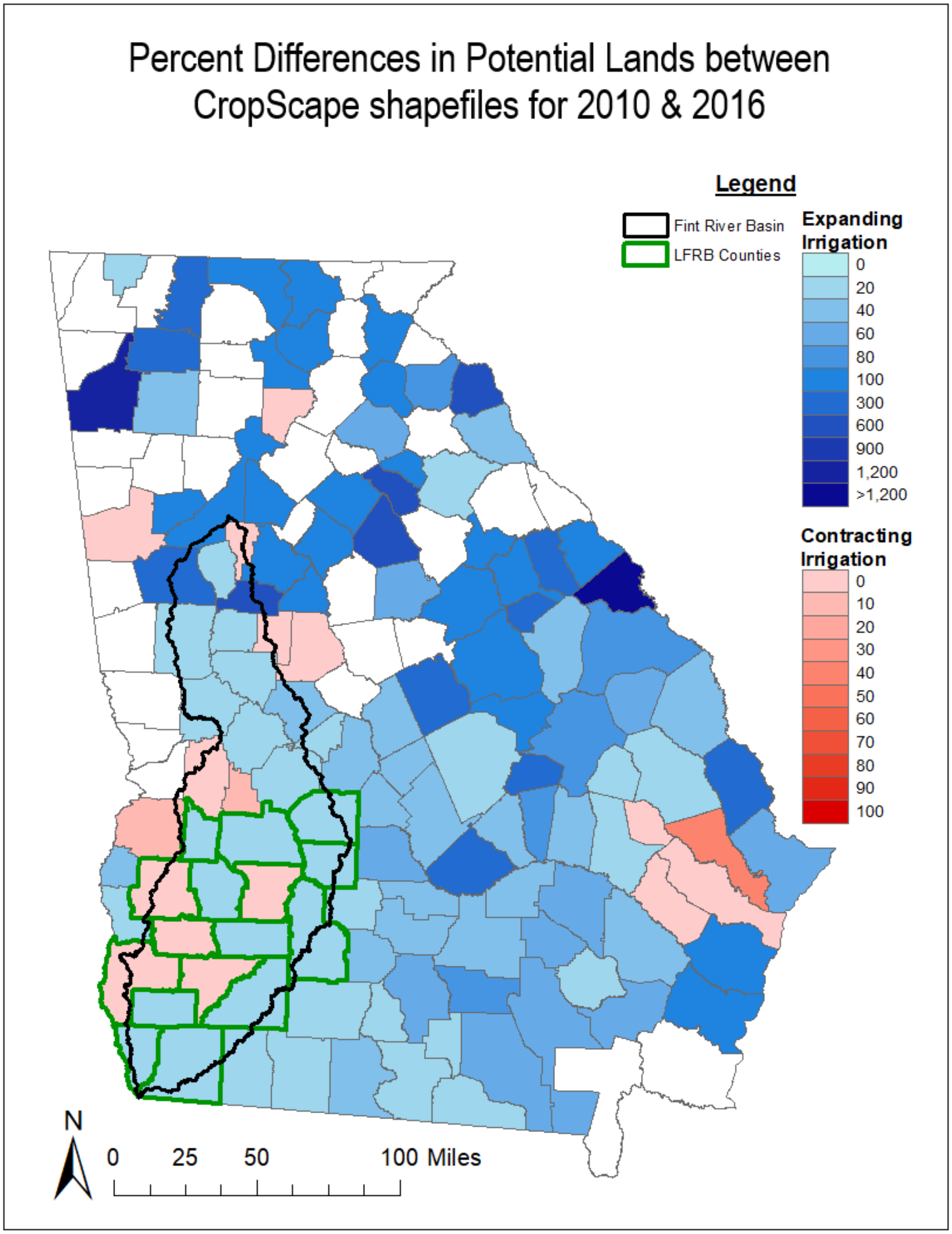

Figure 13: Percent difference map of GA showing the expanding and contracting potential lands from the 2010 and 2016 shapefiles

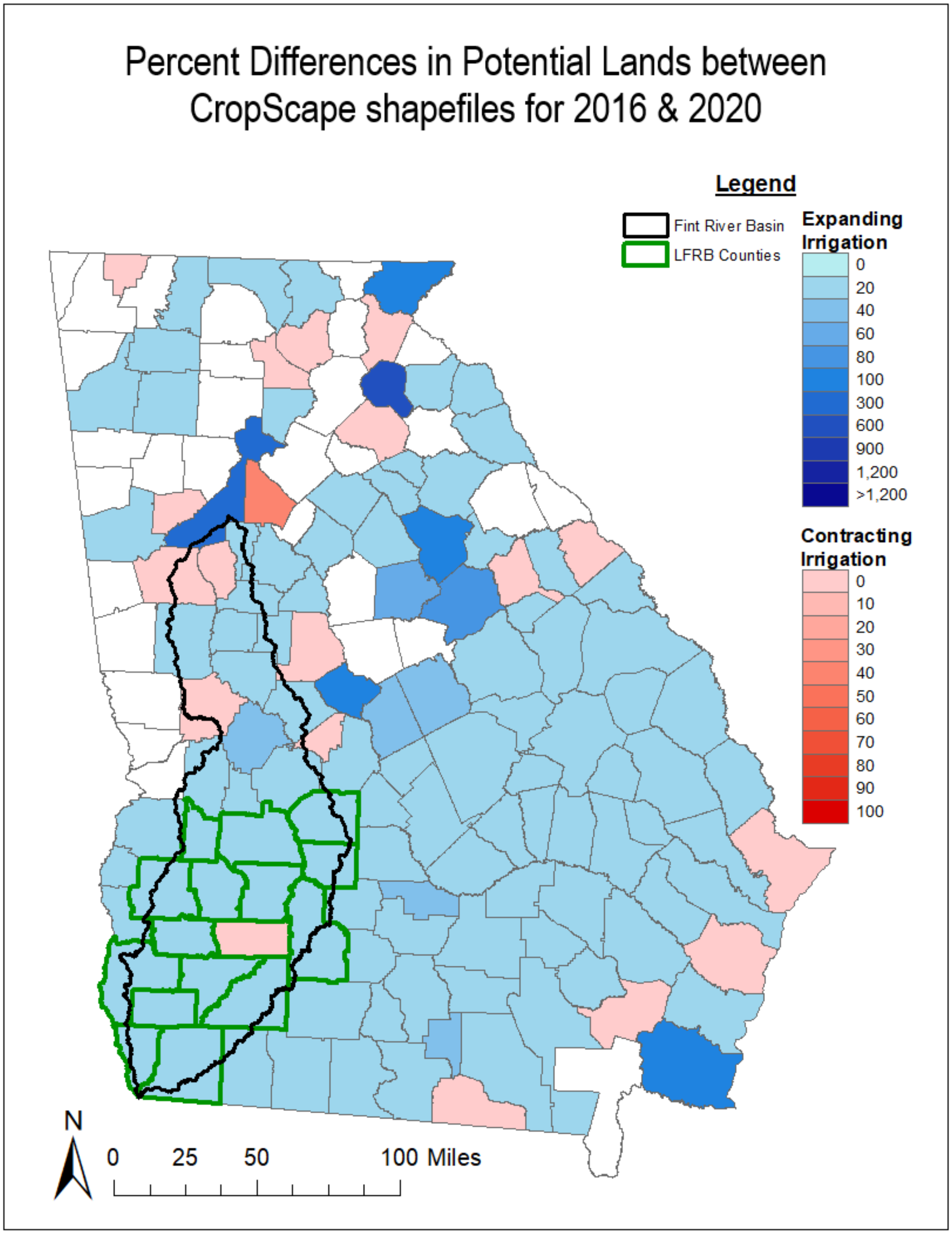

Figure 14: Percent difference map of GA showing the expanding and contracting potential lands from the 2016 and 2021 shapefiles

4.4 USDA Census and CropScape Differences

Figures 15 and 16 show the percent difference in actual land under irrigation between the CropScape wetted lands, irrigated field polygons and the USDA 2017 Census of Agriculture reported data from farmers. This comparison ultimately analyzes the reliability of the Census data to represent the amount of lands under irrigation for a given year and crop as opposed to the geospatial satellite imagery from CropScape and irrigation polygon fields. Shades of red therefore represent counties where the USDA Census acreage estimates are lower than CropScape, while blue depicts the Census acreage estimates are higher.

For 2012, it is evident that nearly all the northern counties show the Census having higher reported irrigation acreage, most often by a 100% or greater difference between the CropScape Shapefile and the USDA Census. When the Census has a 100% difference between CropScape, this indicates CropScape has zero irrigated acres mapped for that county and year. Reversely, if there is a 100% difference from USDA having less acreage than CropScape, it means the Census has reported zero acres for that county in that year. Southwestern counties display trends of contracting irrigated acres where the Census has less acreage by an average 13.98% in 2012 within the LFRB region. Along the southeastern coast, a few counties have higher reported acres by 100%. The overall average in GA shows the USDA has higher irrigated acreage than CropScape by 300%.

When comparing the year 2017, the same trends follow, except for a few key differences. The first being that 2017 has a greater number of counties with lower irrigated acres by the Census expanding into northern regions from mid Georgia. Counties with lower Census acreage now make up the majority of the coastal plains, implying the USDA has less reported irrigated acres than CropScape in recent years in the most agriculturally productive region. Also, the higher reporting counties along the coastline have increased substantially by their percent differences. The LFRB counties are now showing the Census estimates are lower by 5.71%. The overall average for GA has increased from the higher Census estimates by 300% in 2012 to a striking 1,130% in 2017.

Appendix C shows the other maps produced and represent the percent difference of irrigated land from CropScape's big four layers and the Census, by county and specific focus crop in Georgia. The trends in these maps consistently express that USDA Census estimates are lower in their irrigated acres (especially in the south) in comparison to the CropScape geospatial layer across both Census years and all focus crops. Census acreage estimates are substantially less in soybeans out of the other focus crops, with 56 counties in 2012 receiving a lower estimate, and 84 counties in 2017: most often a value of 100%. Corn has the greatest value of higher irrigated acres from the USDA, especially in 2012 with 47 counties total and then 27 counties in 2017.

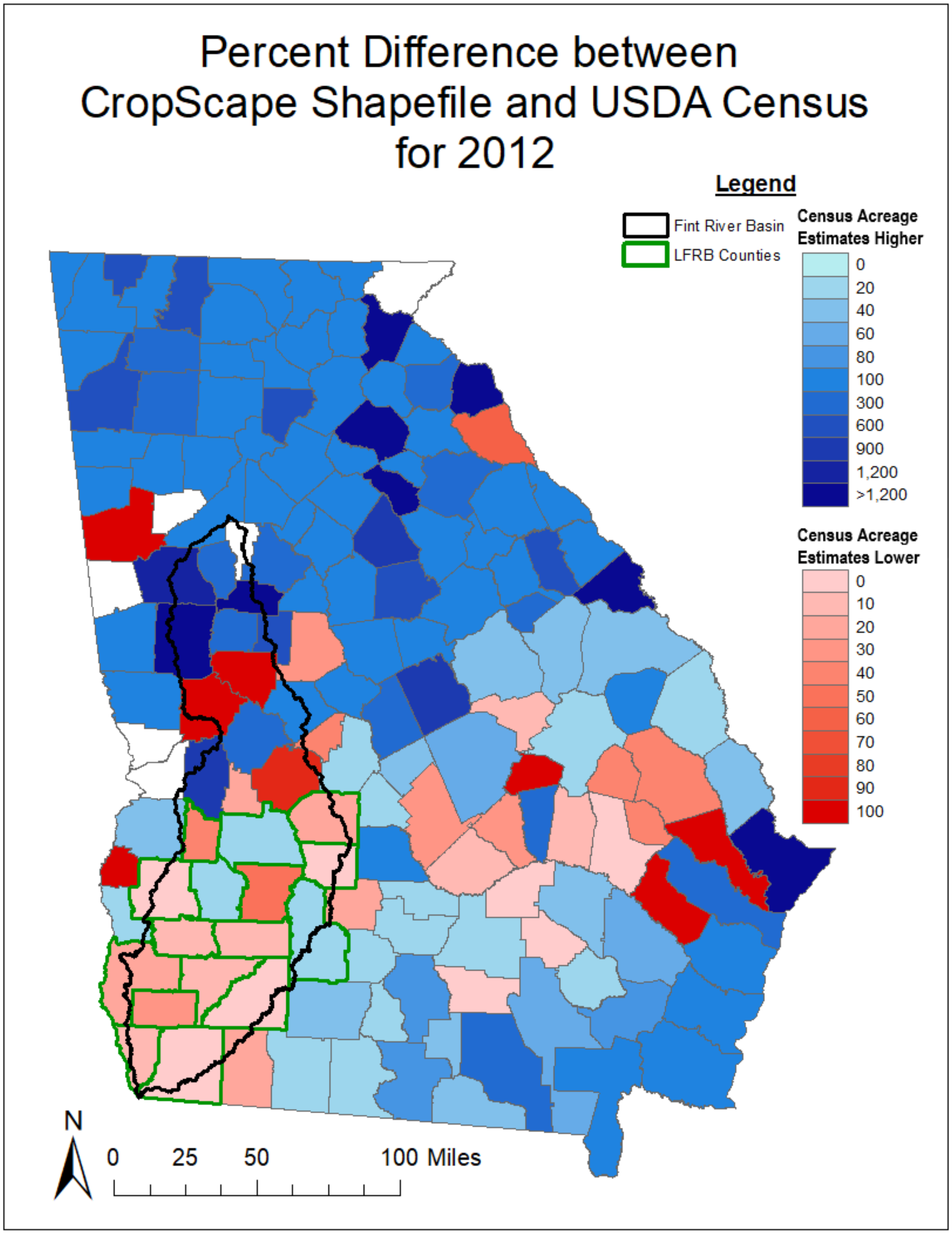

Figure 15: Percent difference between the CropScape Big Four Acres and the USDA Census reported Irrigated Acres in 2012

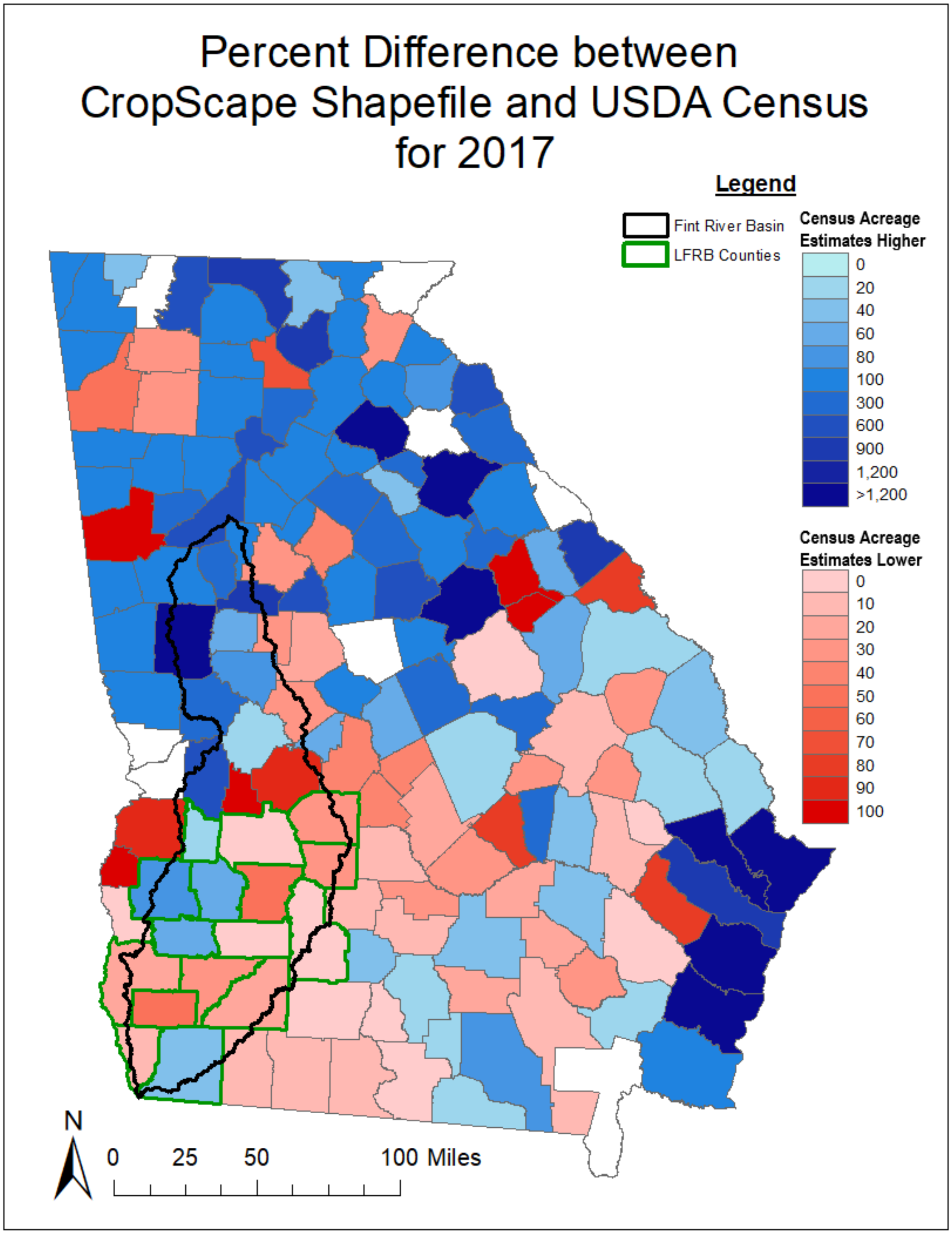

Figure 16: Percent difference between the CropScape Big Four Acres and the USDA Census reported Irrigated Acres in 2017

4.5 DSSAT Irrigation Strategies and Profit Maximization

The profit margin of total revenue over pumping costs was determined from the DSSAT irrigation strategies. The results are shown Appendix D for each focus crop and for on- and off-peak energy costs.

For both energy costs and all crop types, the results are consistent with an irrigation system using a 70% soil moisture threshold as the profit maximizing strategy. Because yields were higher with the increase in irrigation usage, profits were also greater considering the low pumping cost. A low pumping cost suggests that irrigation is not a main concern when considering crop management decisions during a growing season in GA. The data from DSSAT and calculations for profit indicate the simulated models earn more net revenues the more water is withdrawn for irrigation.

4.6 Locational Components to the DSSAT Data

The next step involved determining if there was a locational component to the DSSAT data. The one-way Anova tested the null hypothesis that all the means for irrigation rates across the 14 different weather sites from DSSAT were equal. The tables for the Anova results are presented in Appendix E by each crop and irrigation strategy (data includes years 2016-2020). Both cotton and peanuts reject the null hypothesis at every irrigation strategy, meaning the average irrigation rate used is statistically different between each weather site. Corn cannot reject the null hypothesis for the 10%, 20%, 30%, 40%, 60%, and 70% irrigation strategy, but can for the 50%. Not being able to reject the null hypothesis signifies that the average irrigation rates are not statistically different between the weather sites. Soybeans can reject the null for every irrigation strategy except for the

10% level. These results convey there generally is a locational component to the irrigation rates, but this test cannot say where the difference lies.

4.7 Descriptive Statistics and Anova

One way to compare the DSSAT data involved the calculation of descriptive statistics for the DSSAT irrigation strategies by year and crop. The mean irrigation rate for the different strategies were analyzed to determine if it falls within the 95% confidence intervals produced from the DSSAT descriptive statistics. Also, if the confidence intervals between the strategies and years lie outside of each other, the irrigation strategies are statistically significant. The descriptive statistics for each focus crop are located in Appendix F.

For peanuts, the irrigation strategies are statistically significant and different for every year (2016-2020), meaning the confidence intervals do not overlap, except for the 50% and 60% irrigation strategy in 2016. For cotton, the irrigation strategies are statistically significant except for the 50% and 60% strategy in 2016, 30% and 40% in 2017, 30% in 2018, and 50% in 2020. For corn, the irrigation strategies are statistically significant at every irrigation strategy and every year. For soybeans, the irrigation strategies are not statistically significant for the 50% and 60% irrigation strategy in 2016 and 2017, the 60% strategy in 2018 and 2019, and the 50% strategy in 2020.

The two-way Anova test results are presented in Appendix G by crop type. For peanuts, the variation for sample (years), columns (irrigation strategy), and the interaction between those two variables are all statistically significant at the 0.05 level. The means are all statistically different and can reject the null hypothesis that there is no difference in means between the irrigation strategies and years. The same can be said for corn, cotton, and soybeans. Overall, these results signify that there is interaction between the year and irrigation strategy on the mean irrigation rates in the DSSAT.

Chapter 5: Conclusion and Recommendations

5.1 Summary of Findings and Limitations

This thesis analyzed how GA's irrigated acres have evolved over the past 12 years and compared the CropScape acres to projected irrigated acres as well as USDA Census reported acres. DSSAT was also used to determine the profitability of irrigation strategies. The results from this paper can be used to better understand irrigated land and agricultural water demand in GA, especially in the LFRB.

The findings suggest that irrigated lands have been increasing since 2008, with cotton expanding the most, followed by peanuts and corn, while soybean acreage has been decreasing. This trend is seen in all of the big four and single four irrigated acres in both the LFRB region and statewide. Specifically, there was a greater increase in the amount of single-crop fields since 2008, implying a shift in GA's farming management towards monoculture practices. Farmers may be more focused on high yields and economic returns than biodiversity in their land, which is typically associated with monoculture. Projected irrigated acreages from 2009 and 2015 for 2020 are fairly similar to that of the CropScape, especially in the percent differences between cotton and the statewide total for all focus crops, meaning irrigation projections for GA can efficiently aid agricultural policy makers in decisions around future irrigated land and water needs. Also, the projected irrigated areas are a component of the calculation used in preparing forecasts of water demand by agricultural analysists. With confident projections of irrigated acreage, confident projections of water use can be calculated. This is important in determining future water consumption needs from the agricultural sector in GA for the regional planning councils to curate best water management practices.

The results from the USDA and CropScape comparison suggest that the CropScape geospatial layers may be a more reliable form of crop data and irrigation information when paired with the irrigated field polygons. The USDA Census of Agriculture is only available for every year ending with a 2 or 7, making the CropScape data more accessible and comprehensive, since NASS produces cropland data layers annually covering the continental U.S. The Census data also relies upon self-reports from farmers, while CropScape is based upon satellite imagery. The visual analysis of the shapefile fields for irrigated acres is likely to be more accurate than a limited survey of farmers. Although the CropScape data is abundant in crop data, only three years of polygon shapefile years were used in this study to represent the irrigated fields. Having a layer of field polygons for every year would lead to an even better understanding of changes annually.

5.2 Recommendations

Considering GA's expansive agricultural sector, the state faces a myriad of difficulties in policy planning for water withdrawals and demand in upcoming years. Specifically, the Flint River basin holds the most agricultural irrigation permits in the state and withdraws the most water for the purpose of irrigation. This agriculturally intensive region poses issues related to water quality and quantity for the future, establishing the need for accurate irrigation predictions to better understand trends at the farm, county, and watershed level. The findings in this paper can help support an understanding of the state and the LFRB's history of irrigated acreage and water demand for developing future water plans.

The current trends signify irrigated acres are still expanding in south GA and the USDA Census data imply the existence of possible gaps in self-reported irrigated acres. It is important for prediction in irrigated acreage and water demand to use reliable estimates, which this paper aims to provide. The CropScape and ArcGIS geospatial layers representing irrigated acres for focus crops in GA can provide more confident estimates for future work in irrigation predictions. Future research would benefit from expanding upon the findings in this thesis to include a larger study area enveloping the entire Flint River basin or even the Coastal Plains region.

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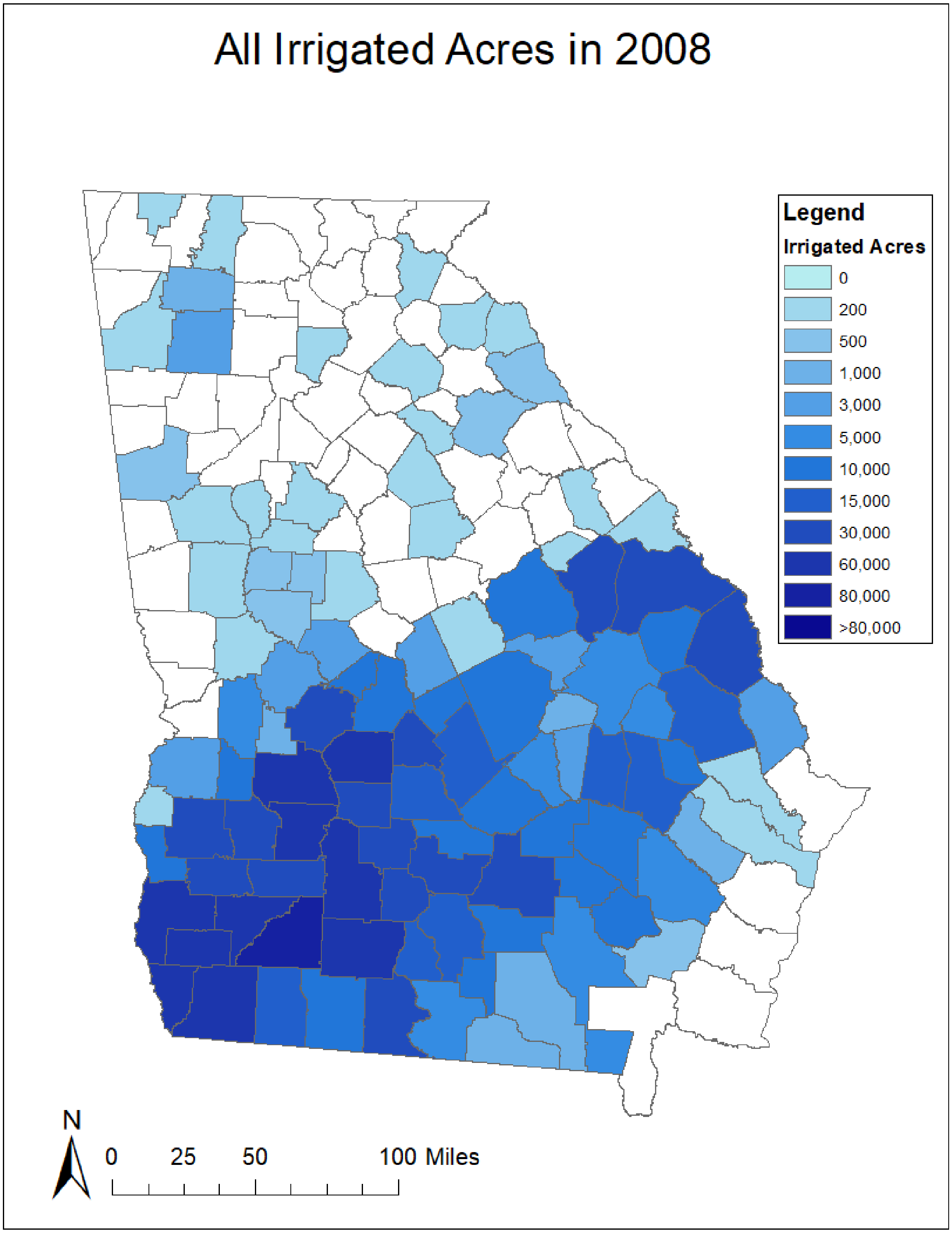
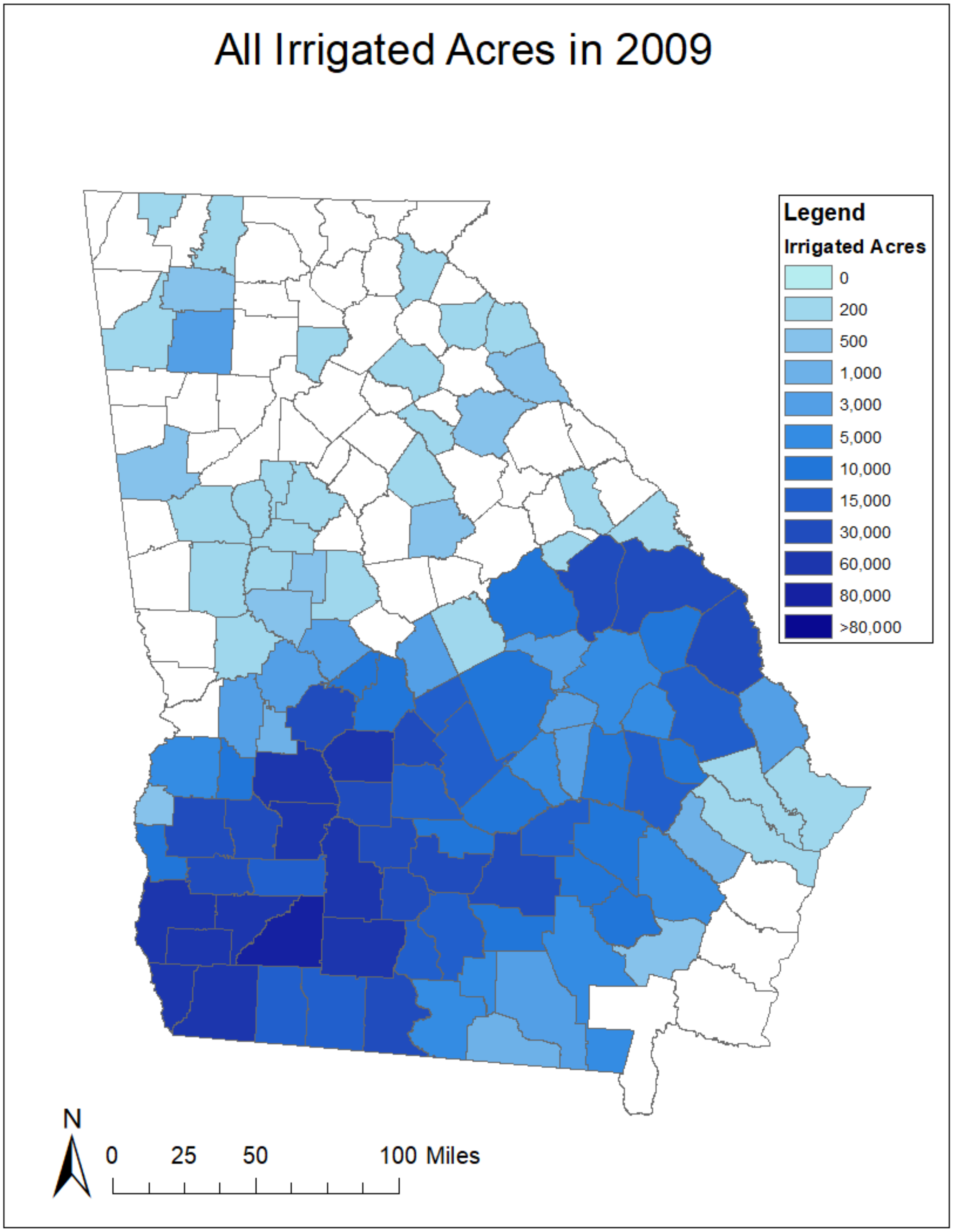
Appendices

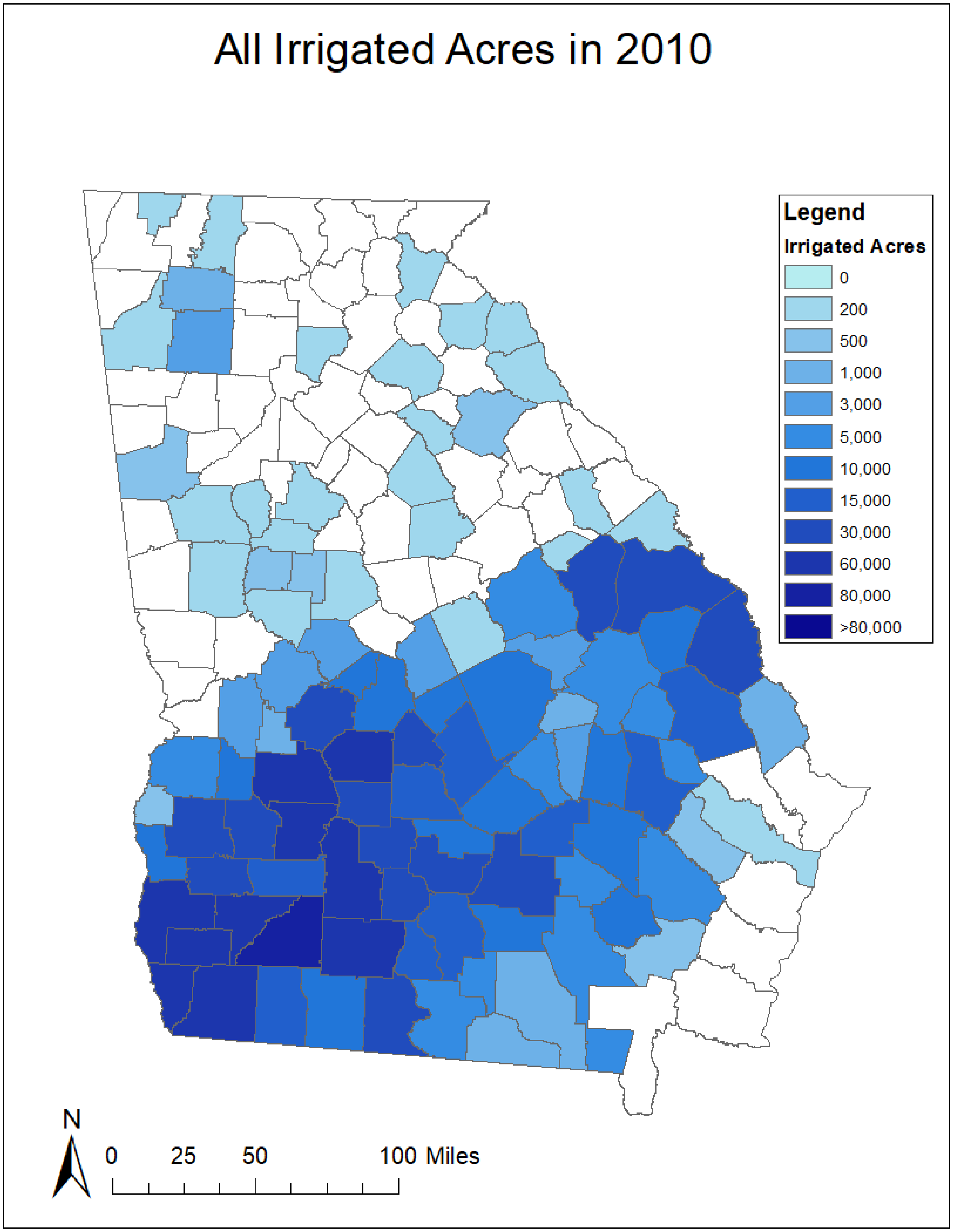
Appendix A: Irrigated Acres in Georgia Maps



Map A.1 Irrigated Acres in Georgia for 2008



Map A.2 Irrigated Acres in Georgia for 2009



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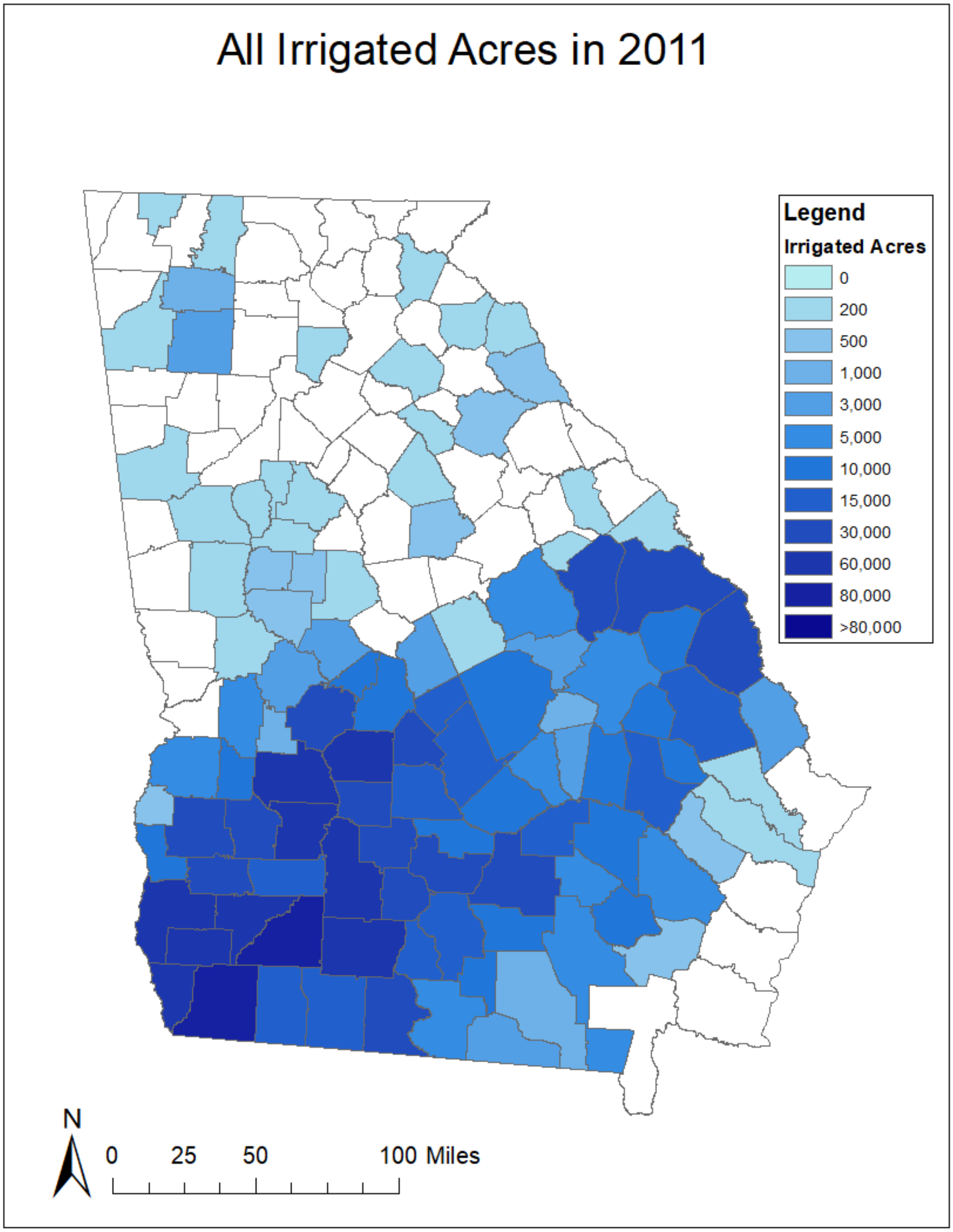

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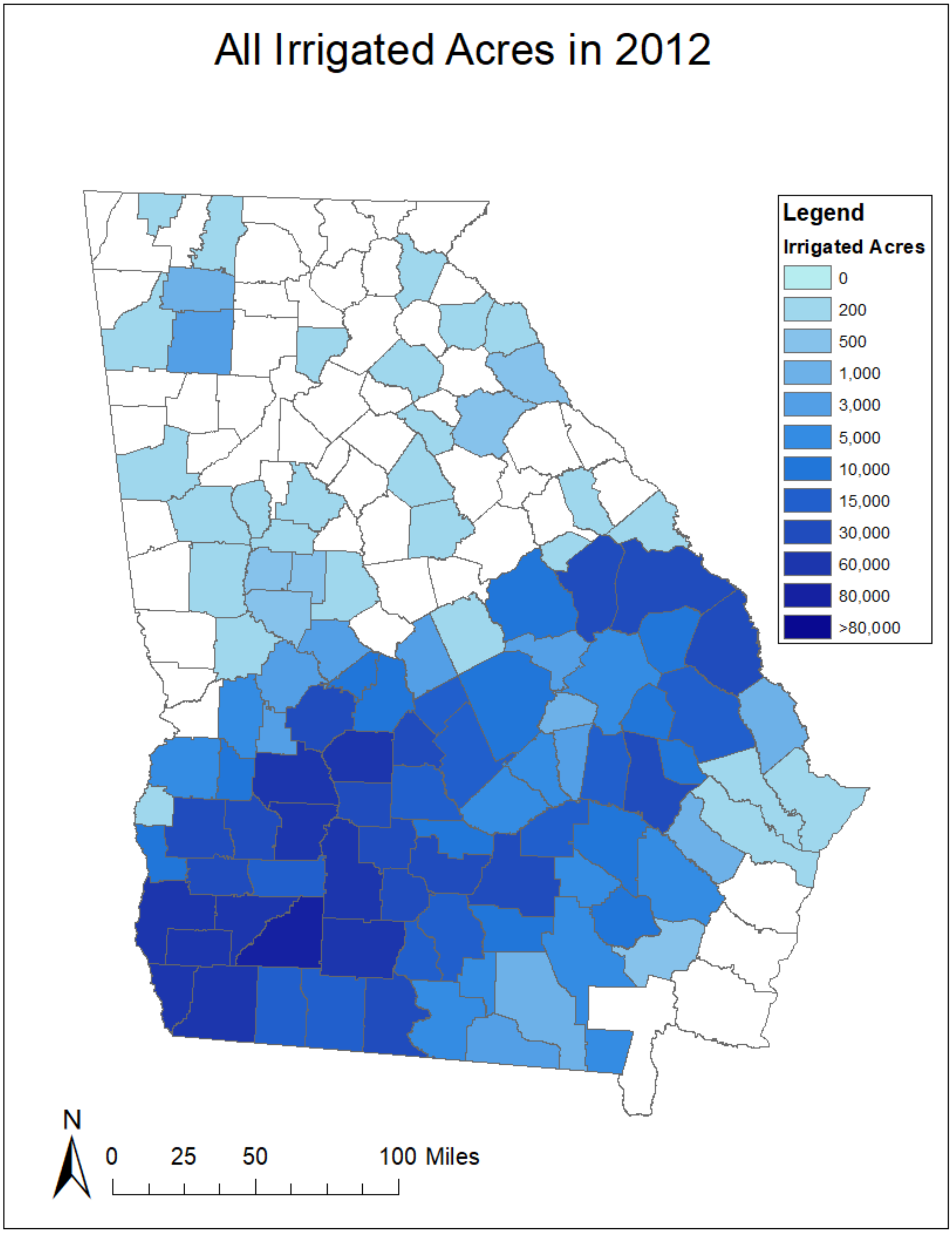
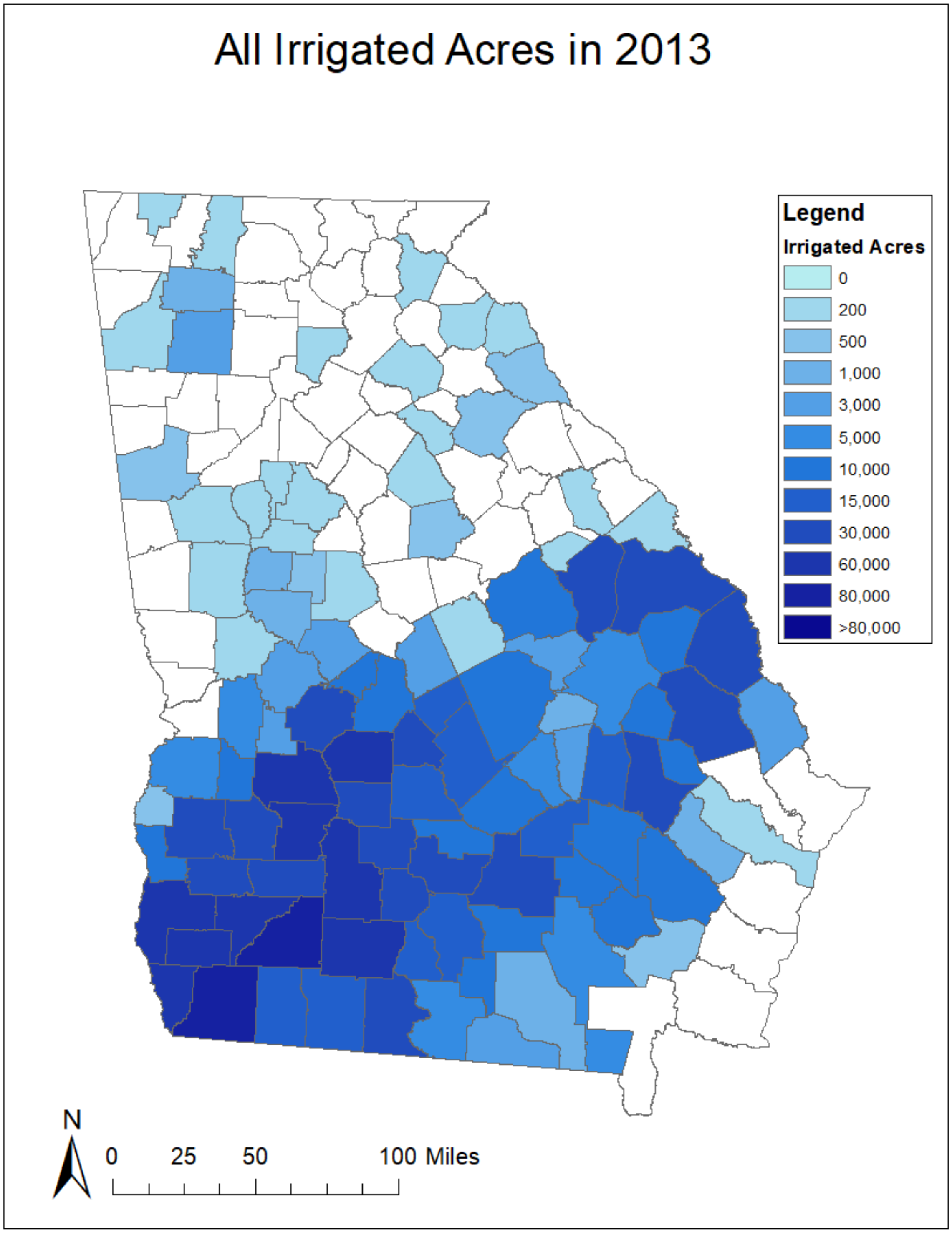


Map A.5 Irrigated Acres in Georgia for 2012



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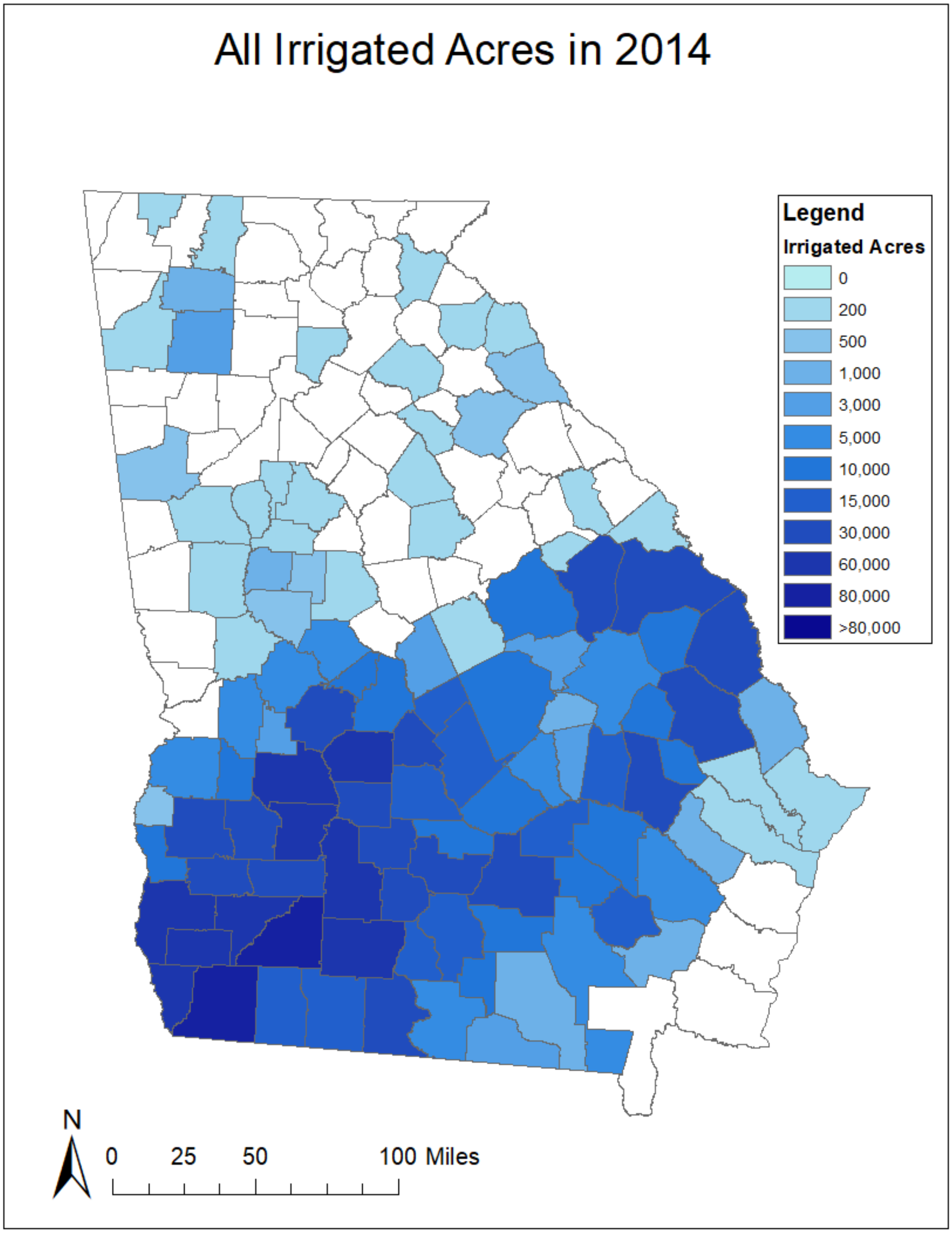

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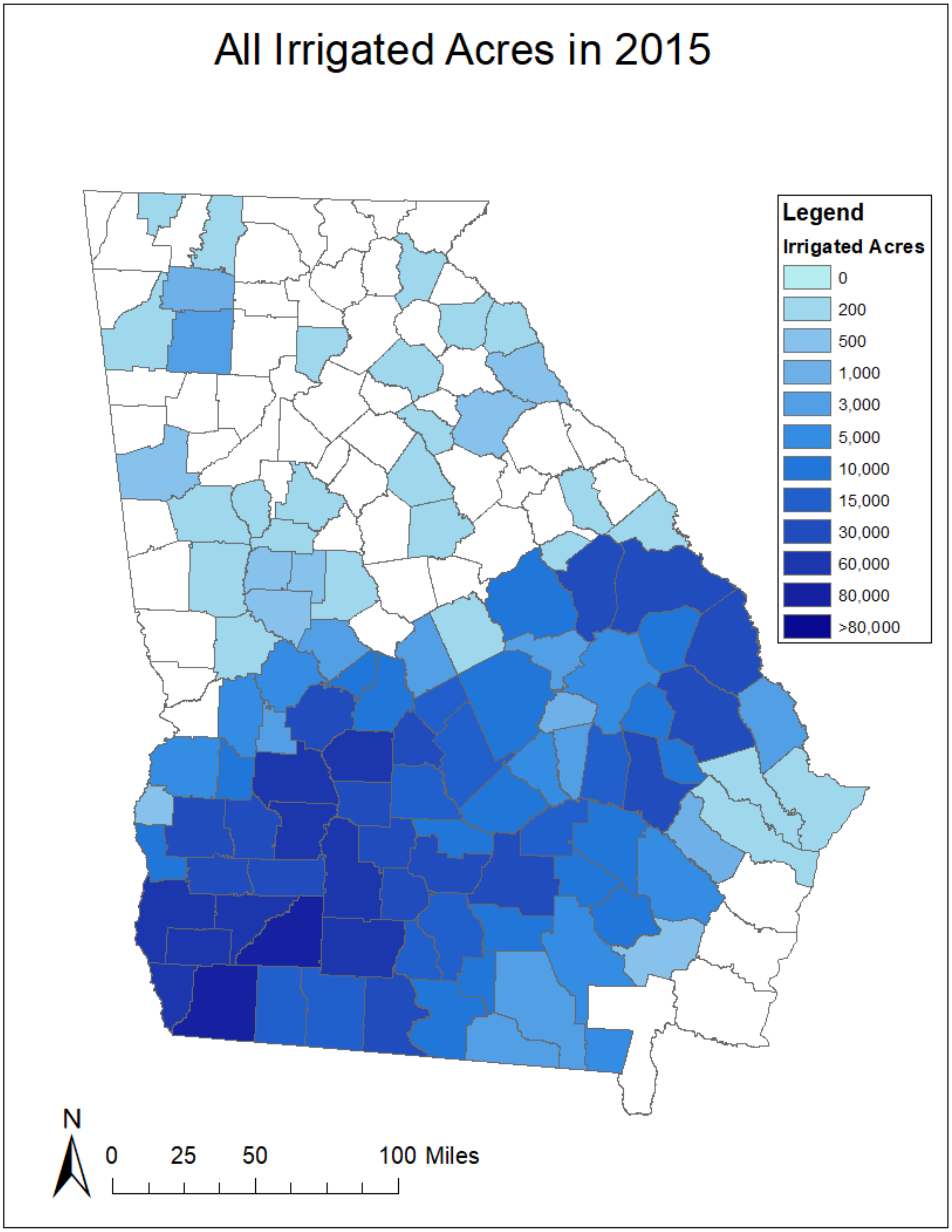
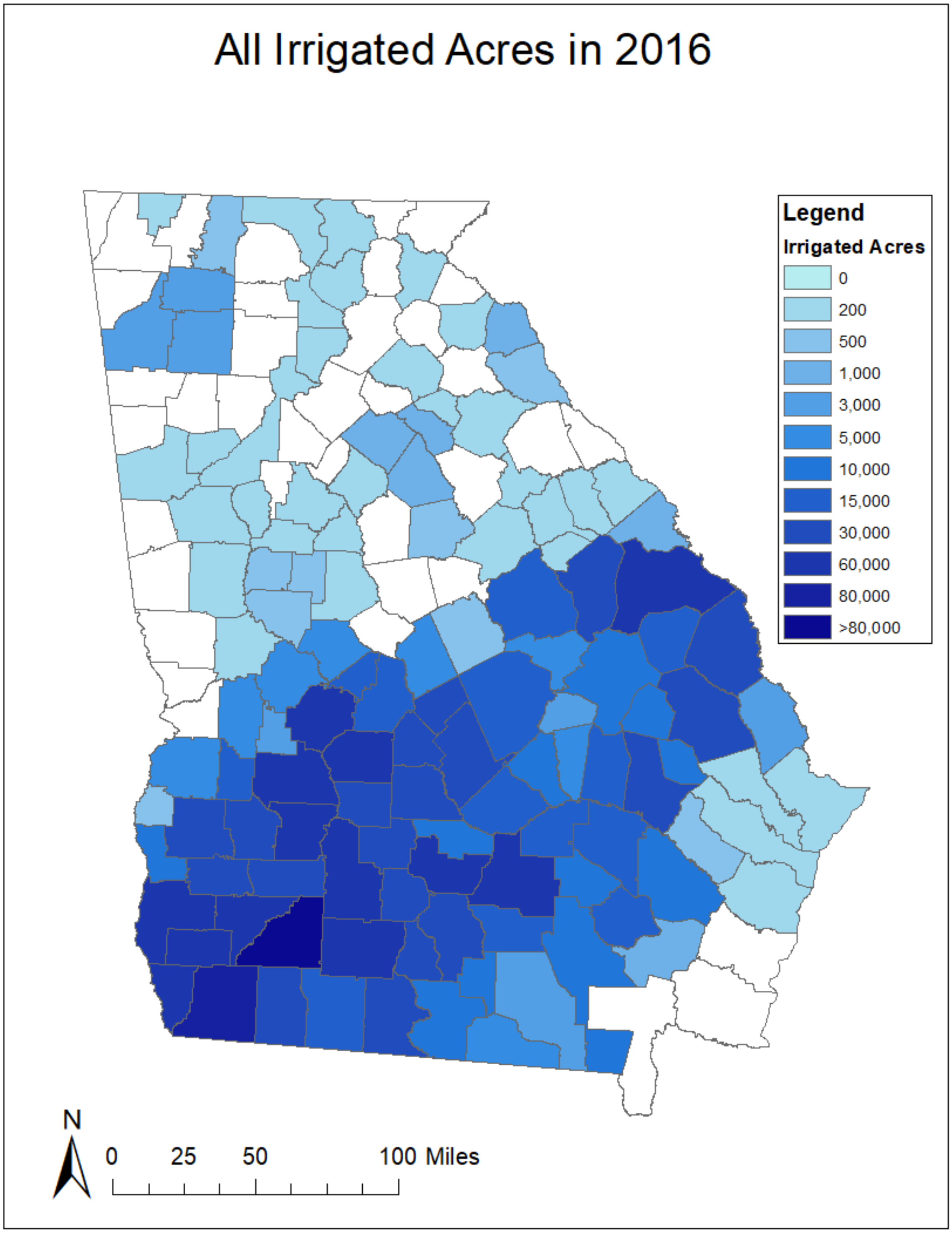
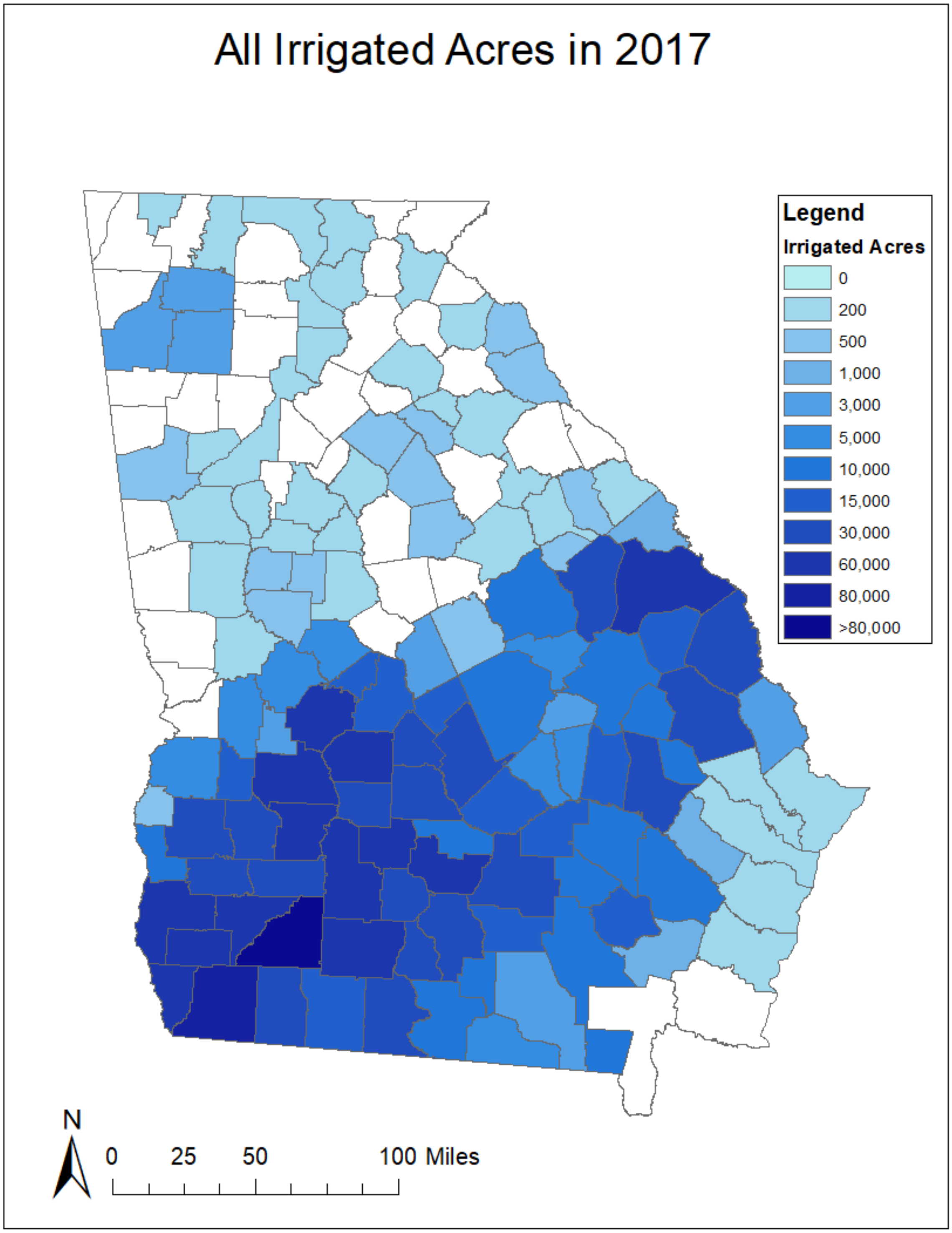


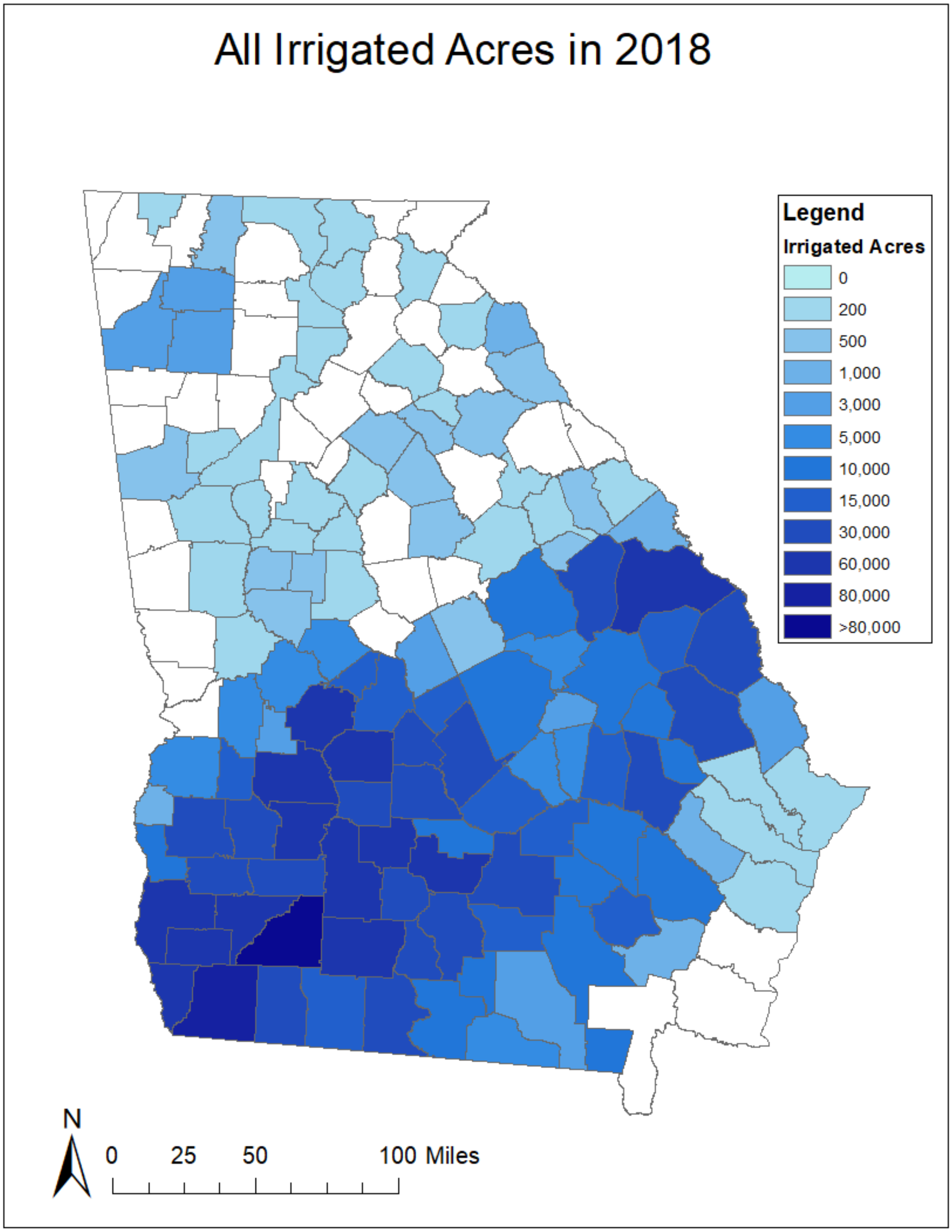
Map A.8 Irrigated Acres in Georgia for 2015



Map A.9 Irrigated Acres in Georgia for 2016



Map A.10 Irrigated Acres in Georgia for 2017



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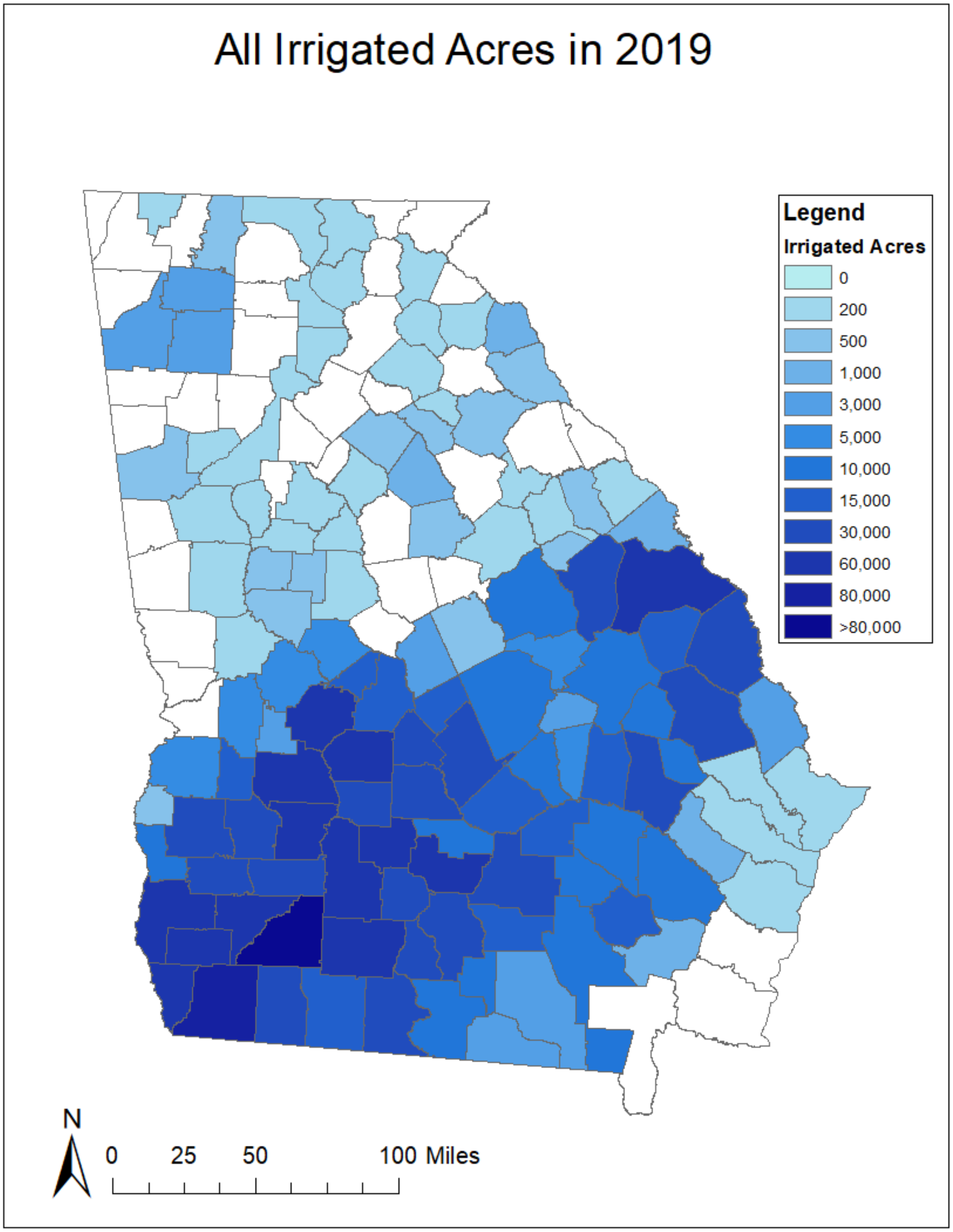

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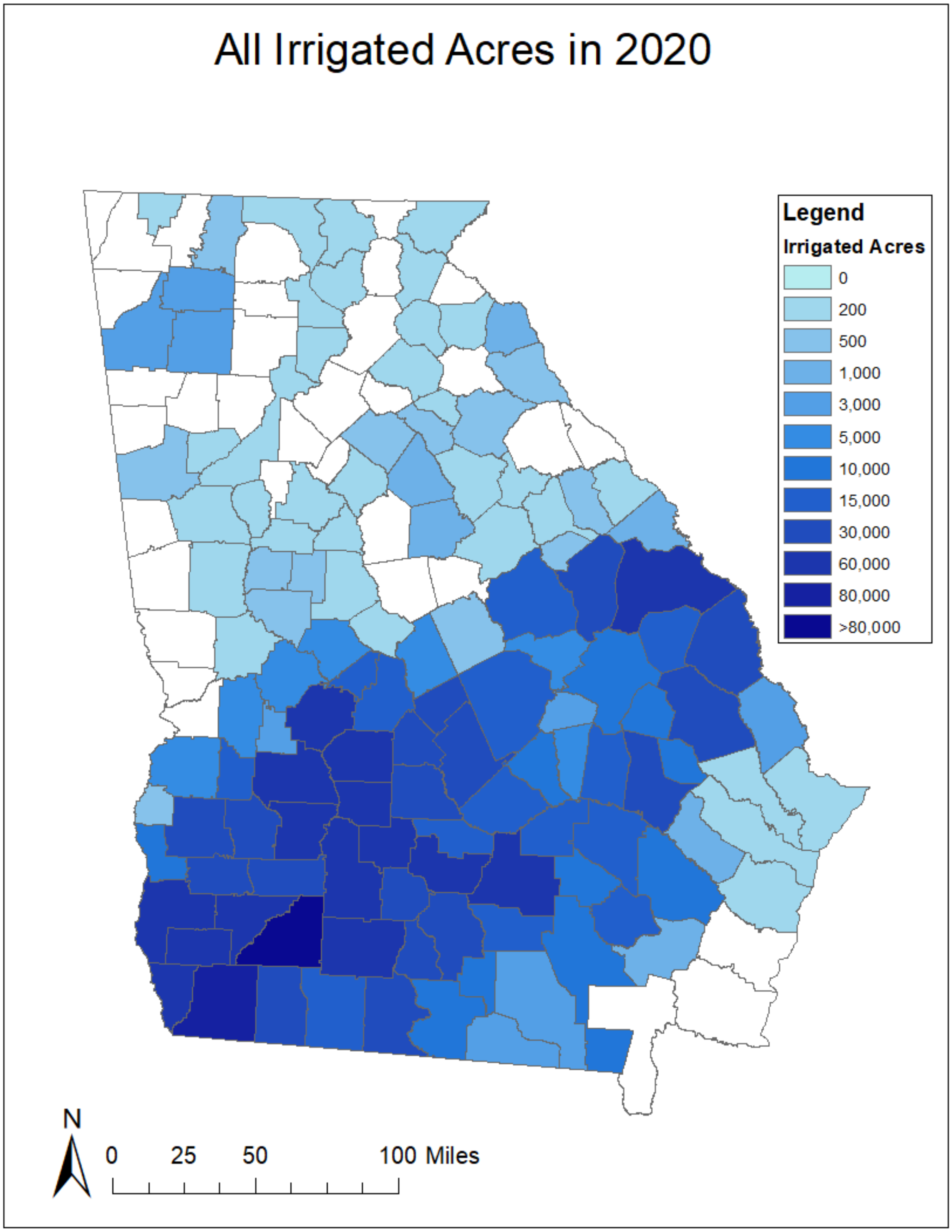
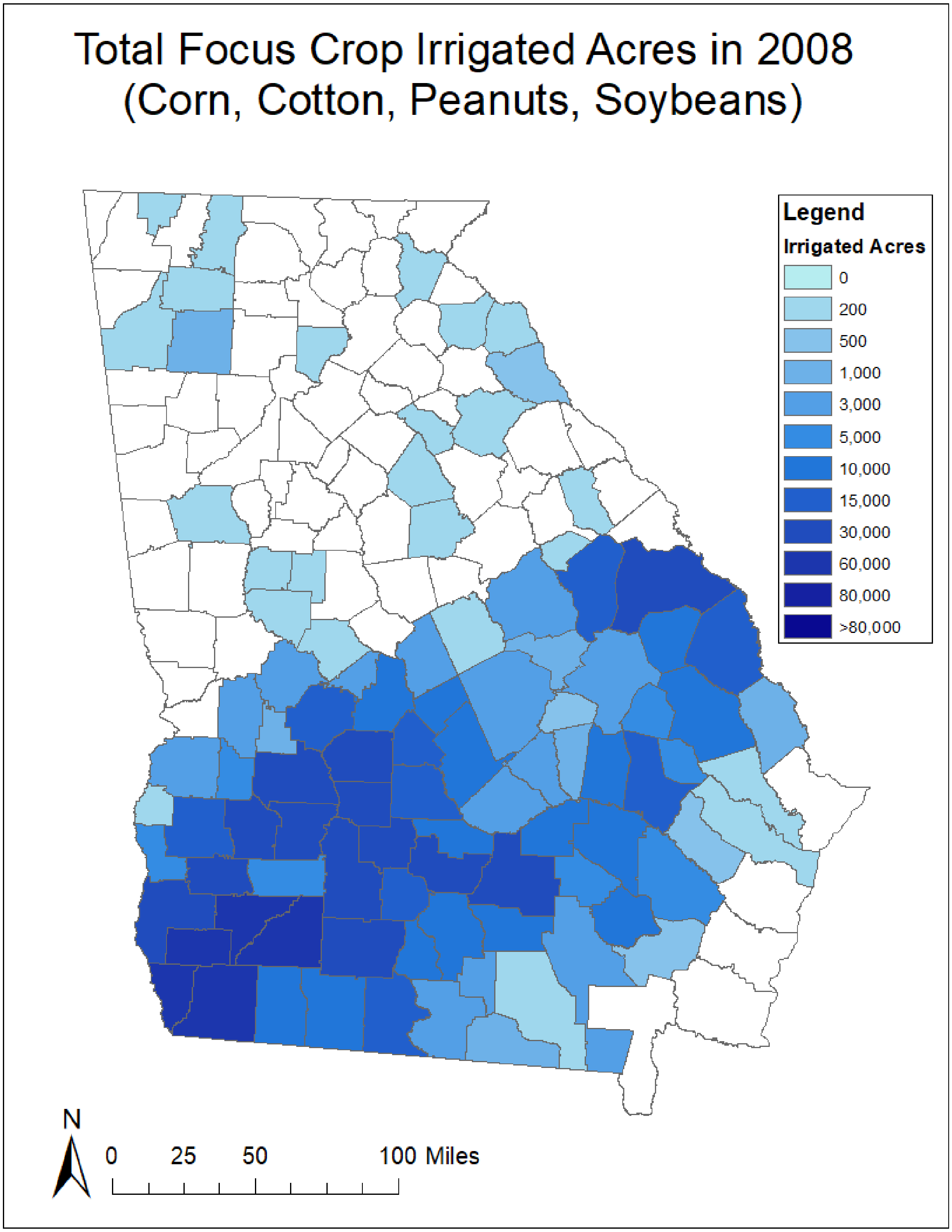
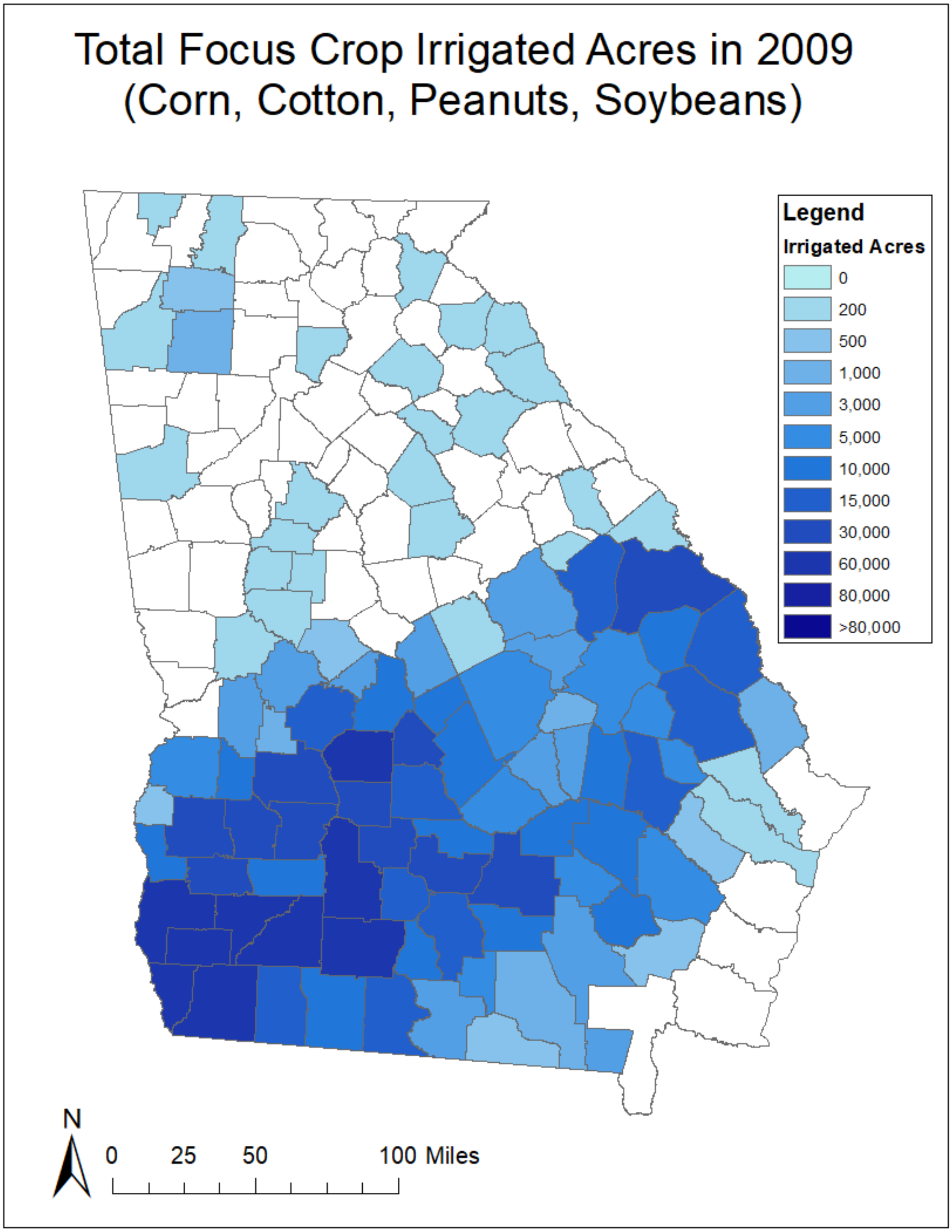


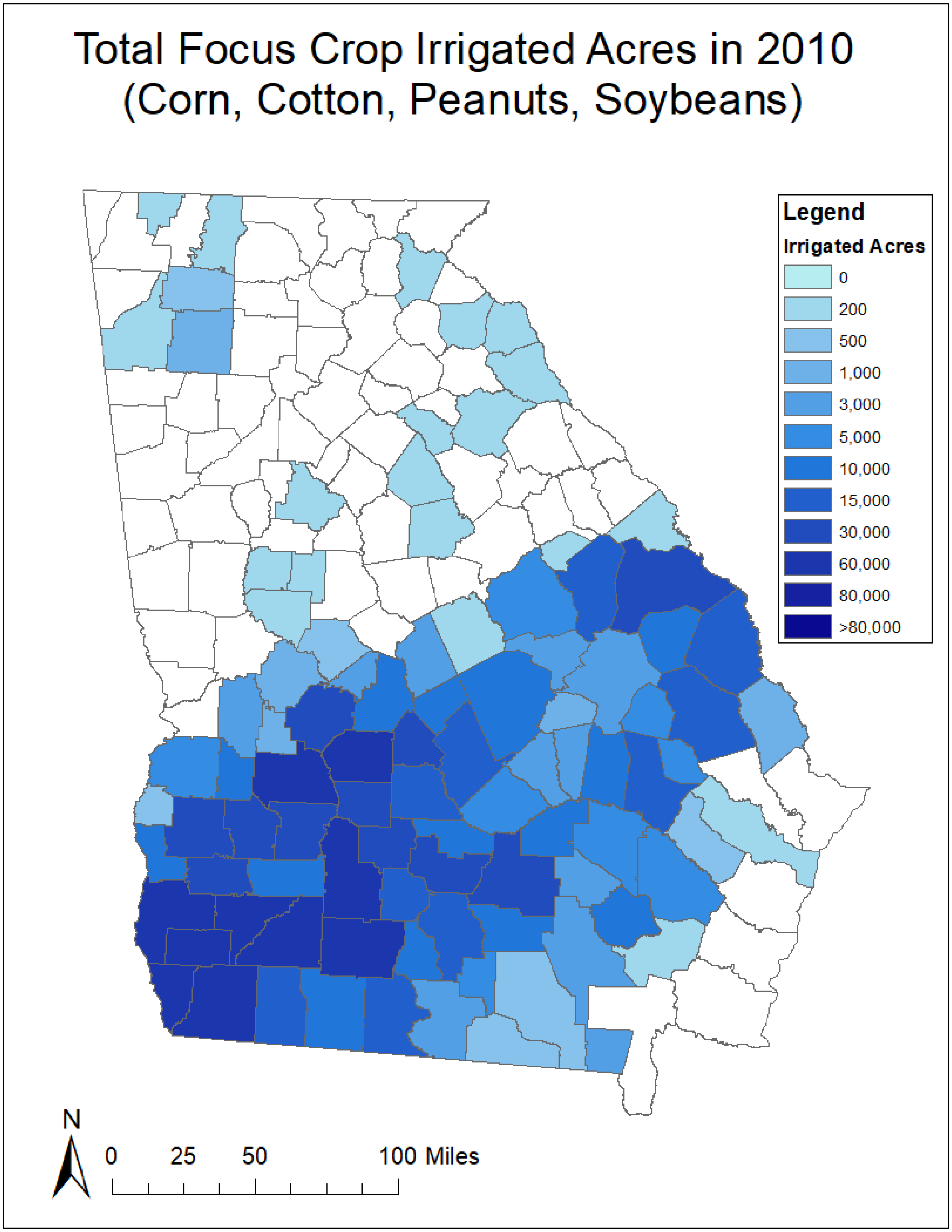
Map A.13 Irrigated Acres in Georgia for 2020



Map A.14 All Focus Crop Irrigated Acres in Georgia for 2008



Map A.15 All Focus Crop Irrigated Acres in Georgia for 2009



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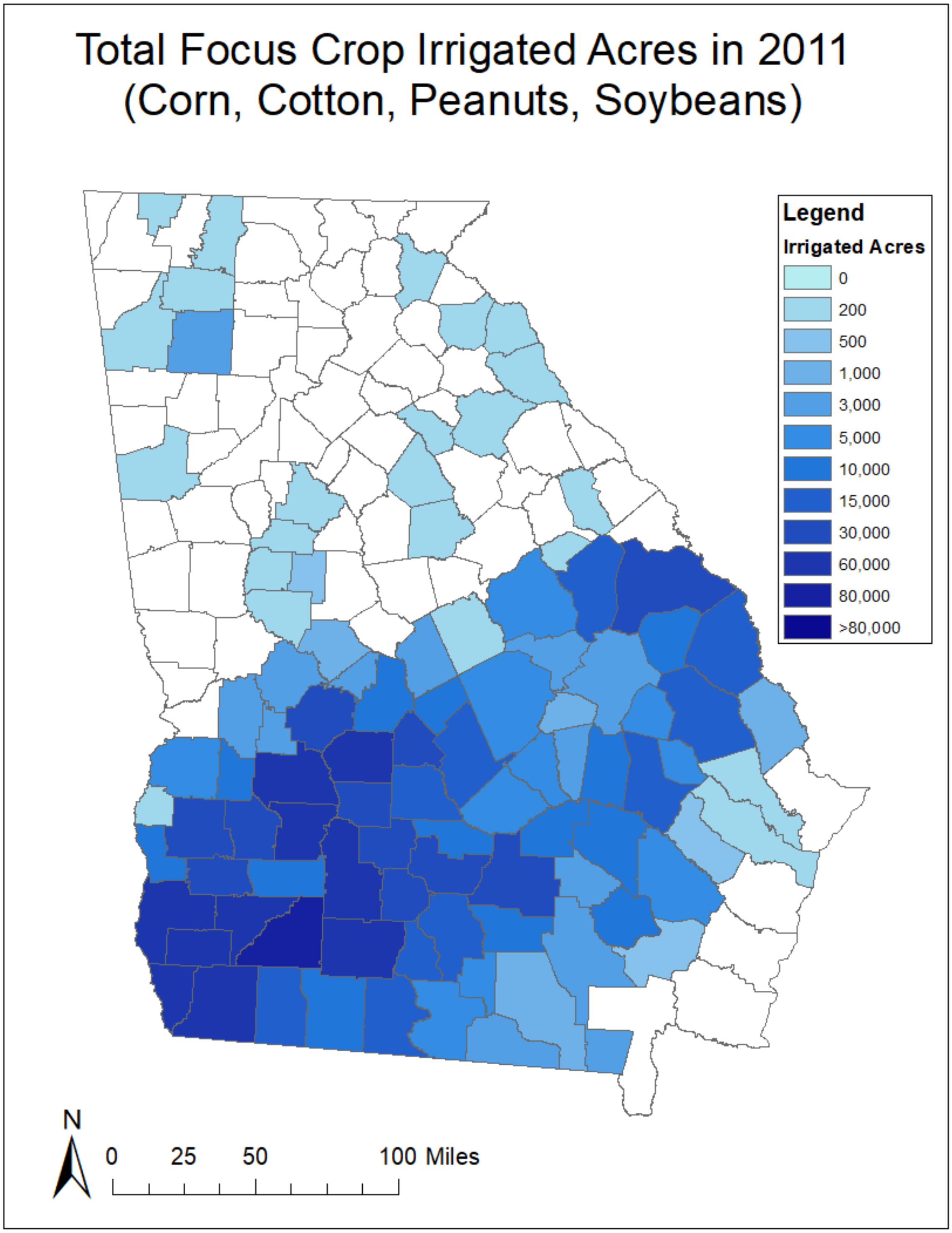
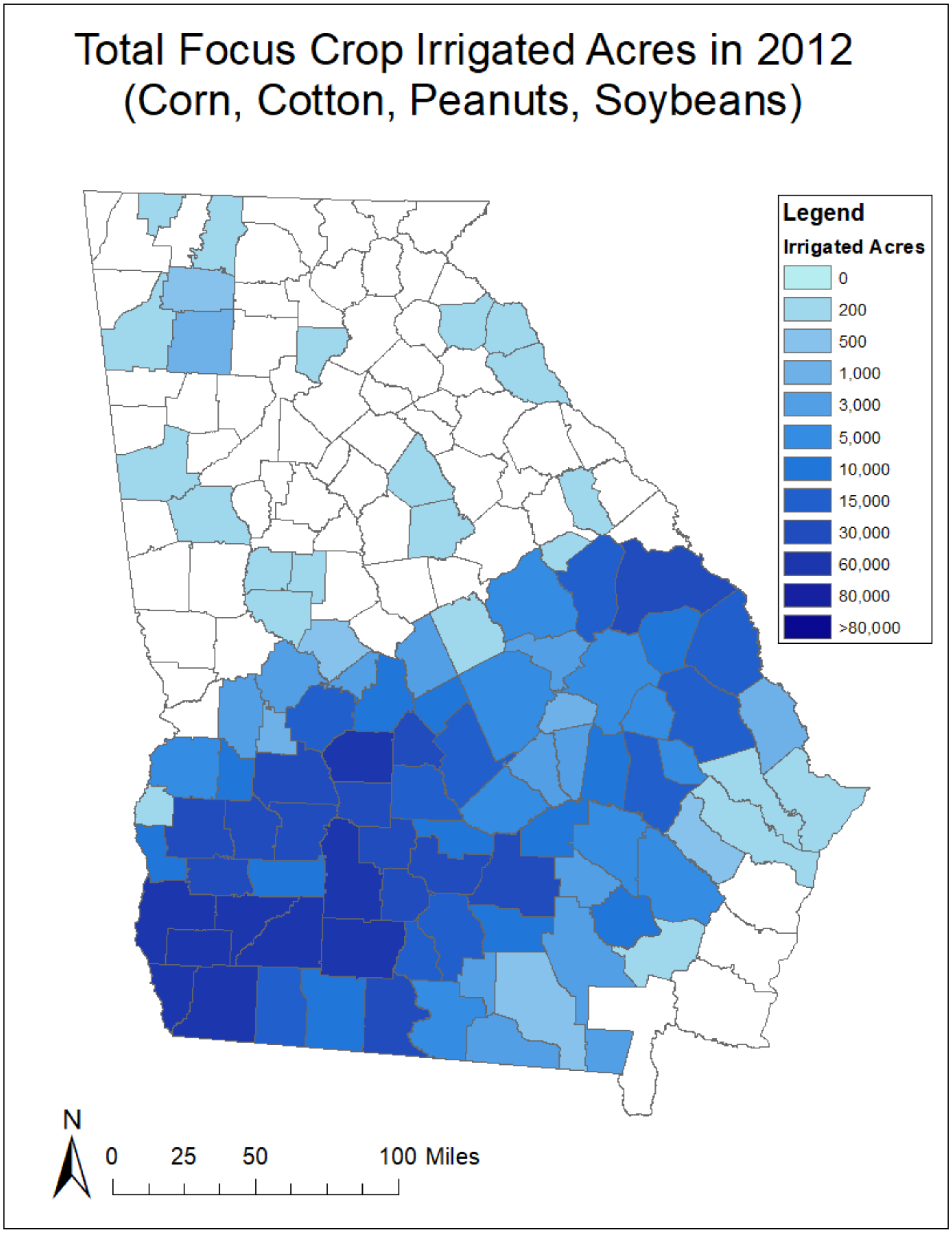


Map A.17 All Focus Crop Irrigated Acres in Georgia for 2011



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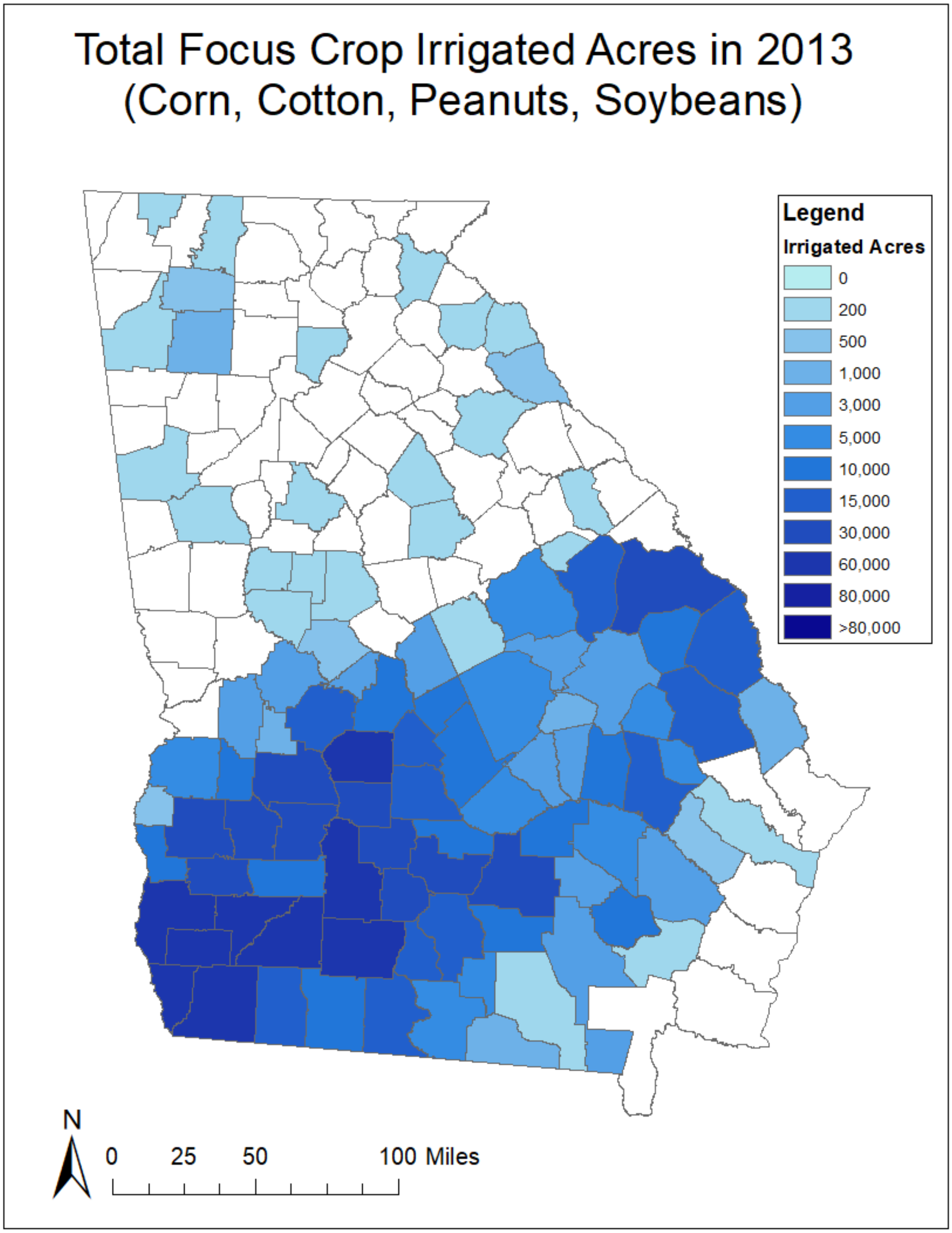

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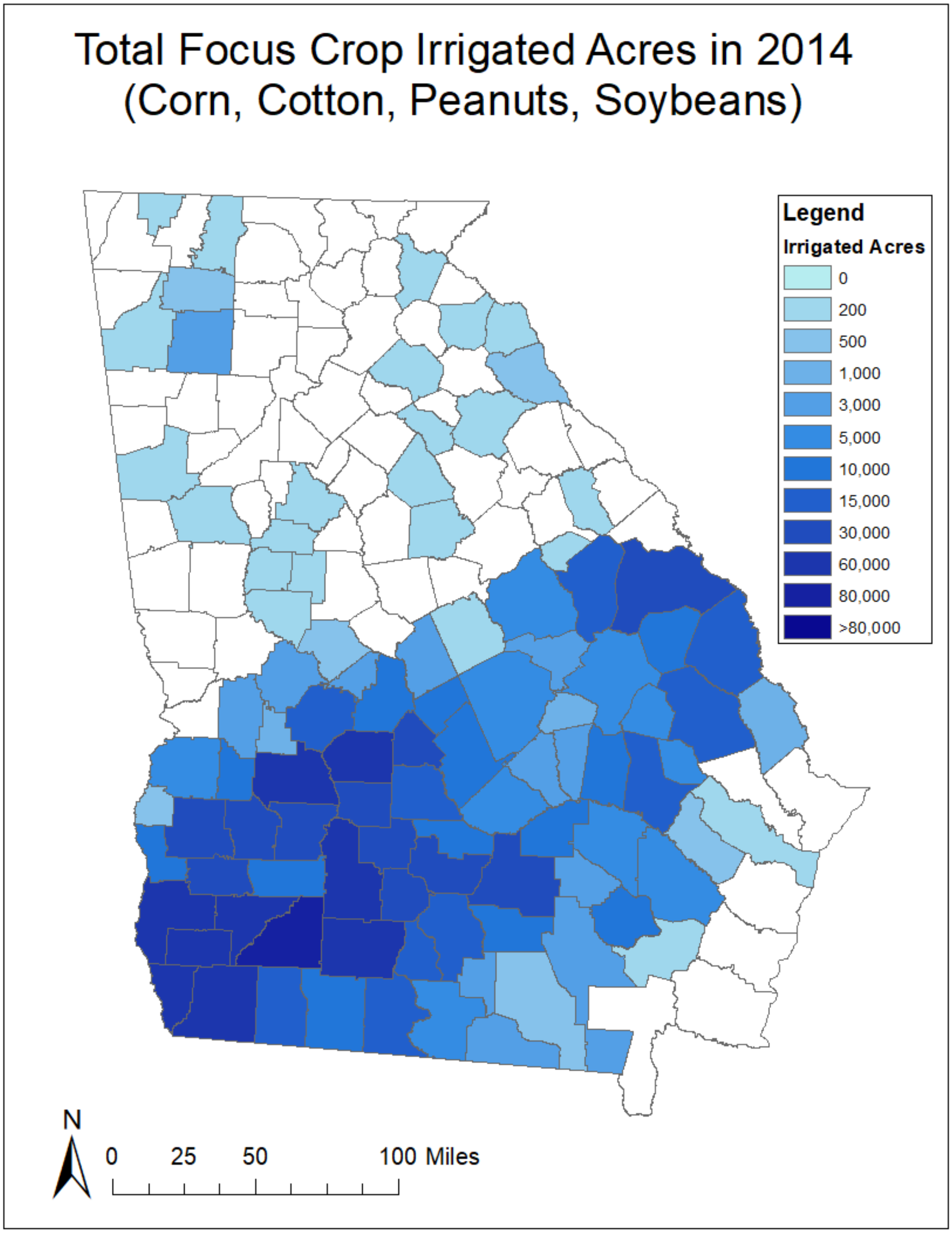
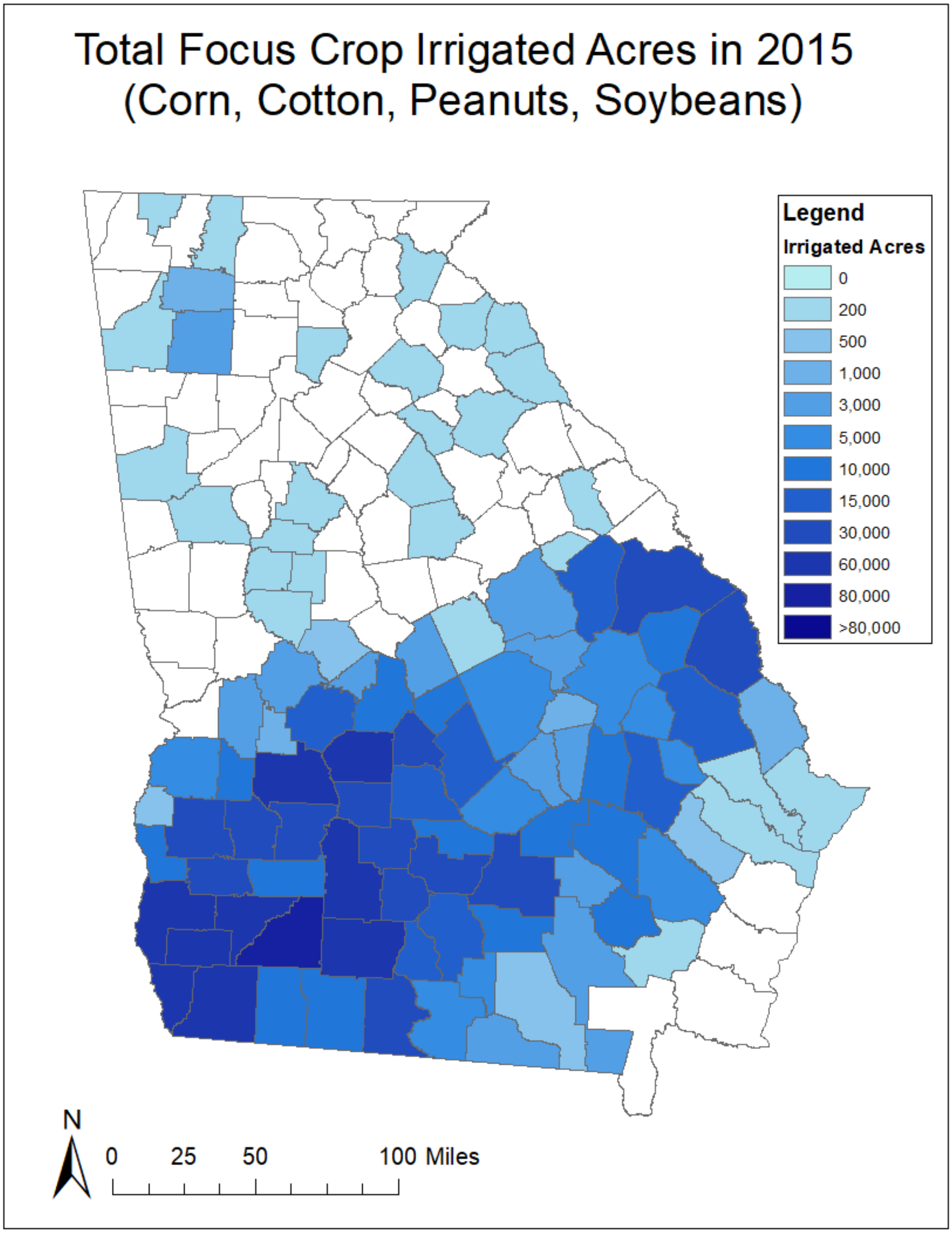
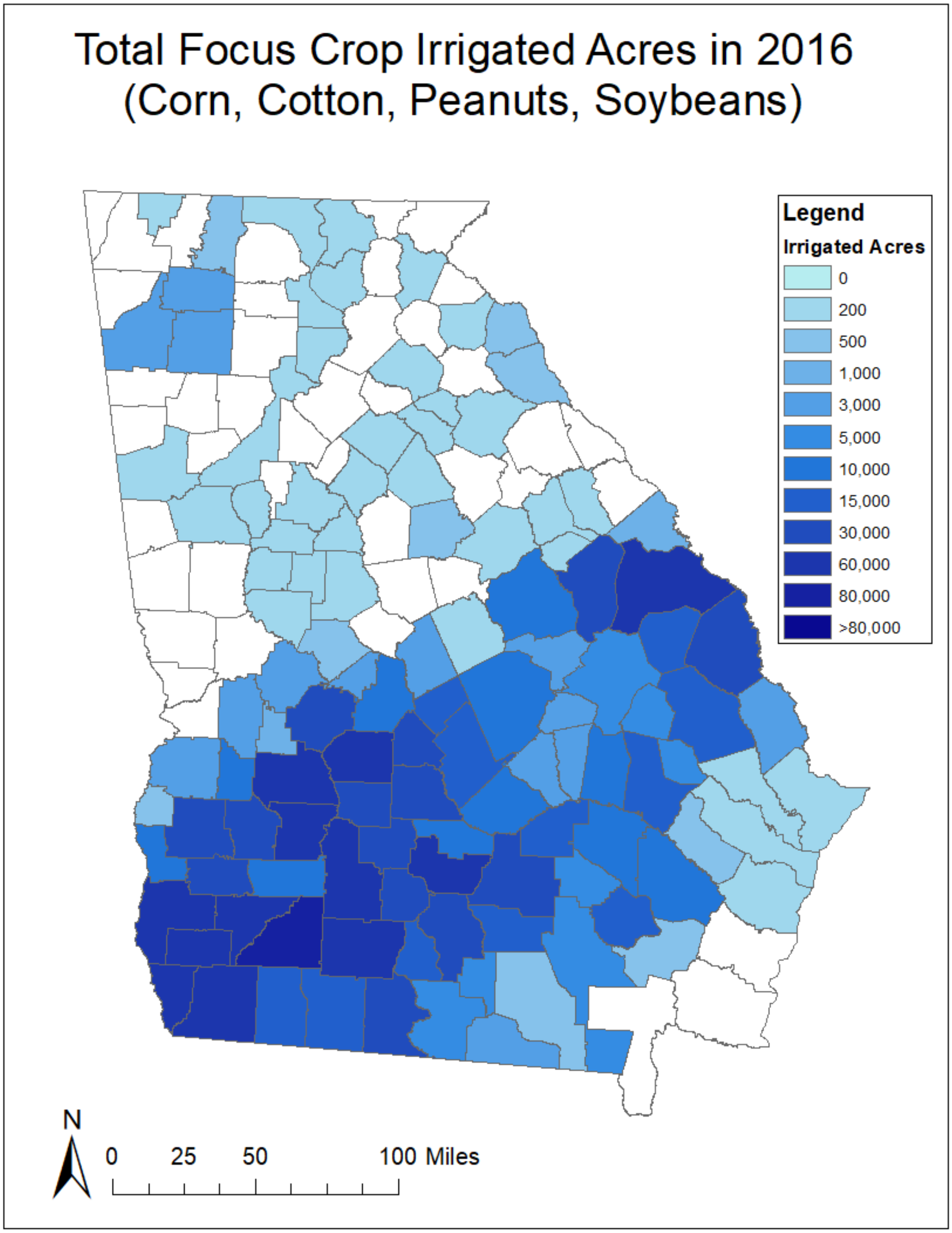


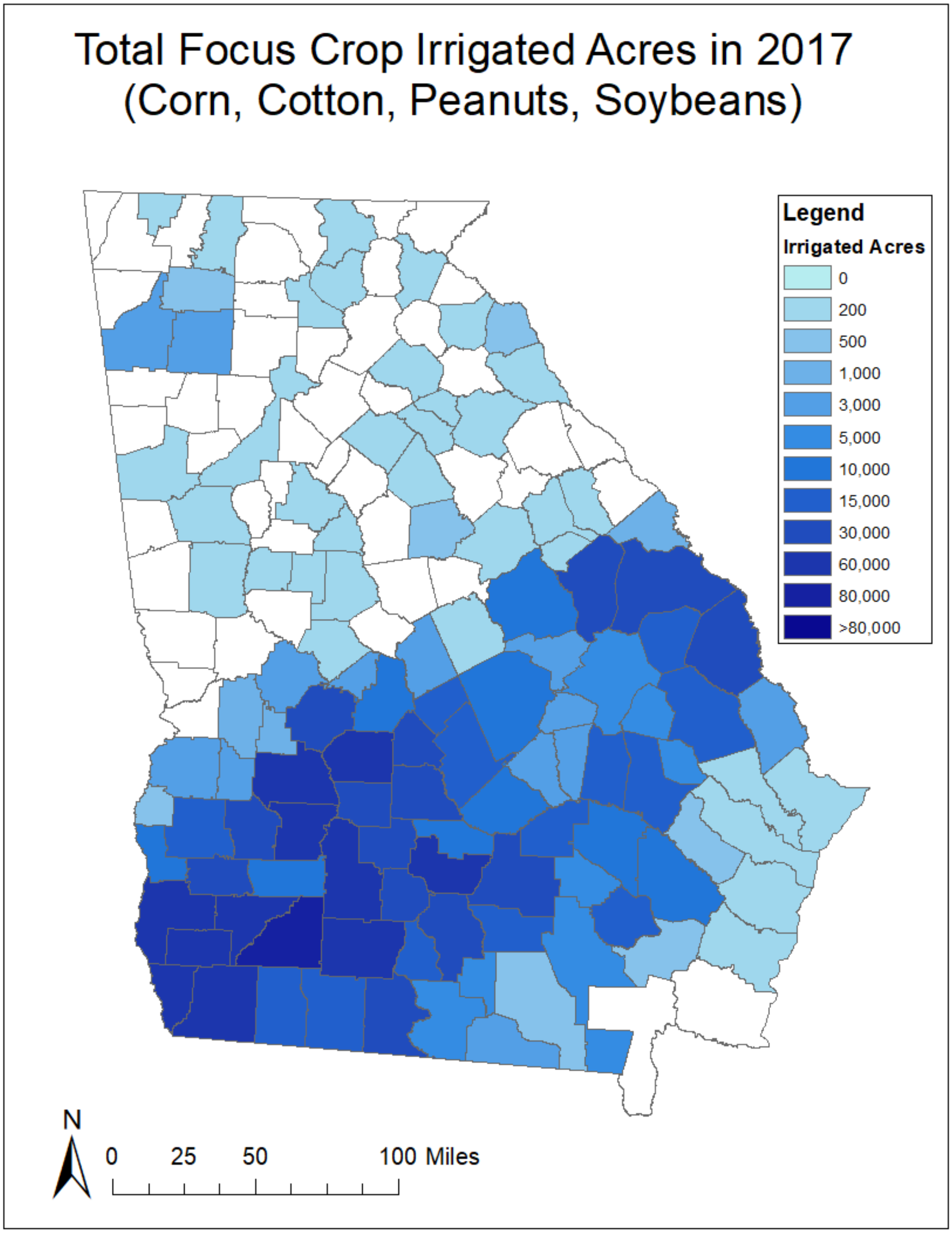
Map A.20 All Focus Crop Irrigated Acres in Georgia for 2014



Map A.21 All Focus Crop Irrigated Acres in Georgia for 2015



Map A.22 All Focus Crop Irrigated Acres in Georgia for 2016



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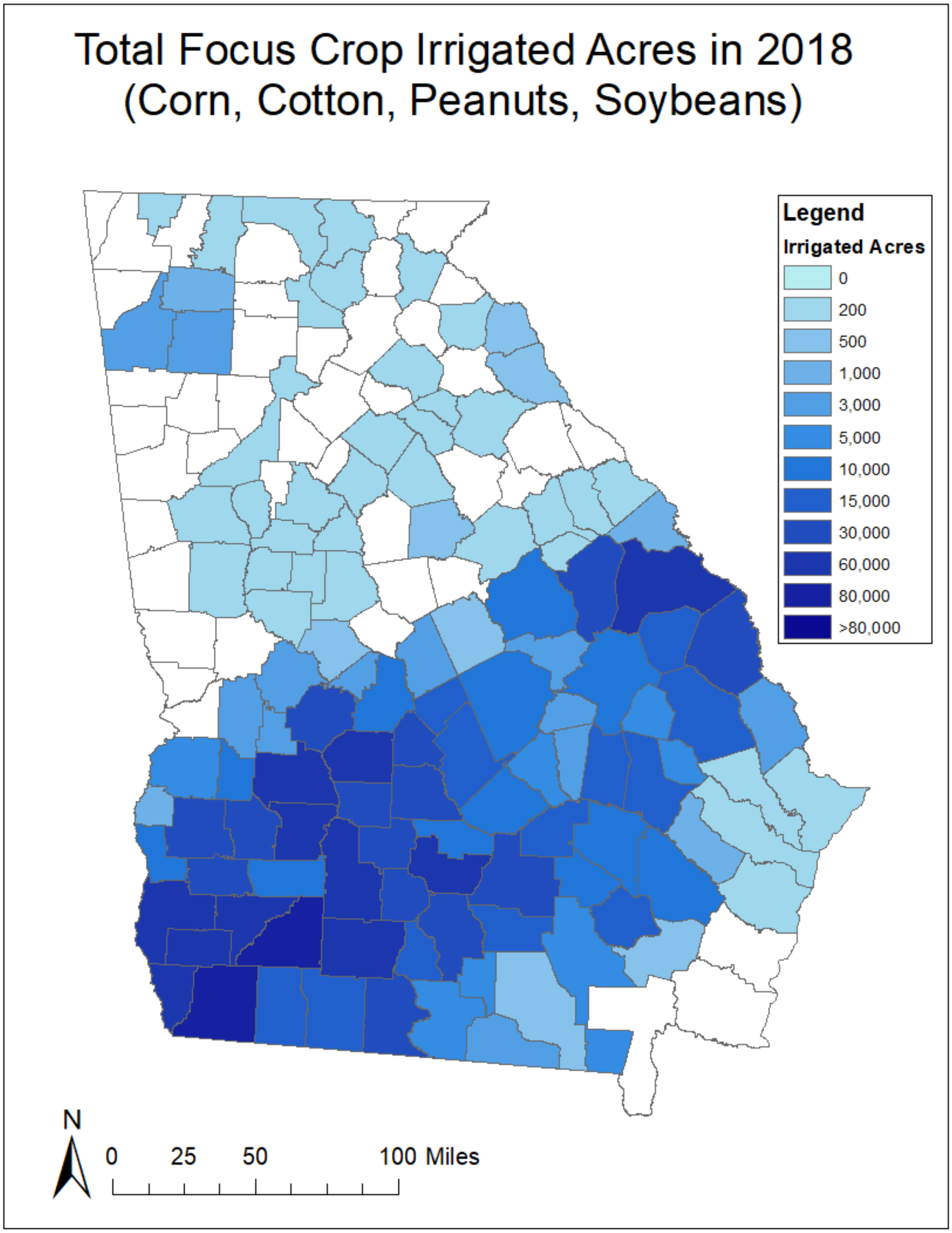

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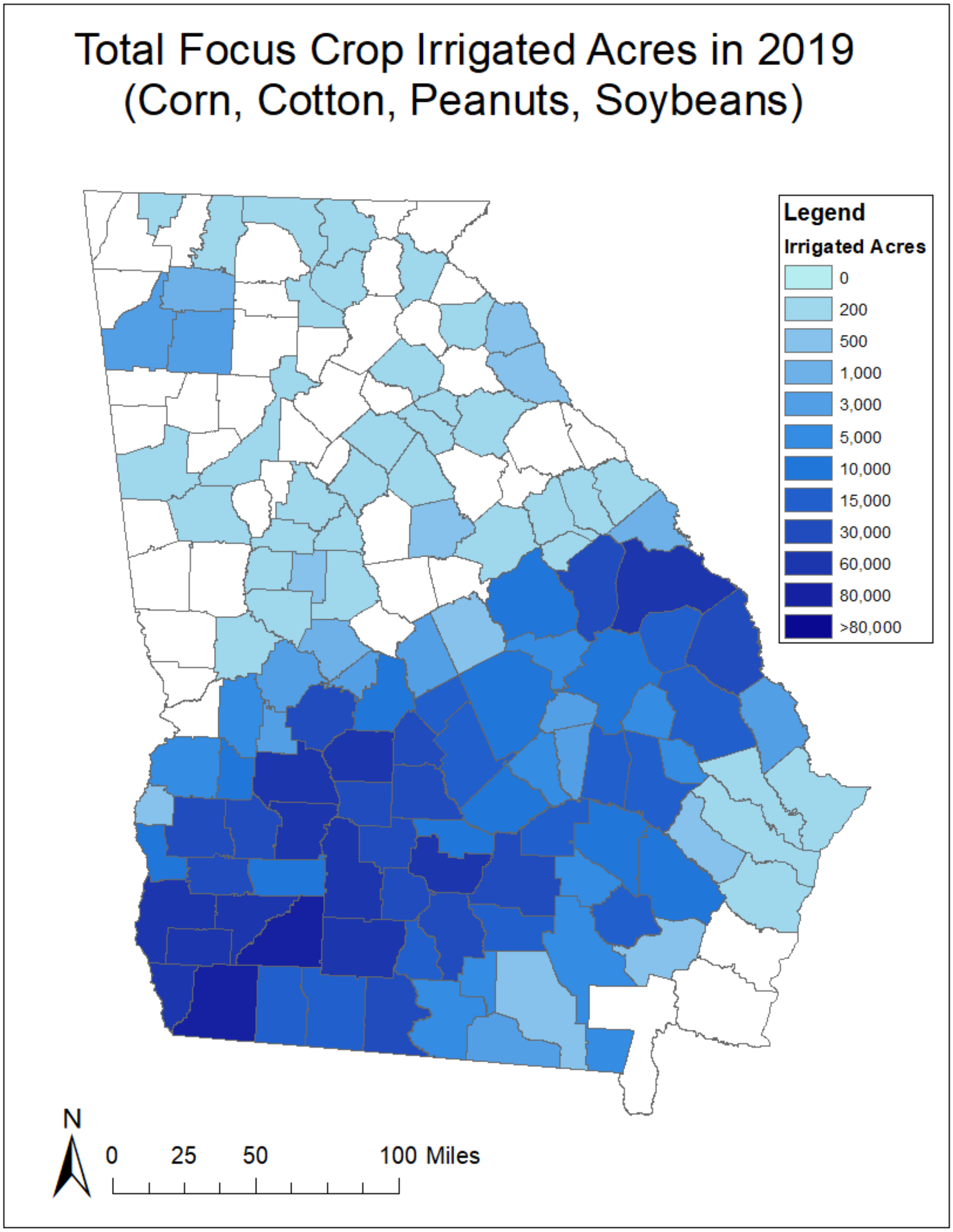
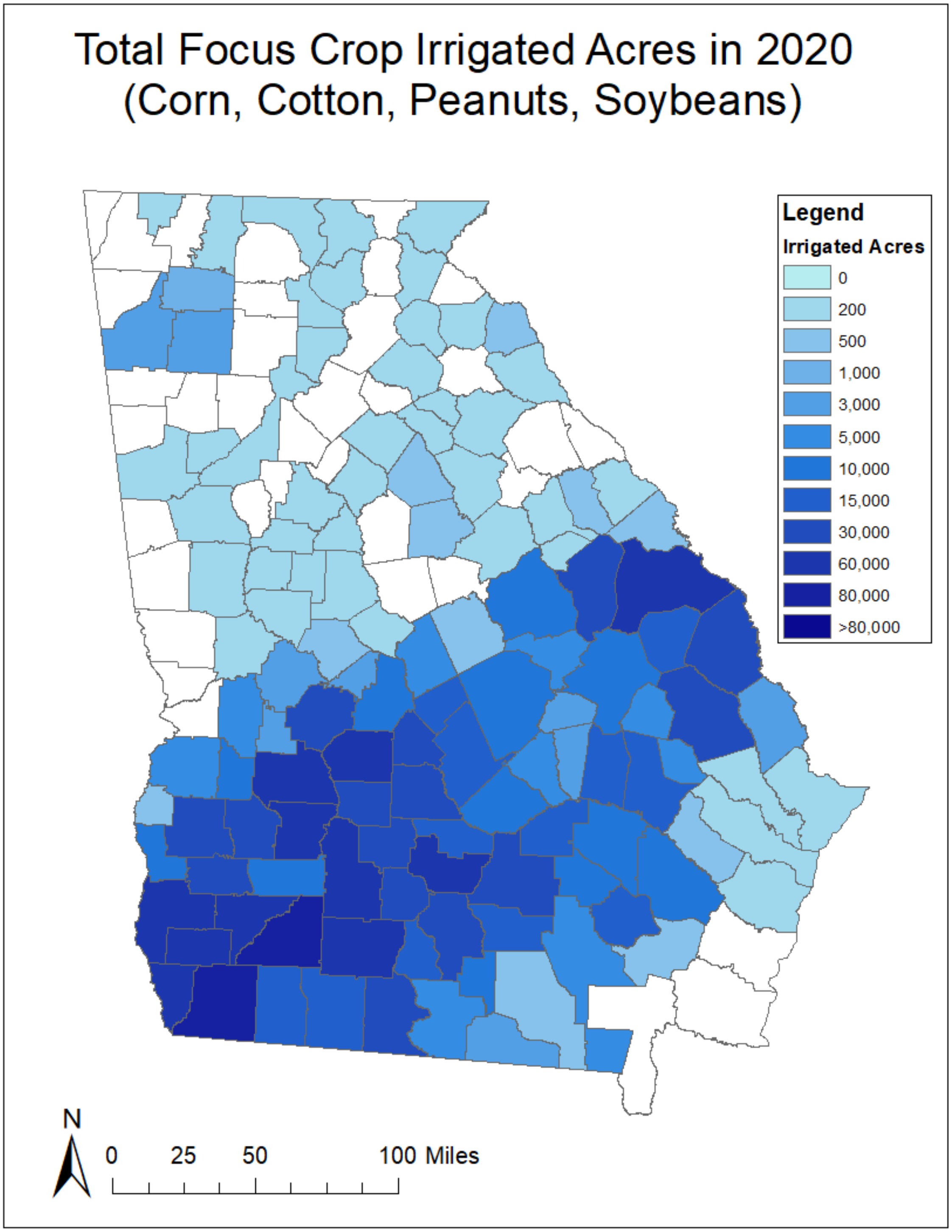


Map A.25 All Focus Crop Irrigated Acres in Georgia for 2019



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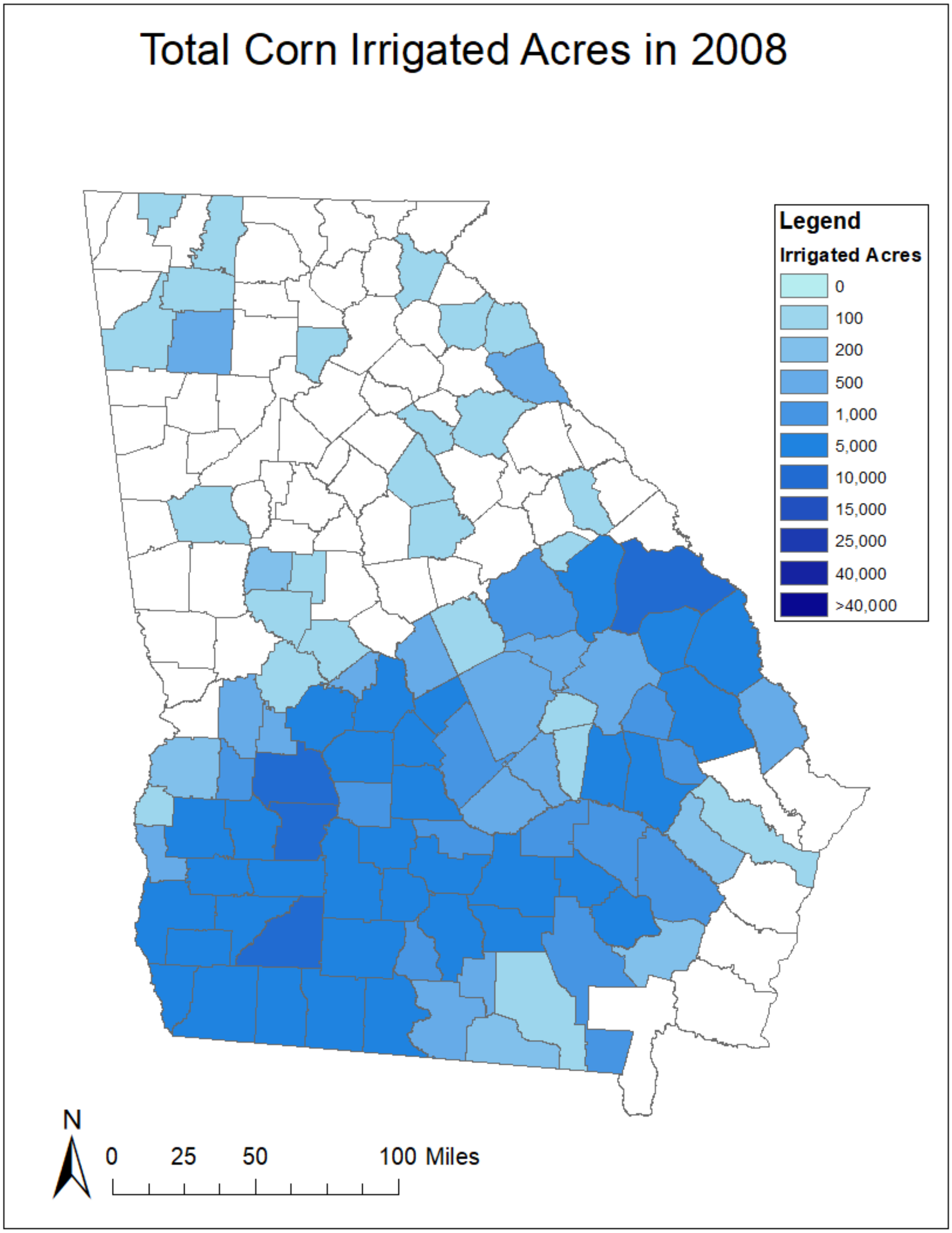

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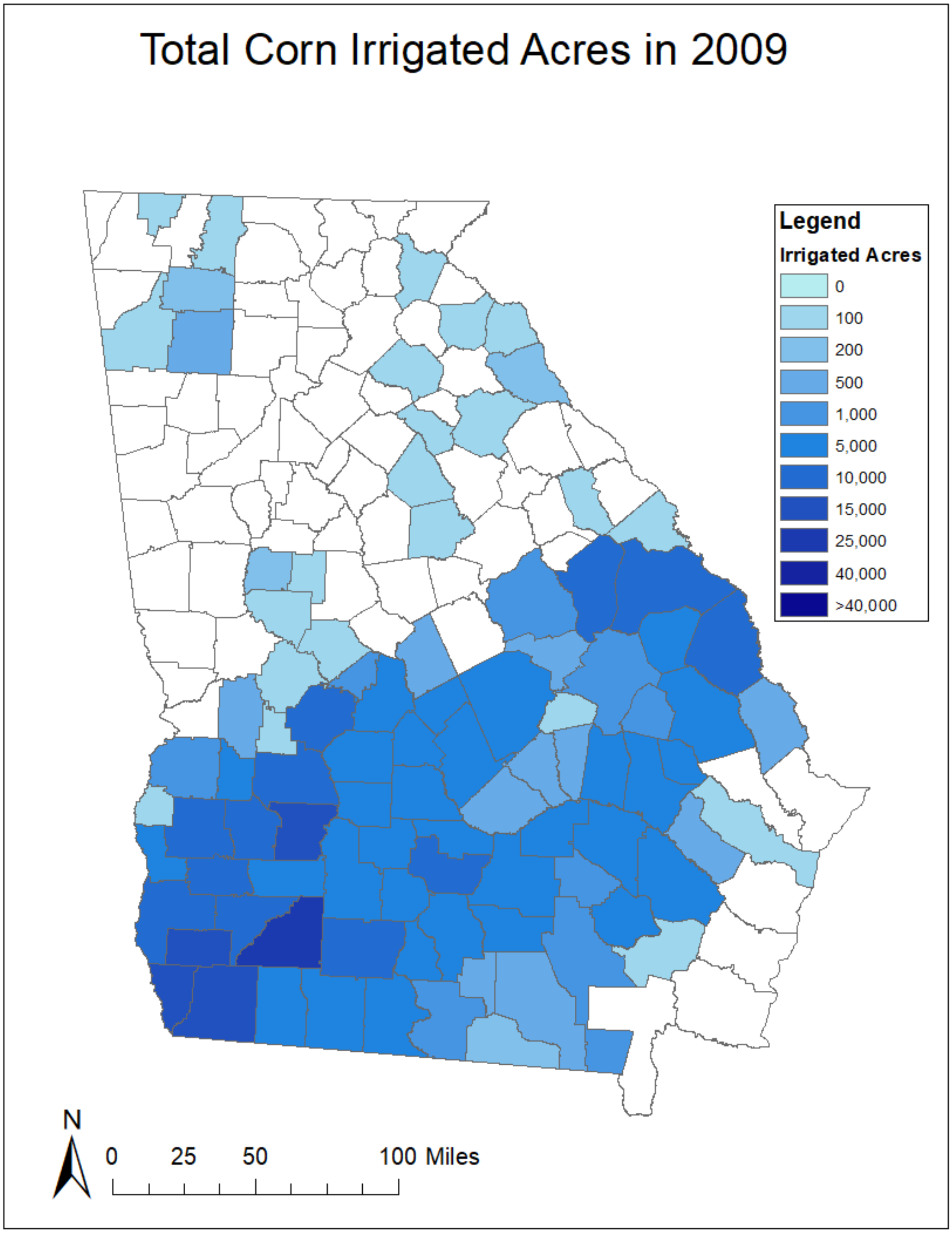

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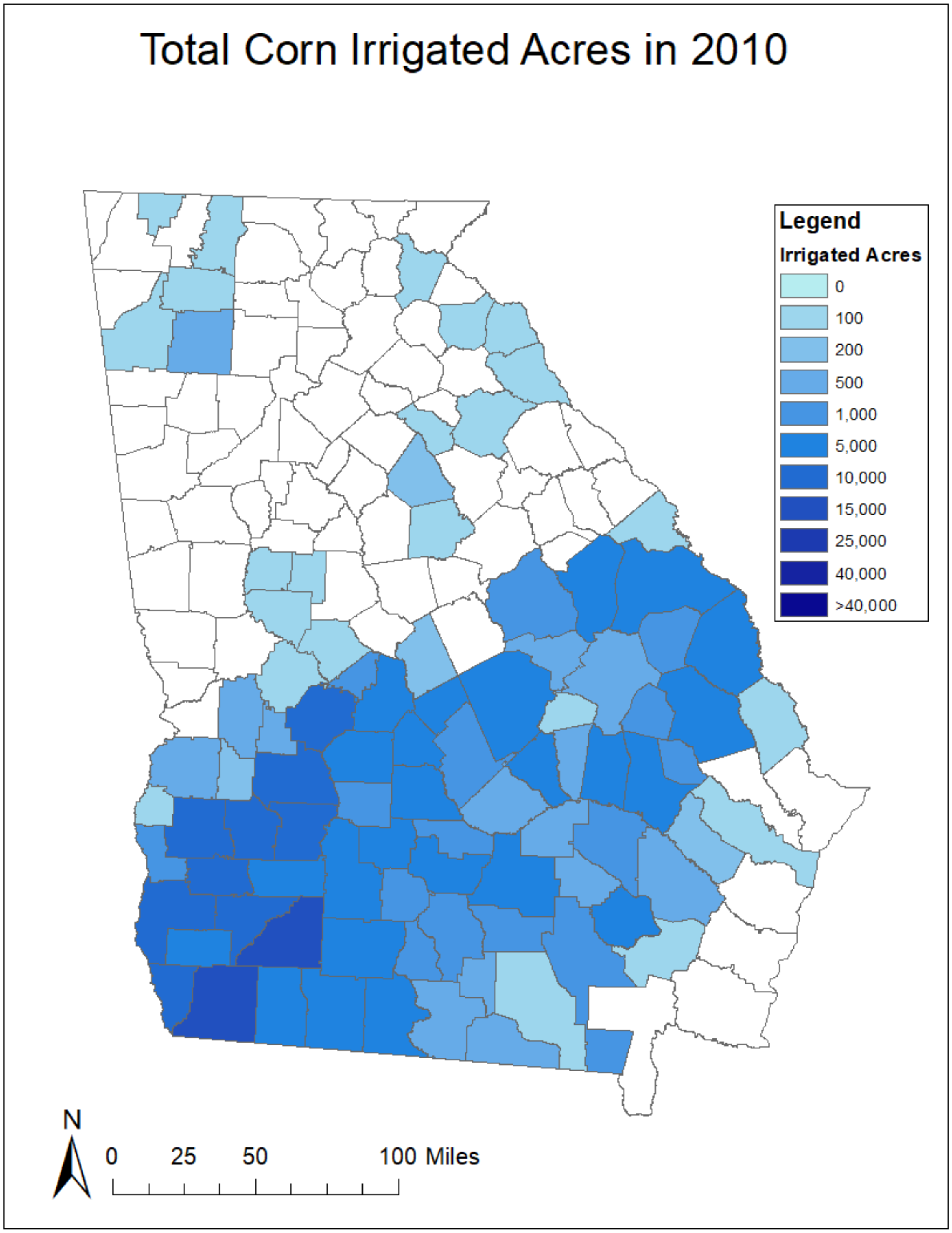

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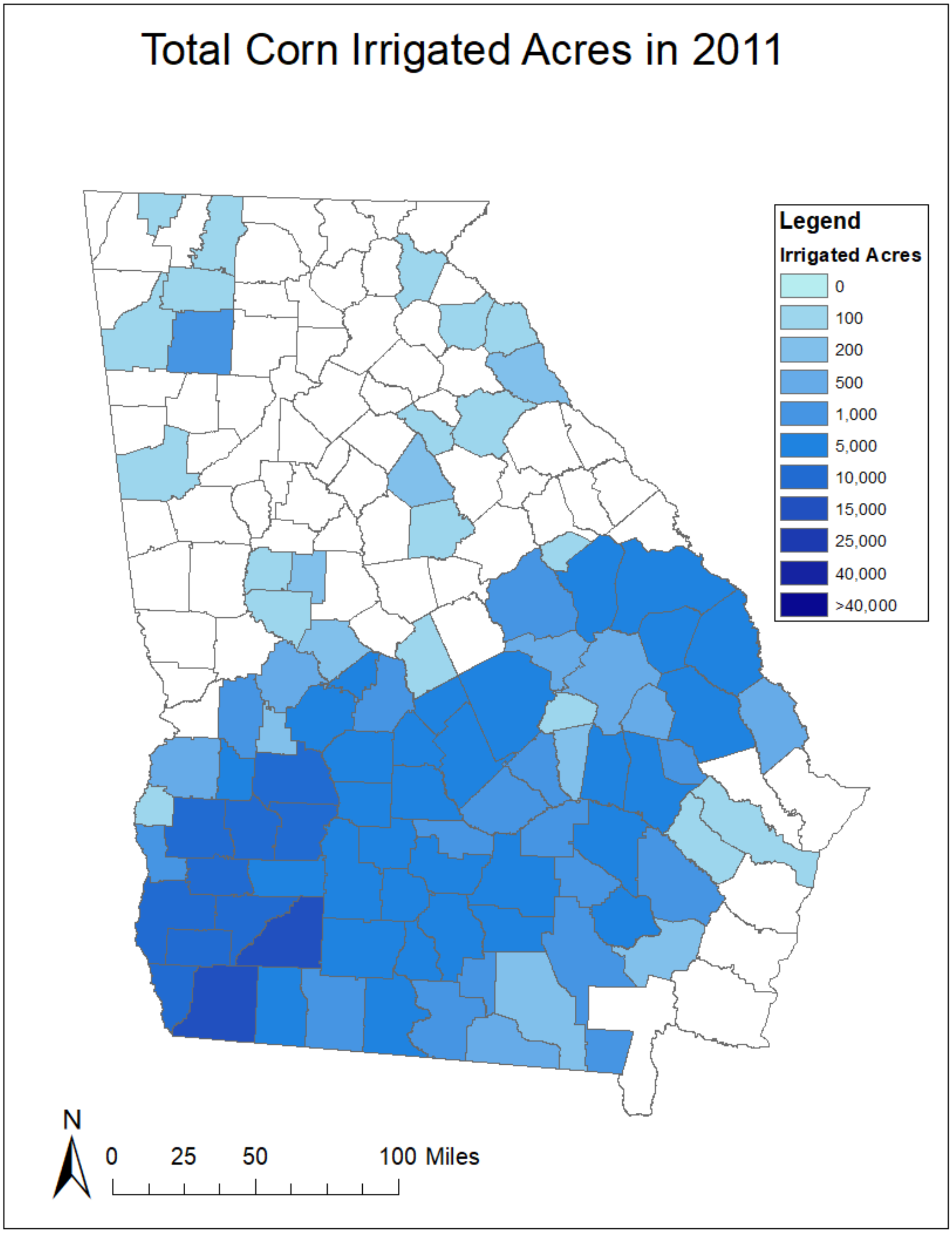

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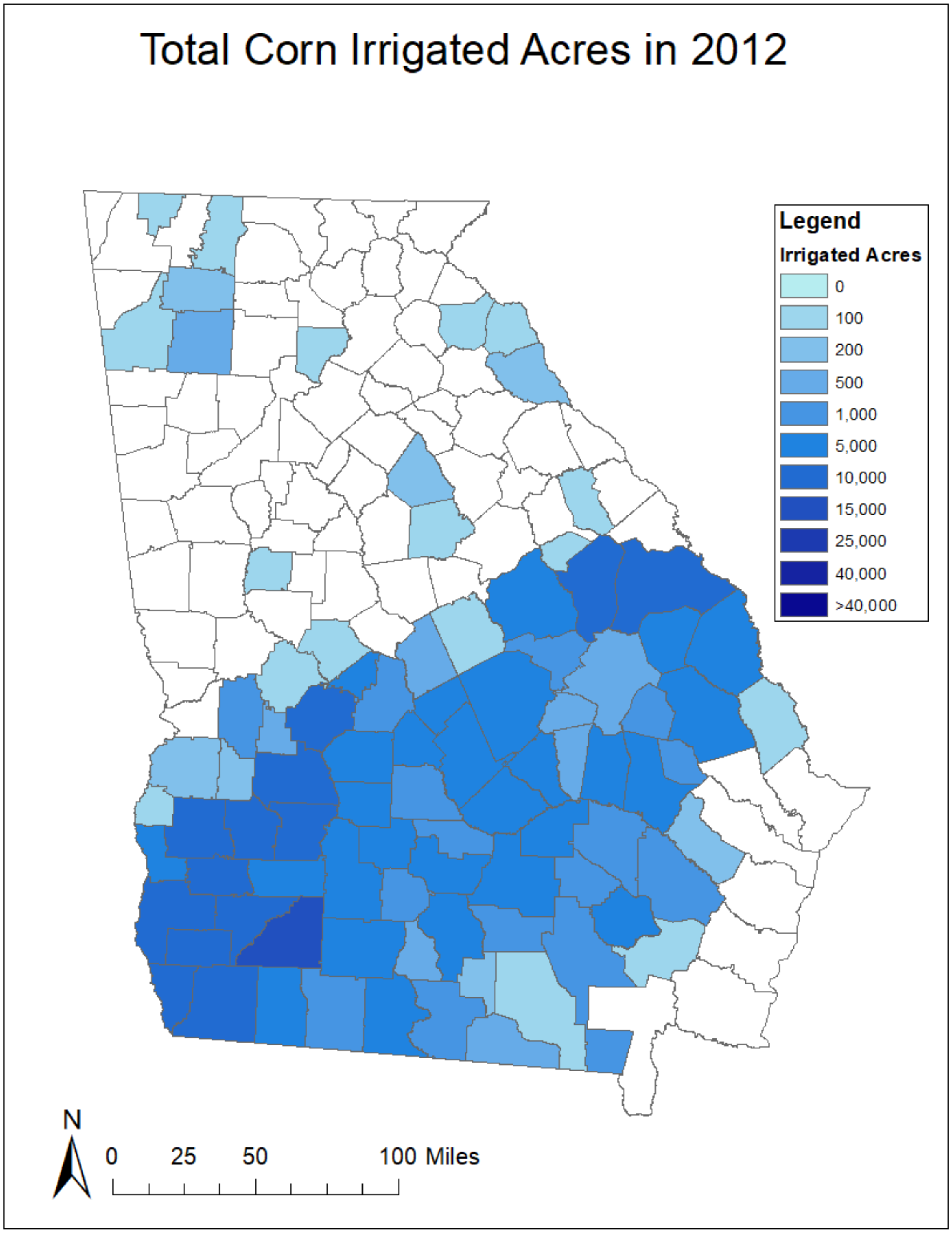

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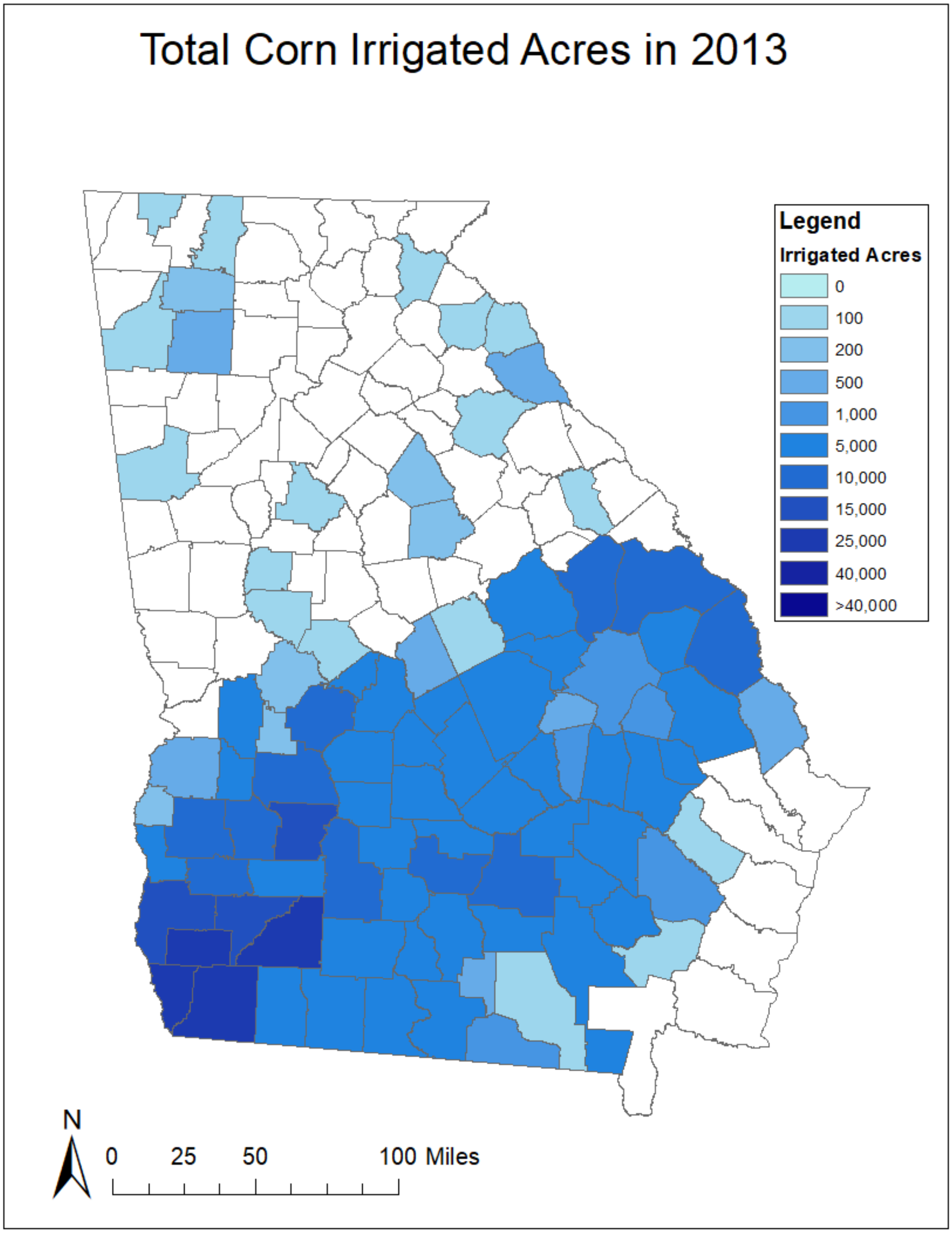

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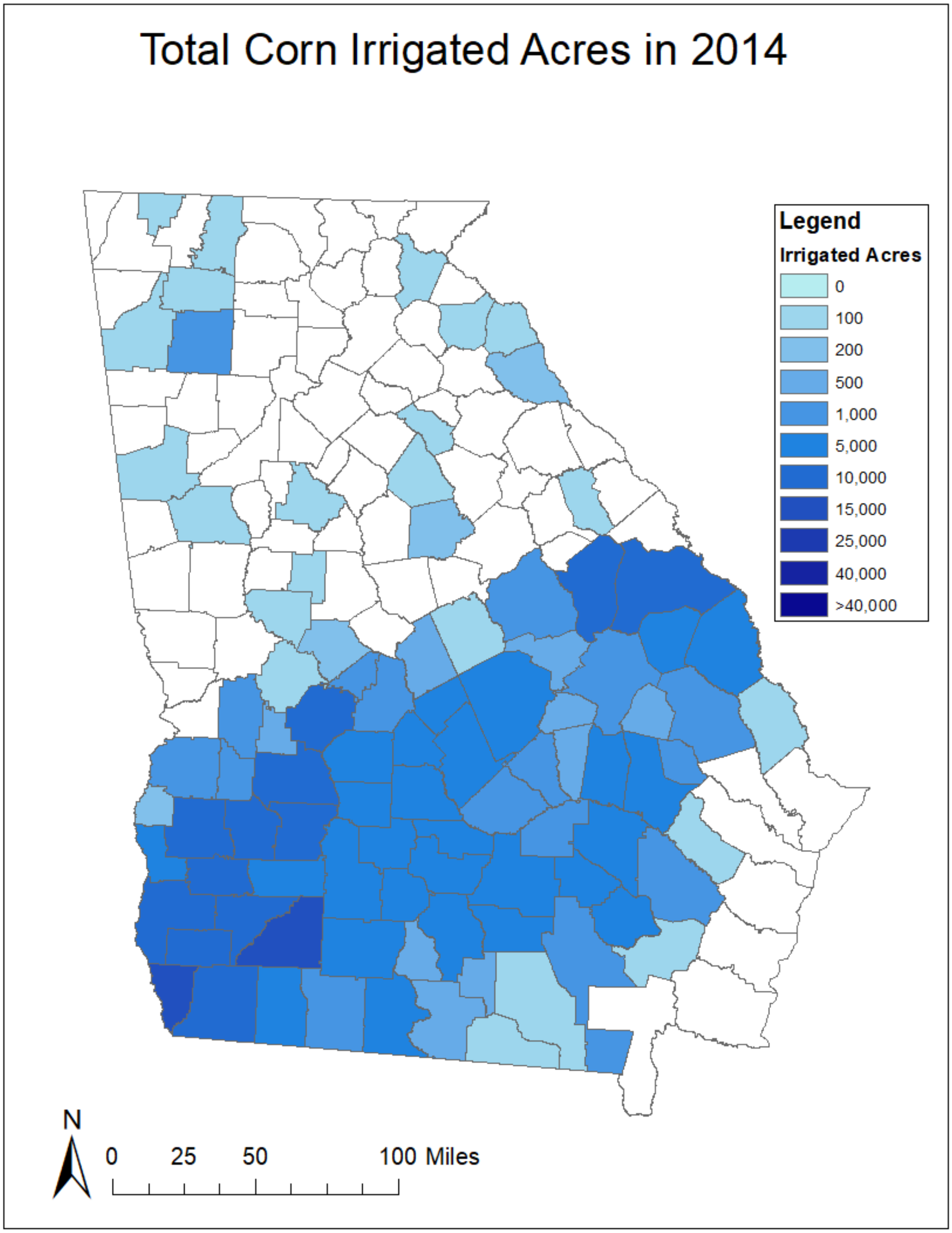

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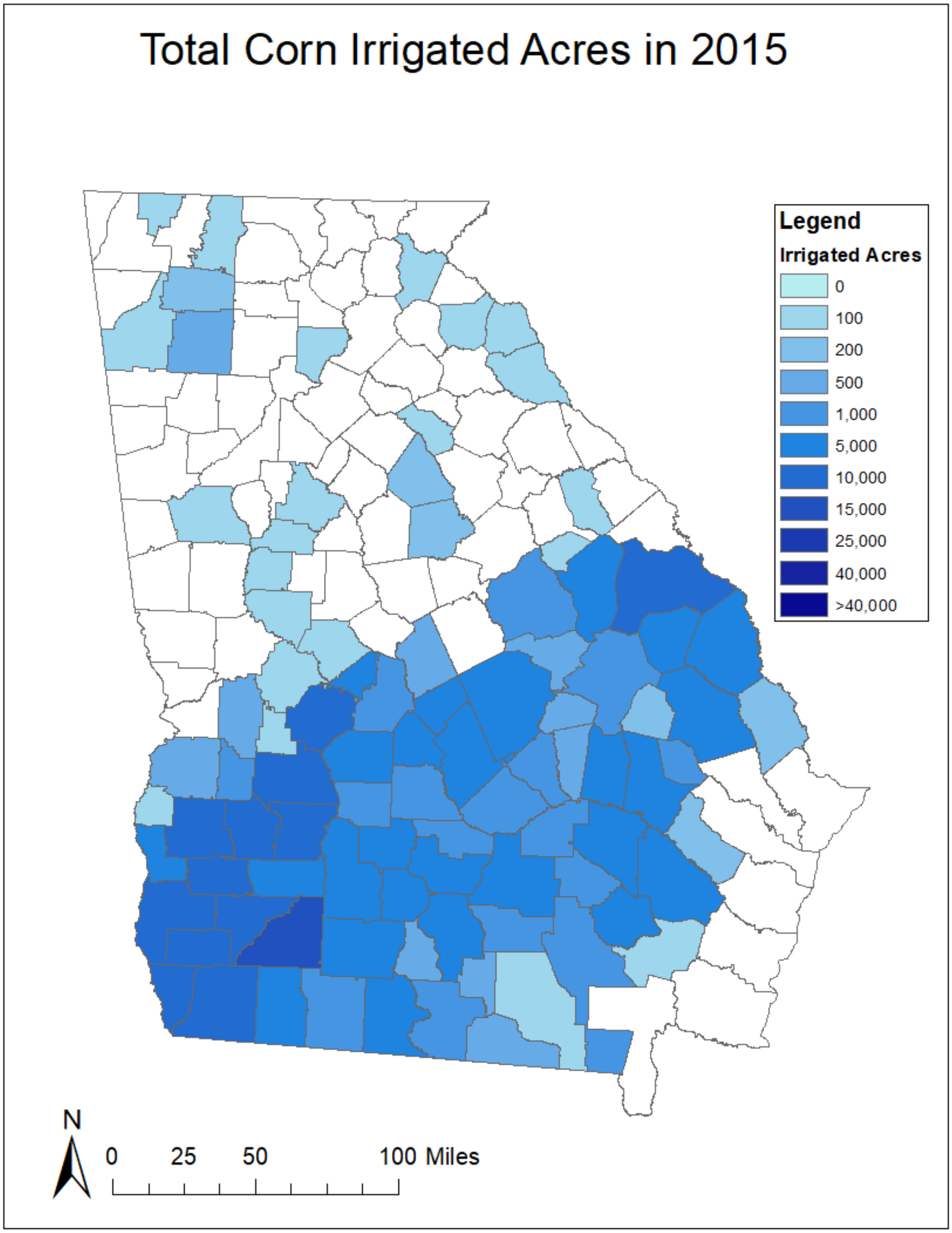

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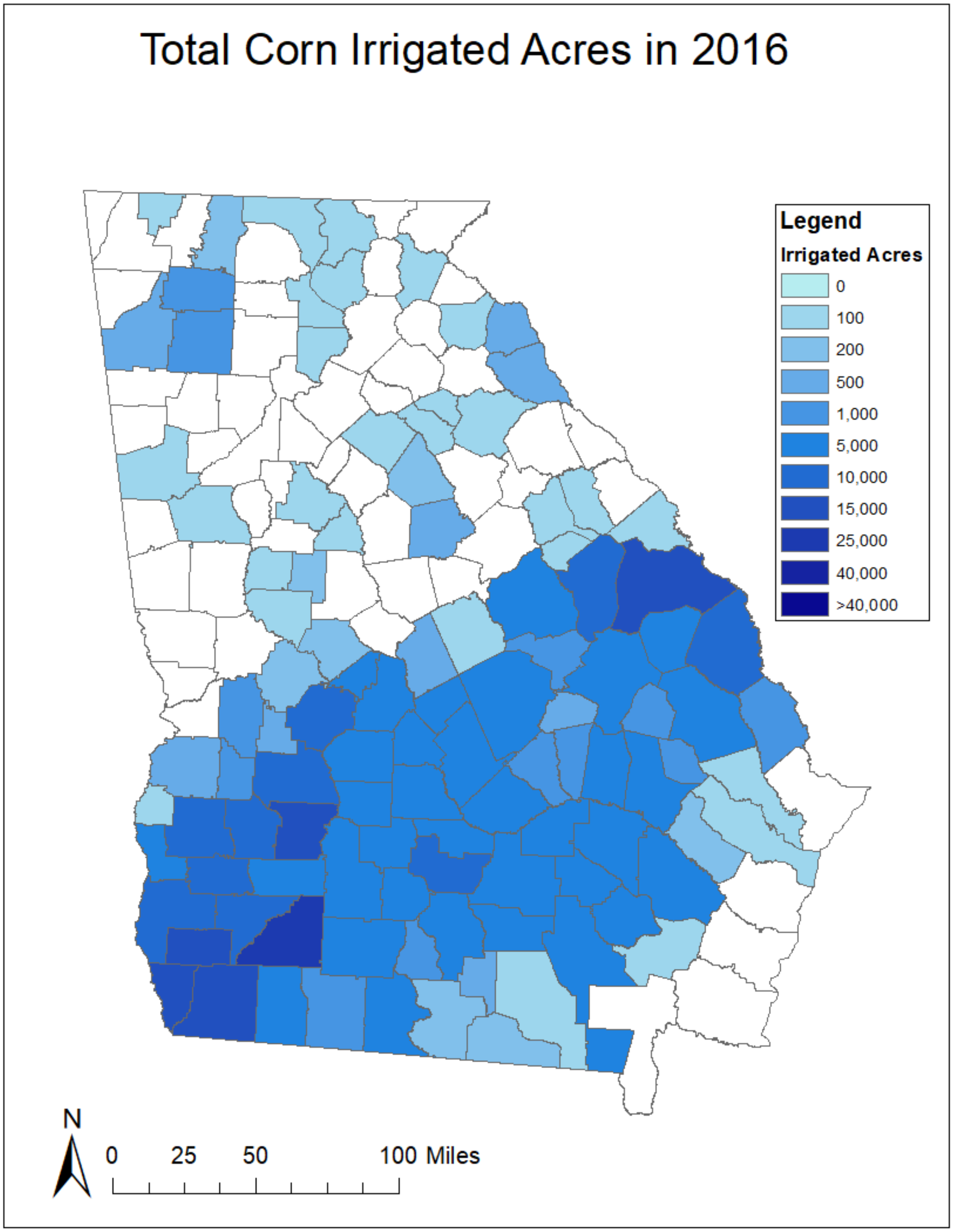

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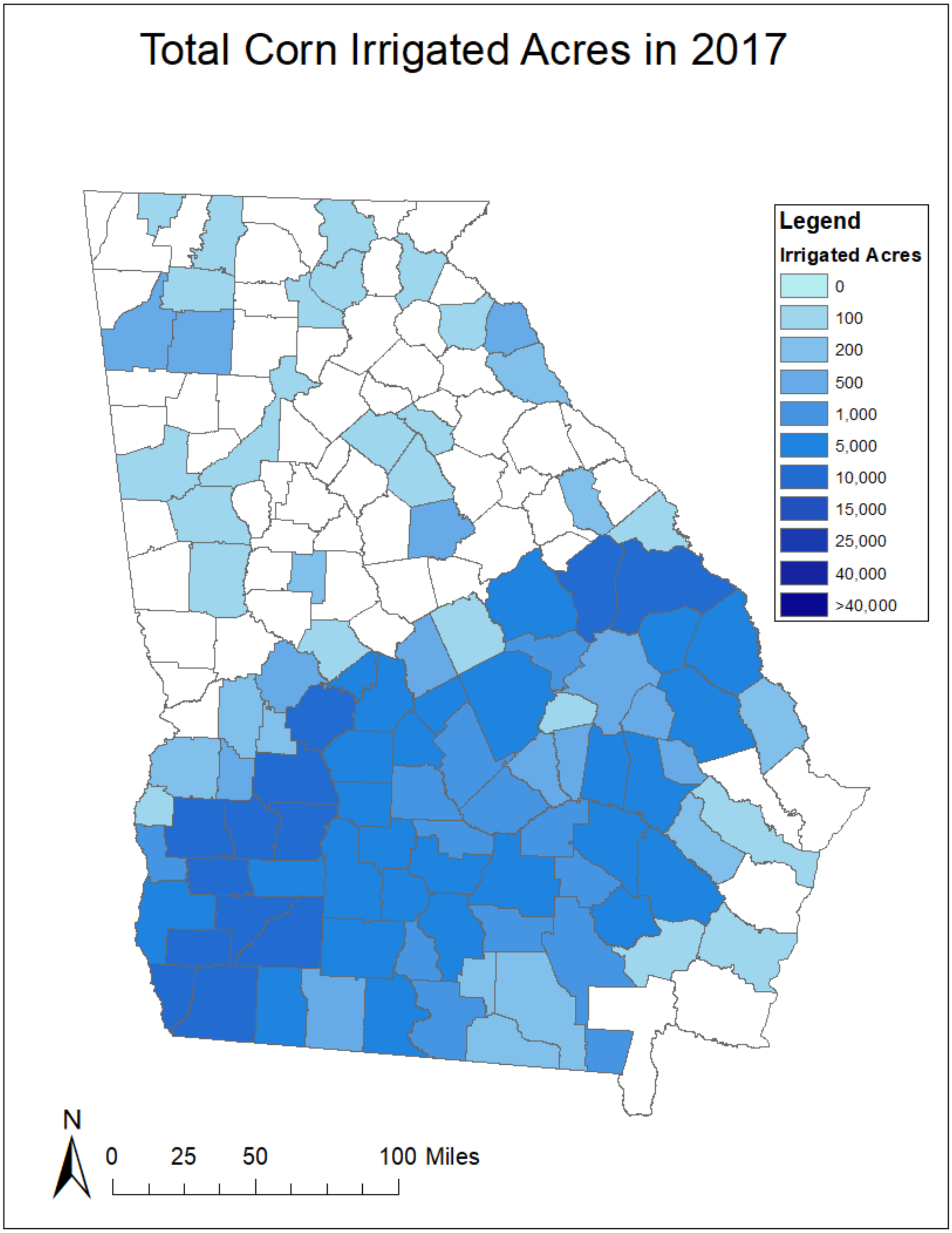
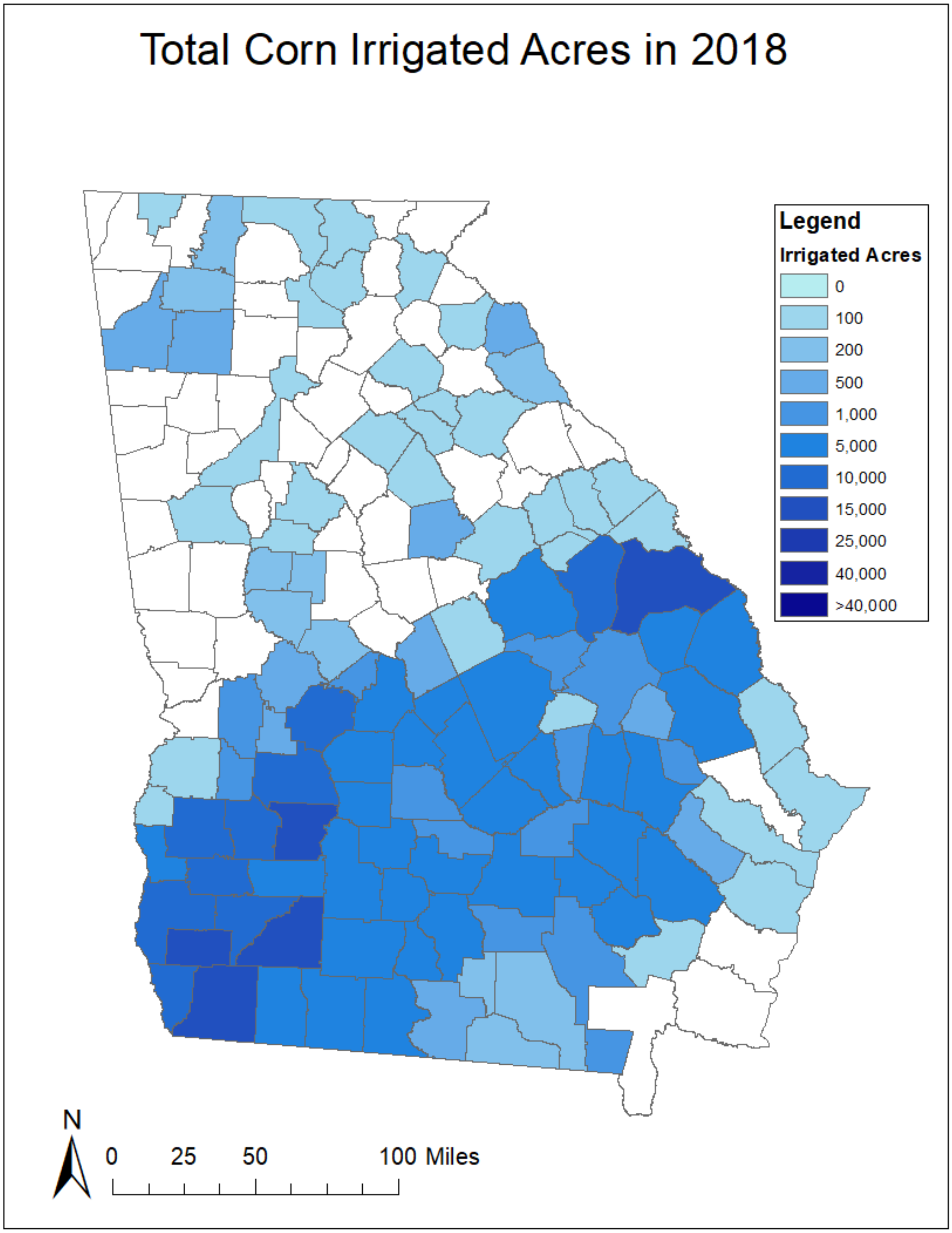
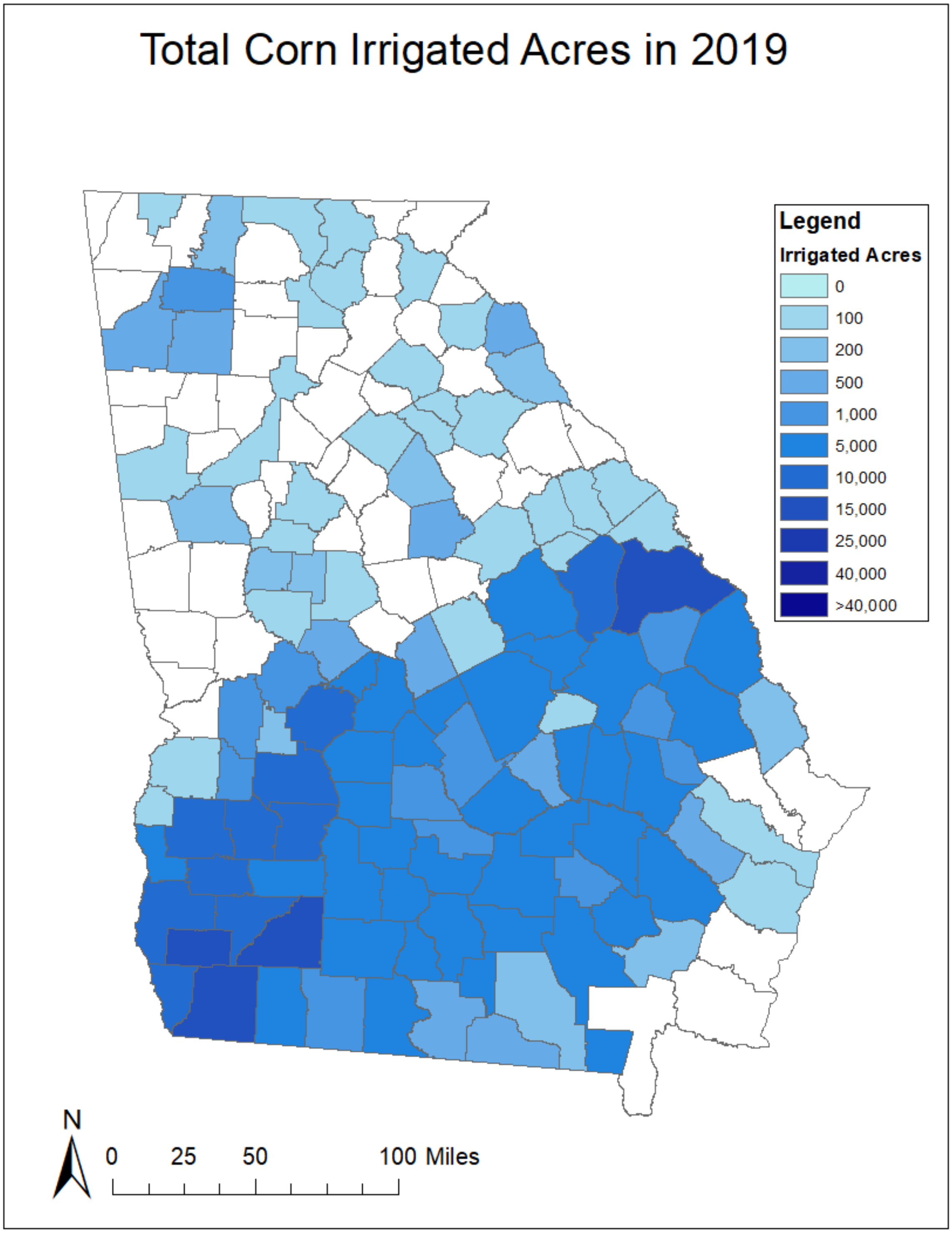


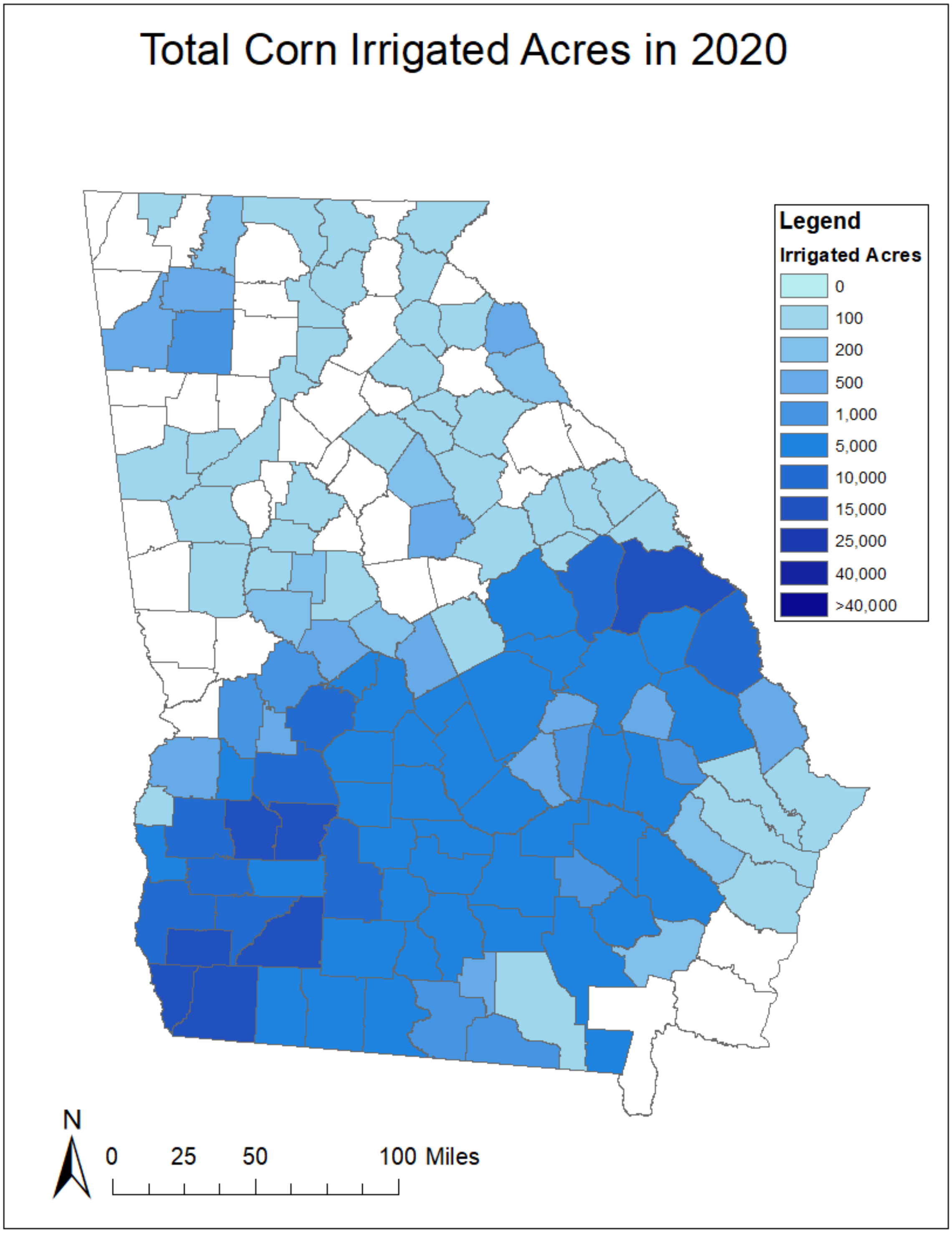
Map A.36 All Corn Irrigated Acres in Georgia for 2017



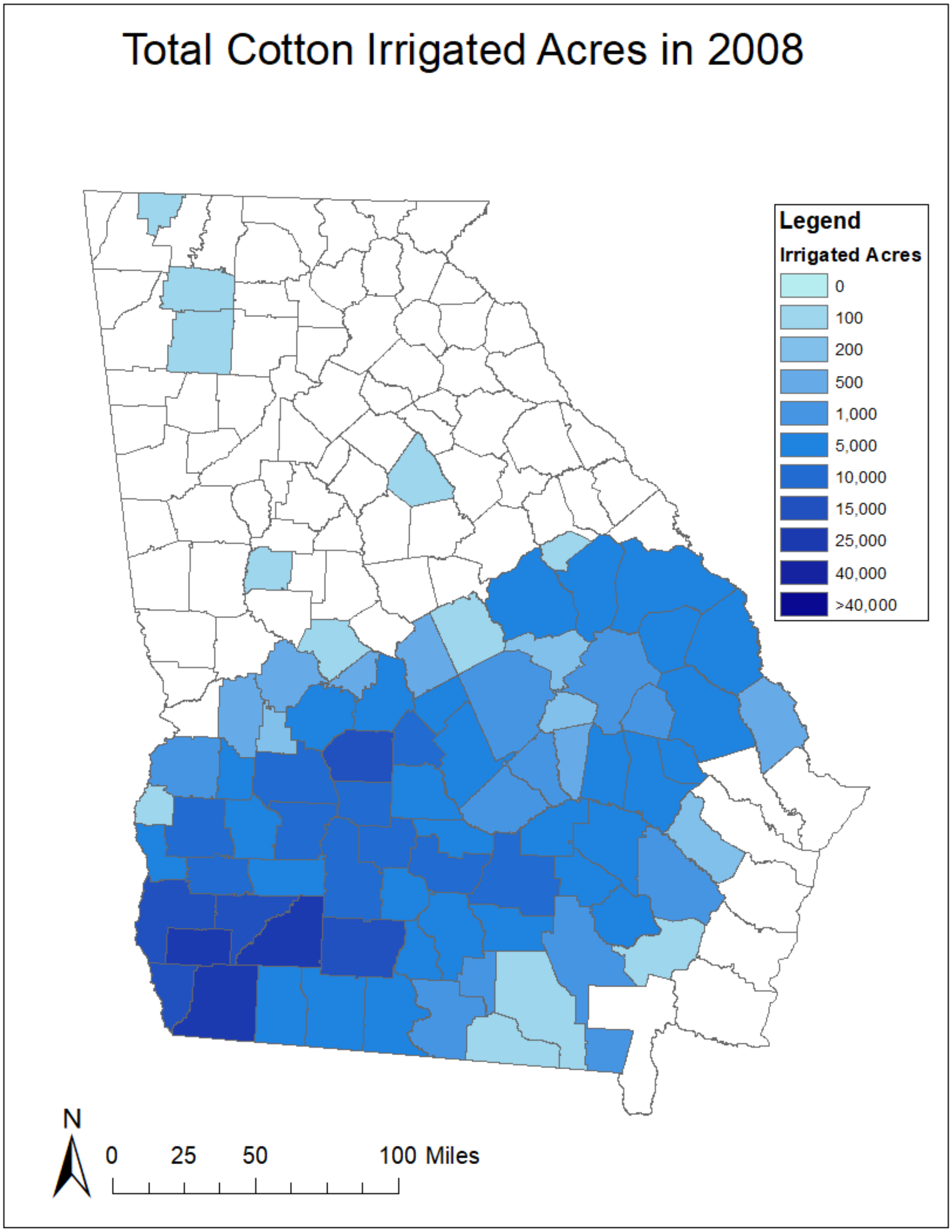
Map A.37 All Corn Irrigated Acres in Georgia for 2018



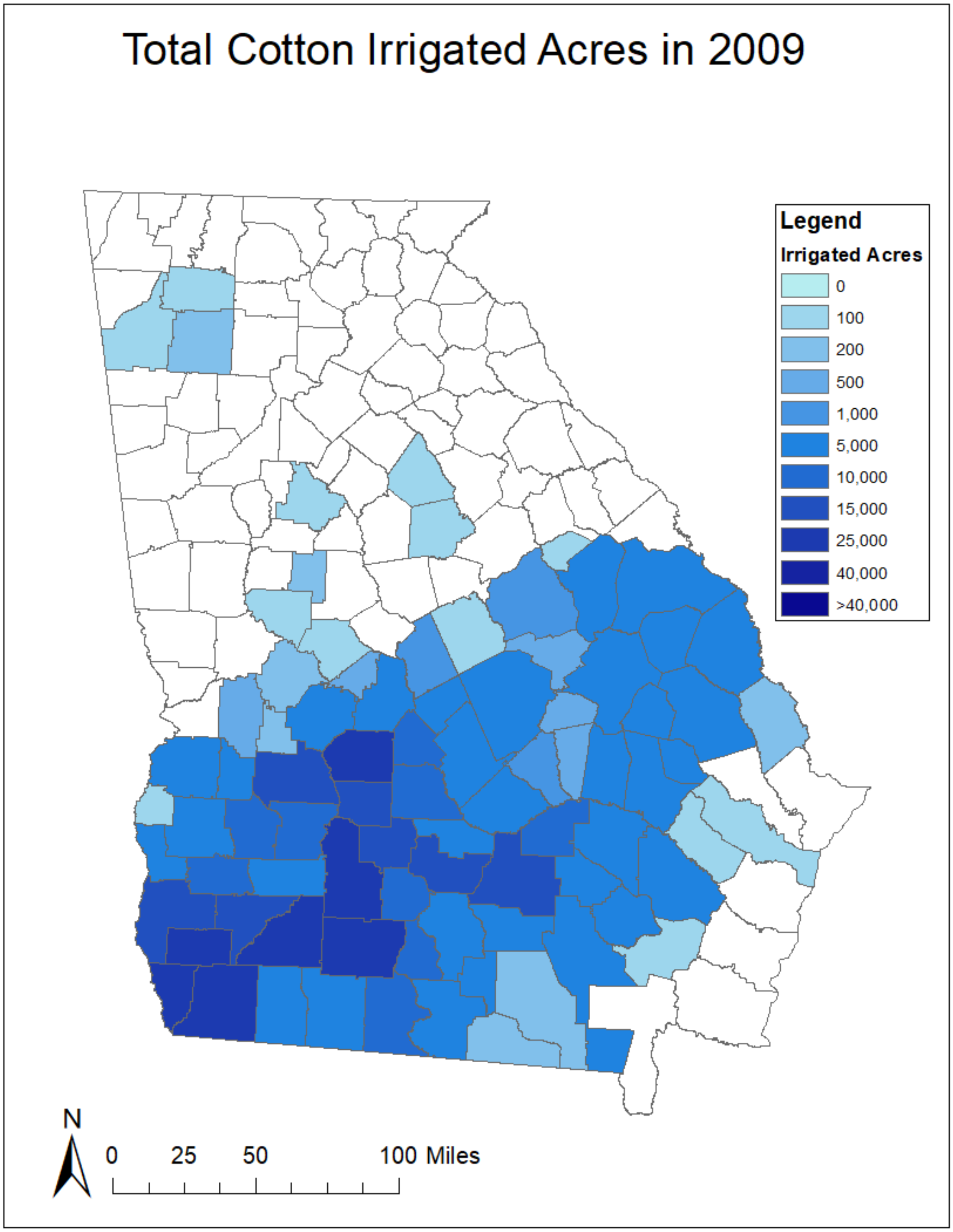
Map A.38 All Corn Irrigated Acres in Georgia for 2019



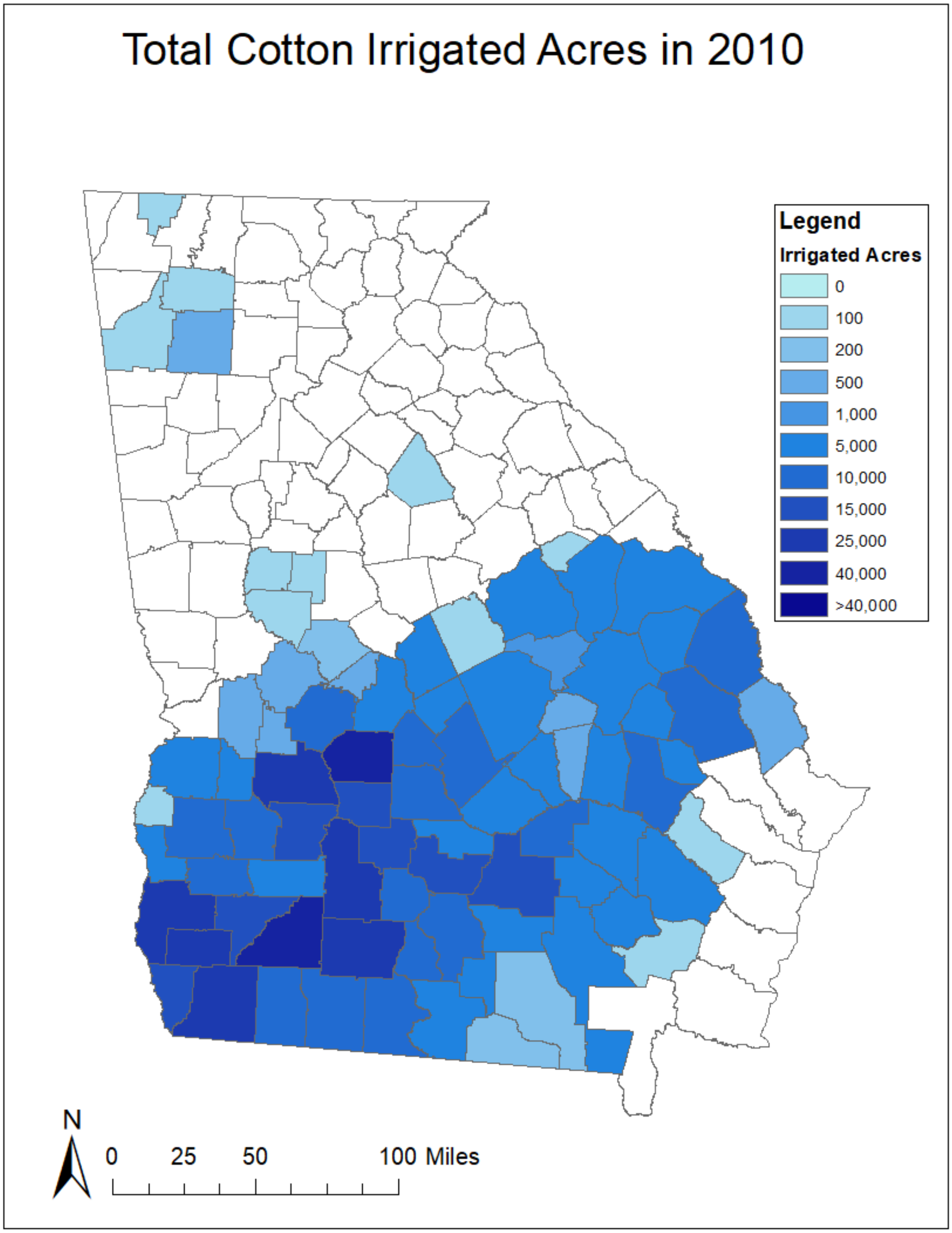
Map A.39 All Corn Irrigated Acres in Georgia for 2020



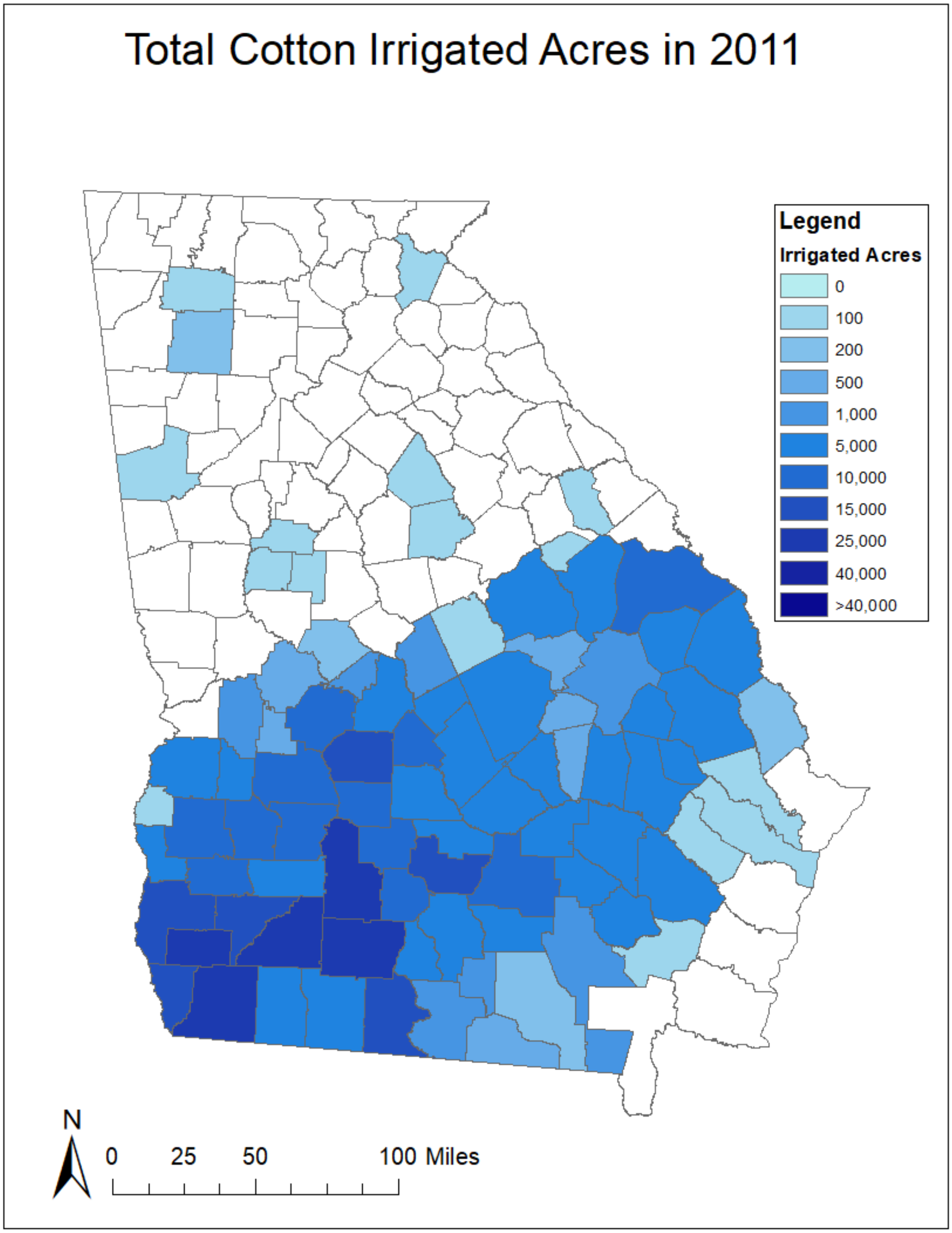
Map A.40 All Cotton Irrigated Acres in Georgia for 2008



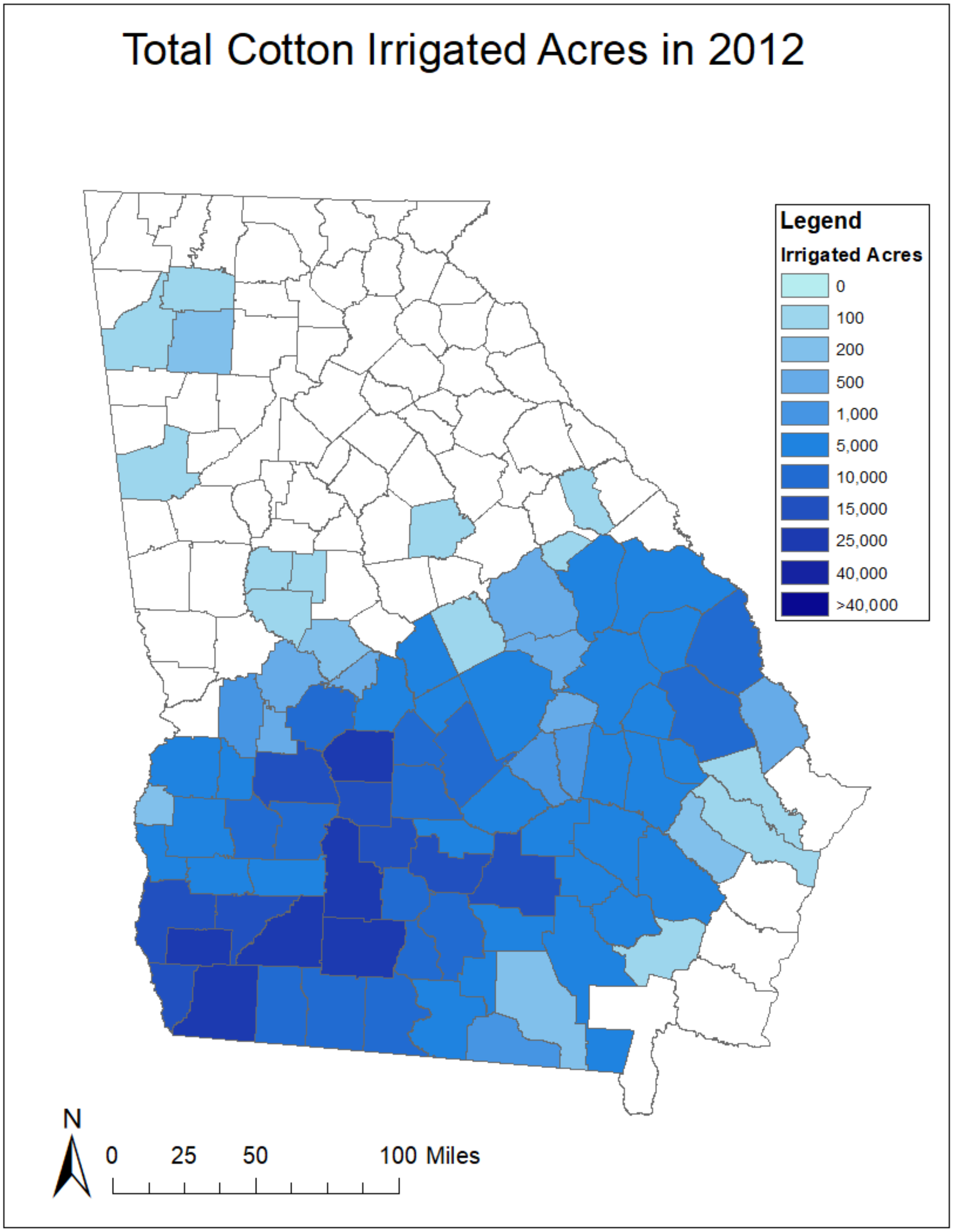
Map A.41 All Cotton Irrigated Acres in Georgia for 2009



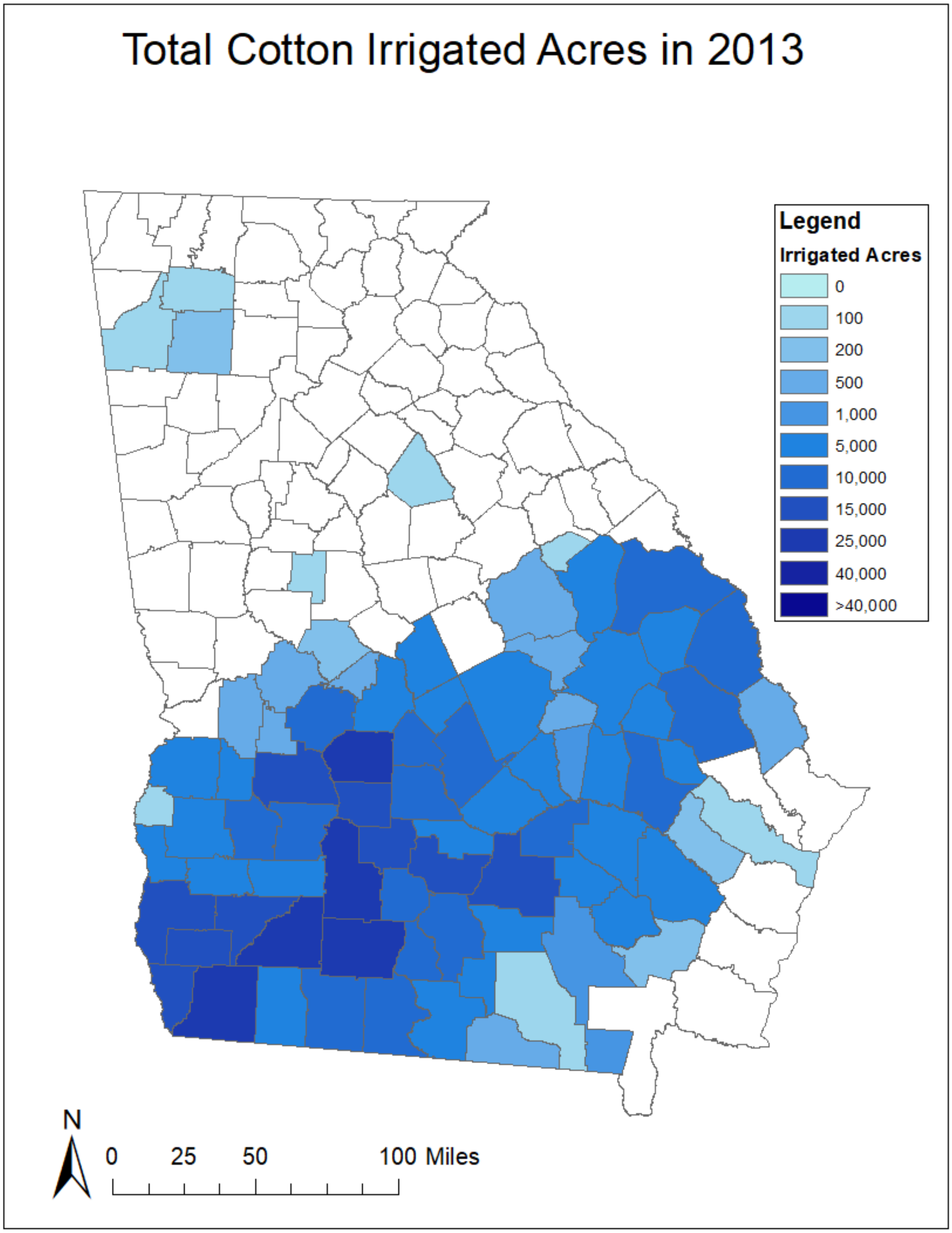
Map A.42 All Cotton Irrigated Acres in Georgia for 2010



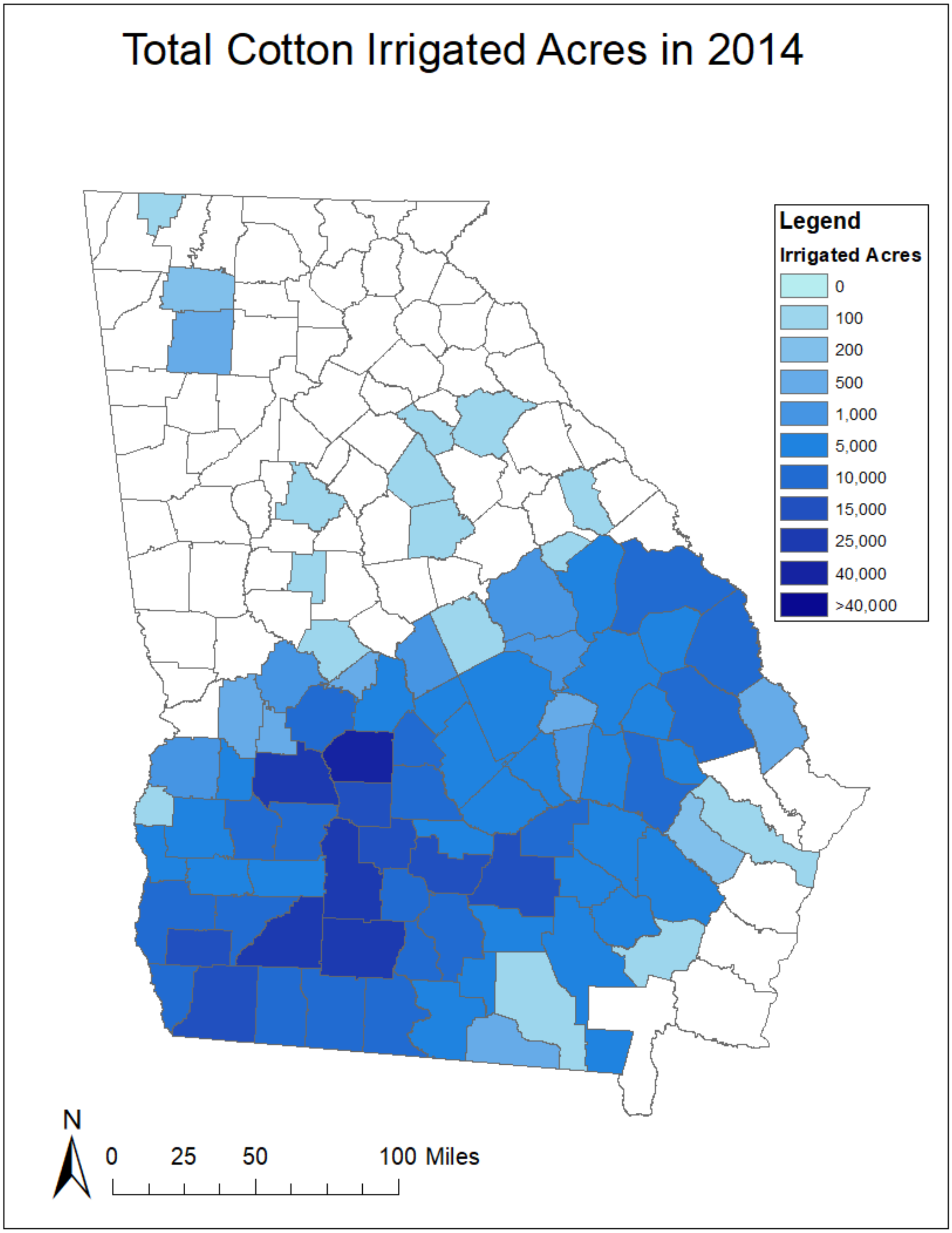
Map A.43 All Cotton Irrigated Acres in Georgia for 2011



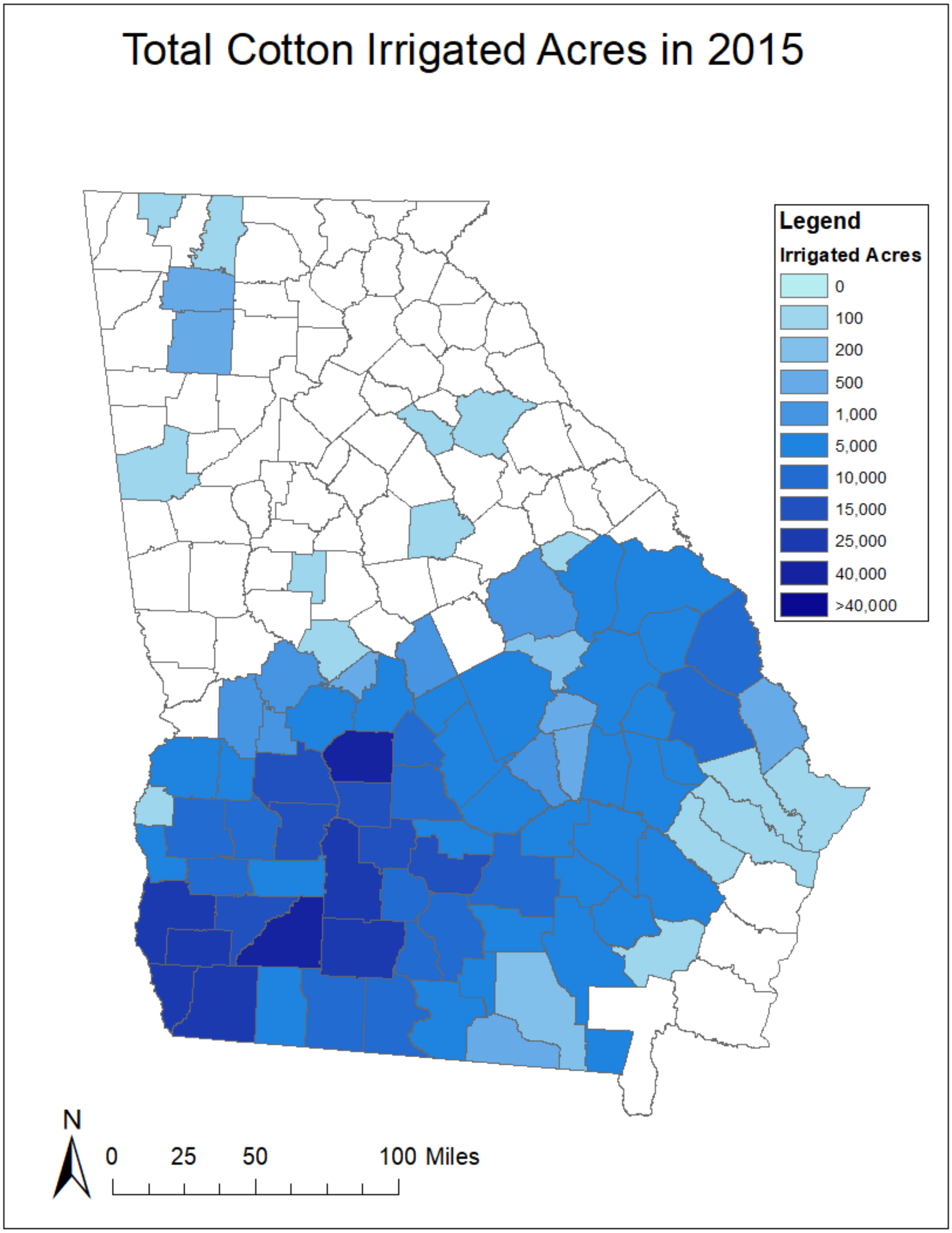
Map A.44 All Cotton Irrigated Acres in Georgia for 2012



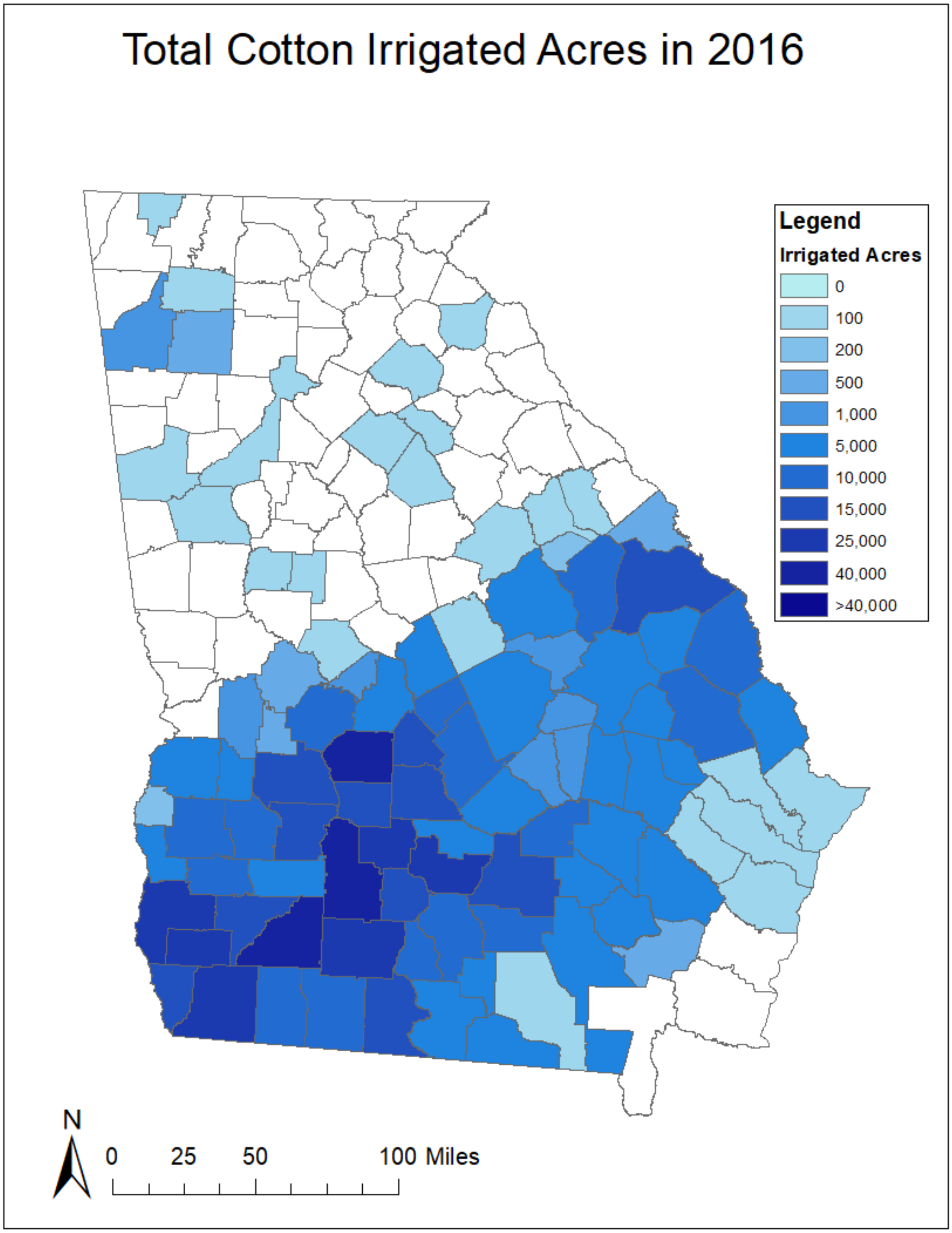
Map A.45 All Cotton Irrigated Acres in Georgia for 2013



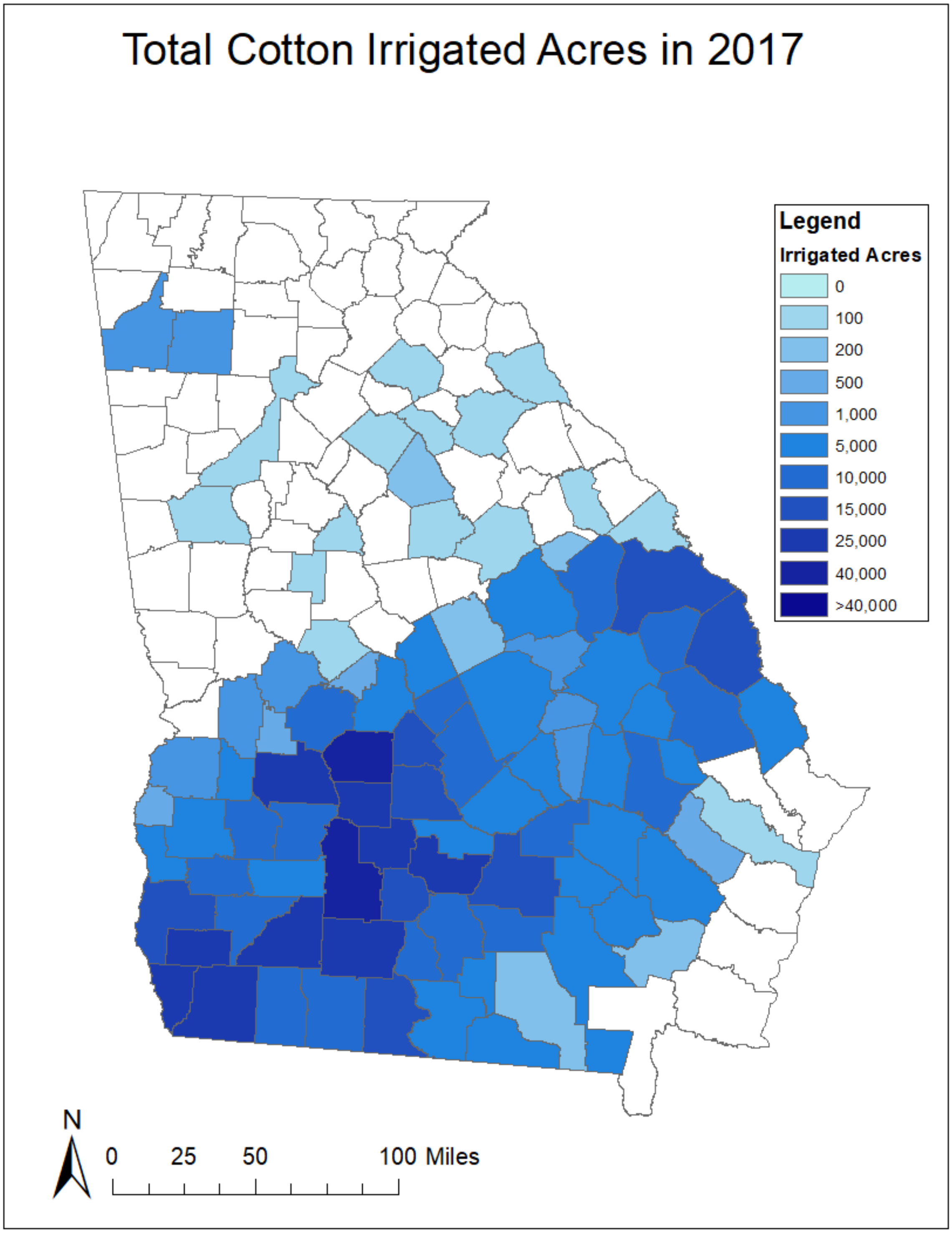
Map A.46 All Cotton Irrigated Acres in Georgia for 2014



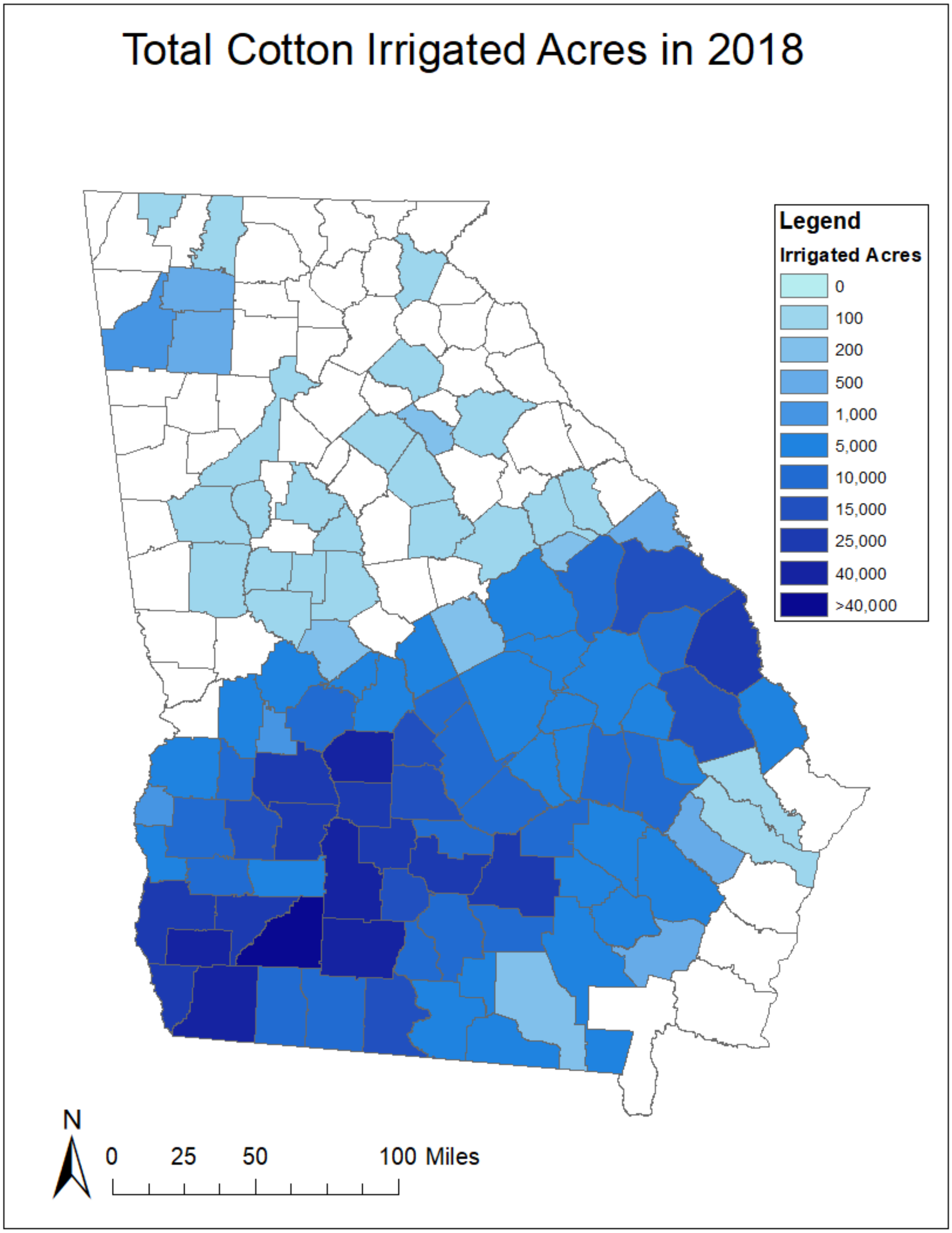
Map A.47 All Cotton Irrigated Acres in Georgia for 2015



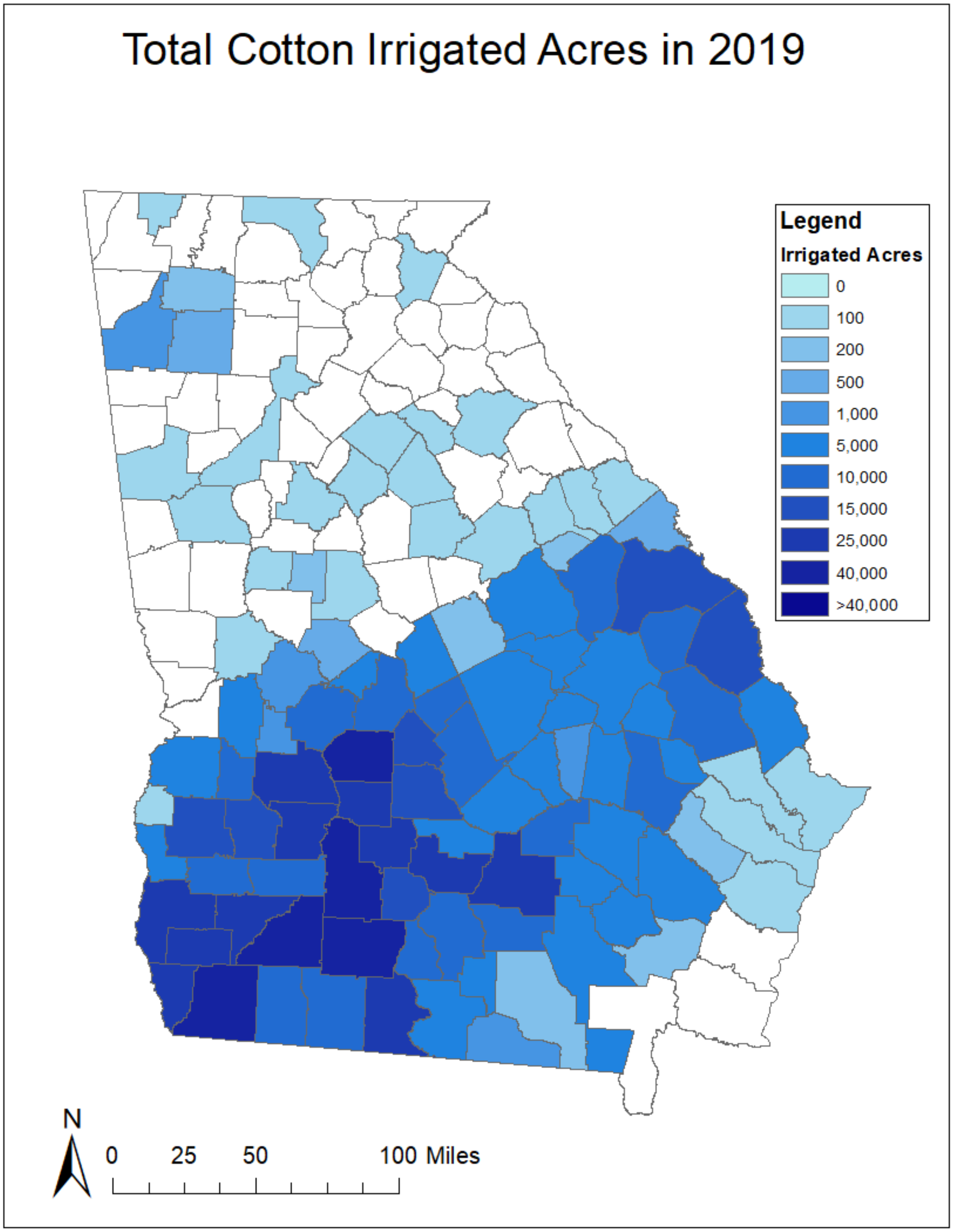
Map A.48 All Cotton Irrigated Acres in Georgia for 2016



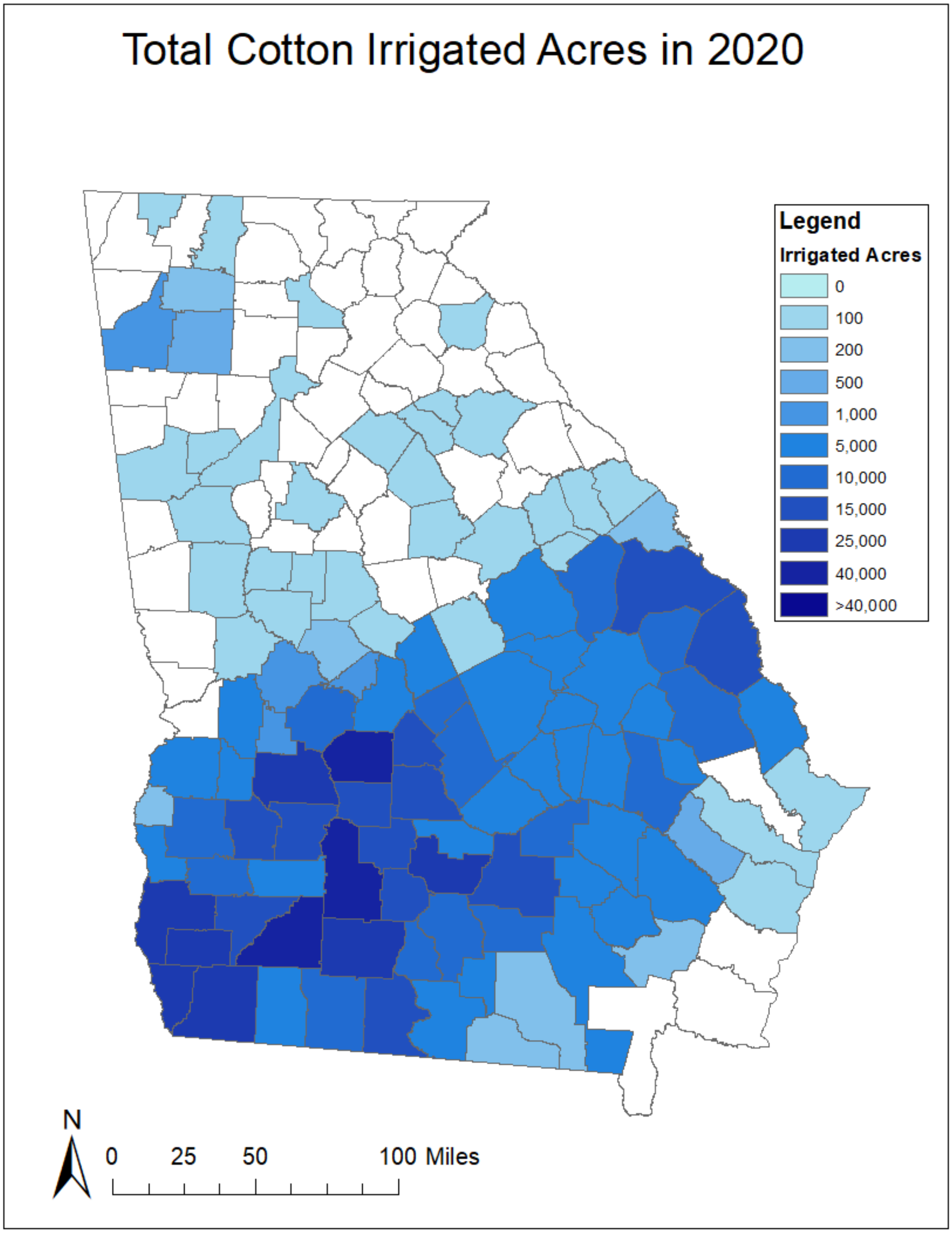
Map A.49 All Cotton Irrigated Acres in Georgia for 2017



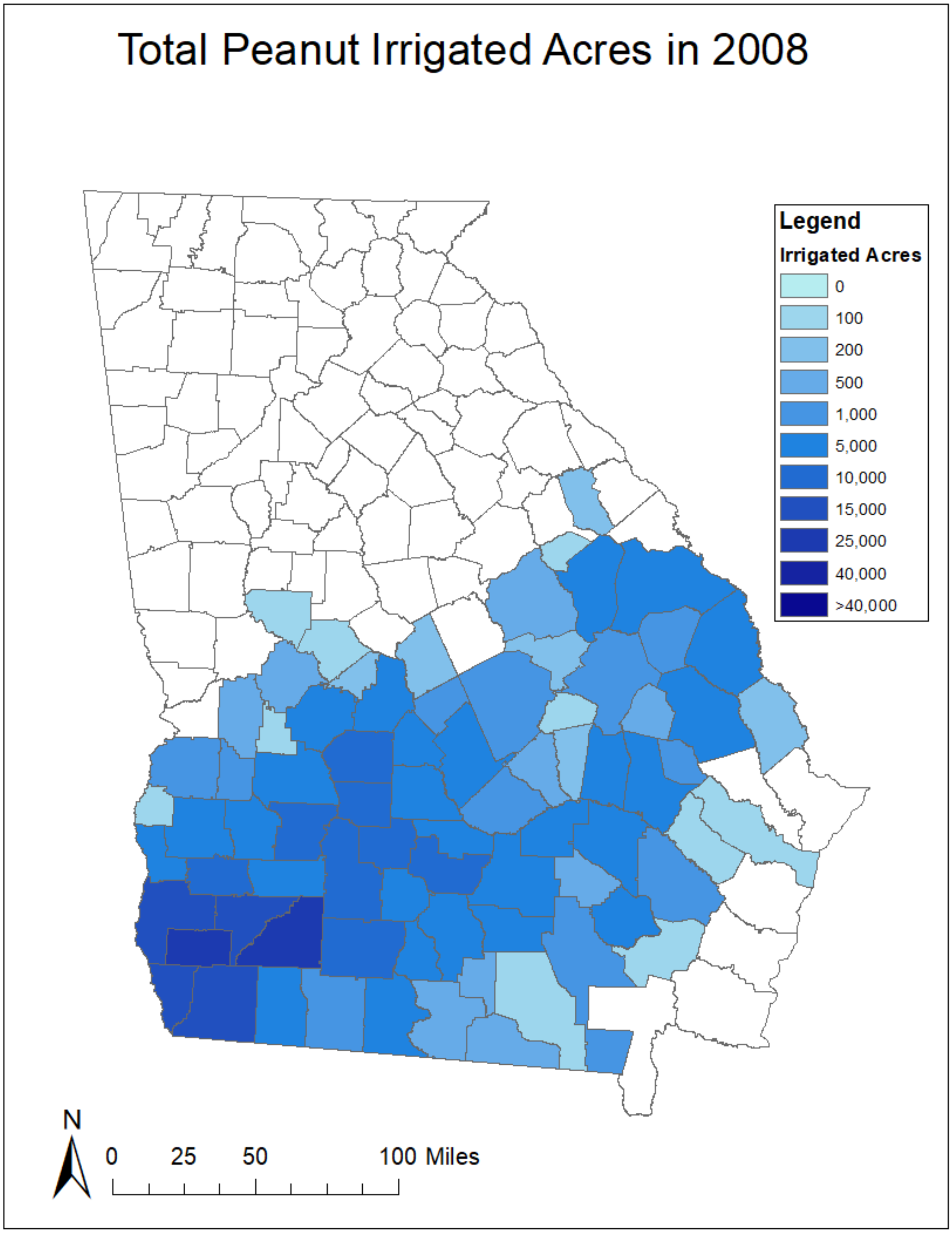
Map A.50 All Cotton Irrigated Acres in Georgia for 2018



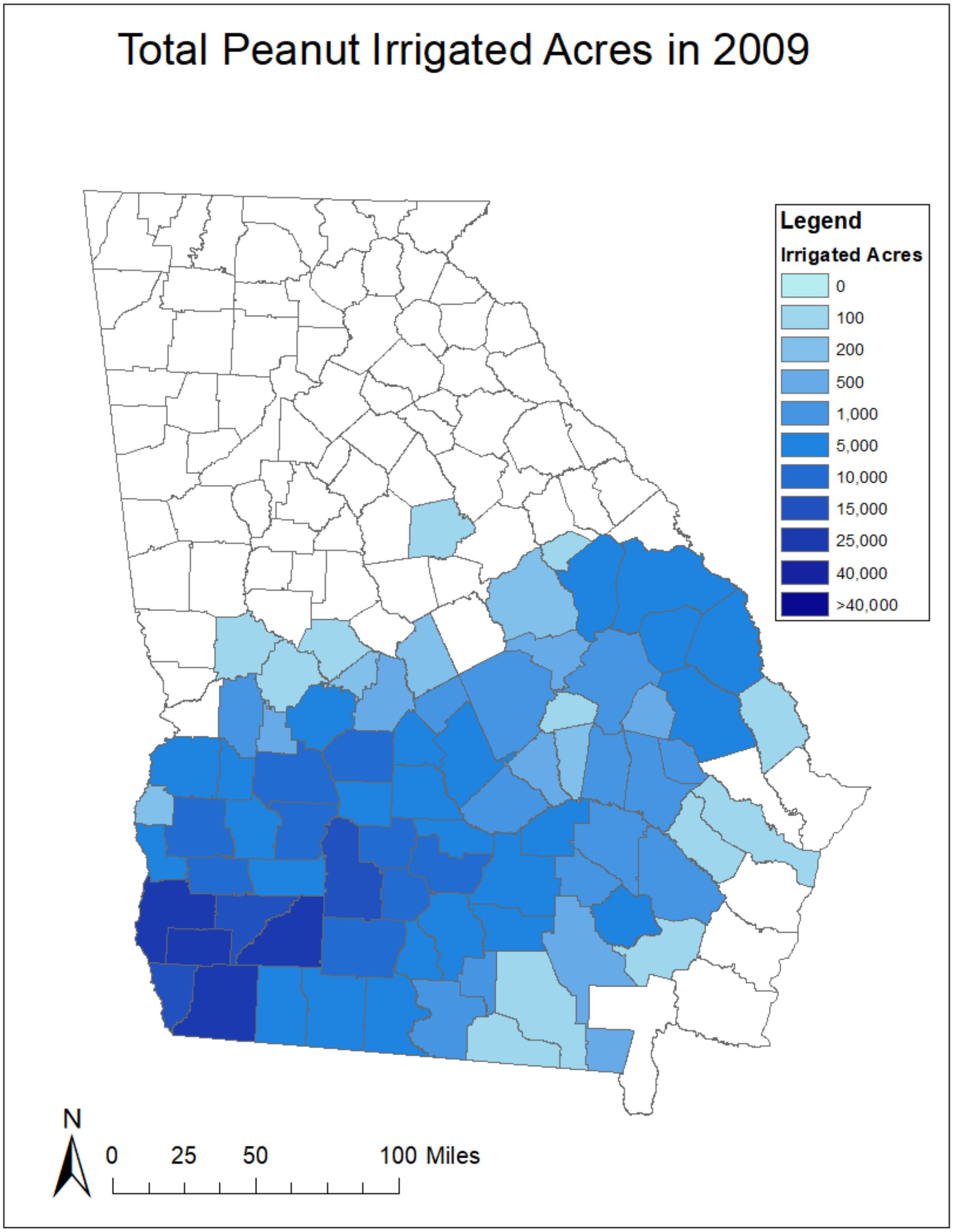
Map A.51 All Cotton Irrigated Acres in Georgia for 2019



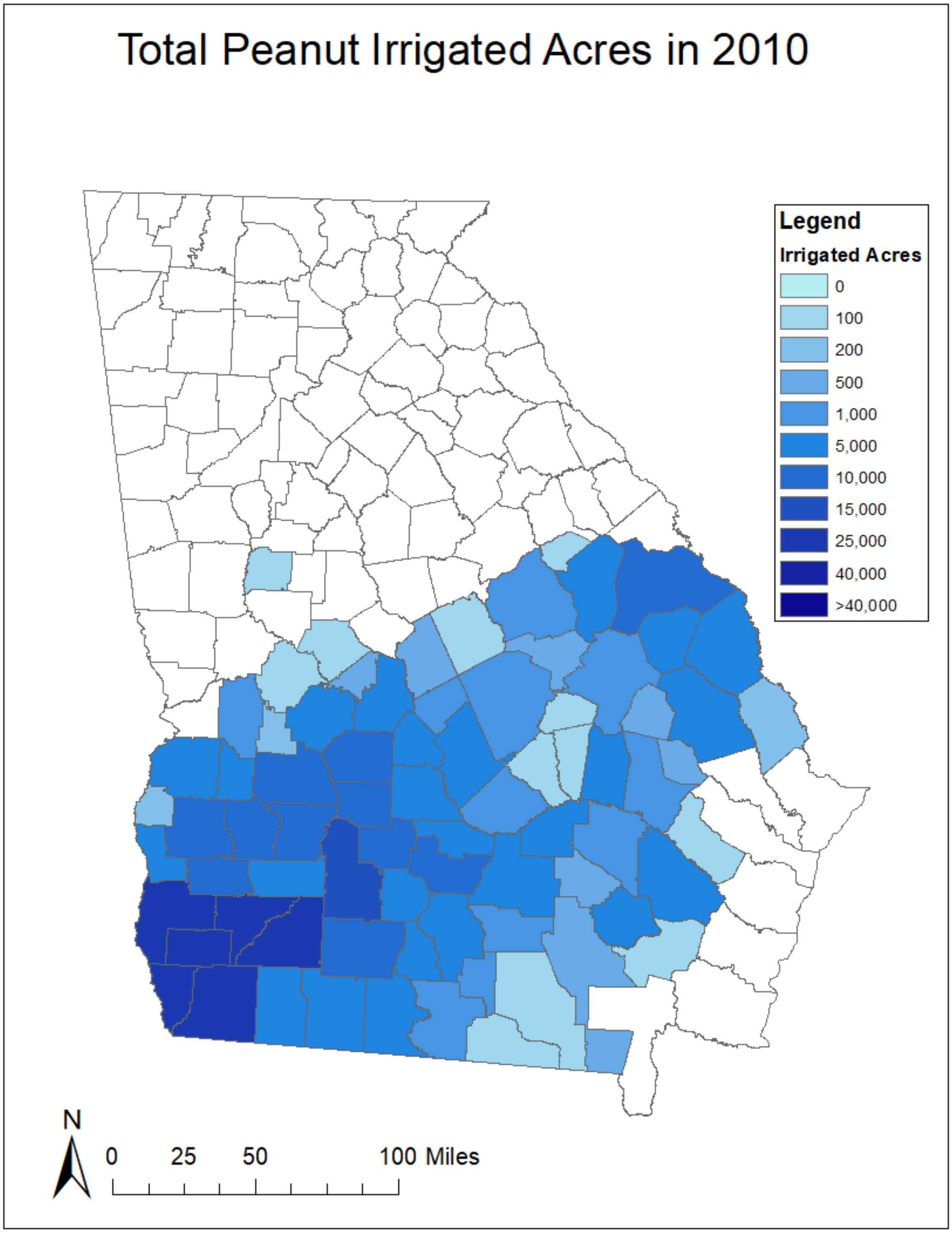
Map A.52 All Cotton Irrigated Acres in Georgia for 2020



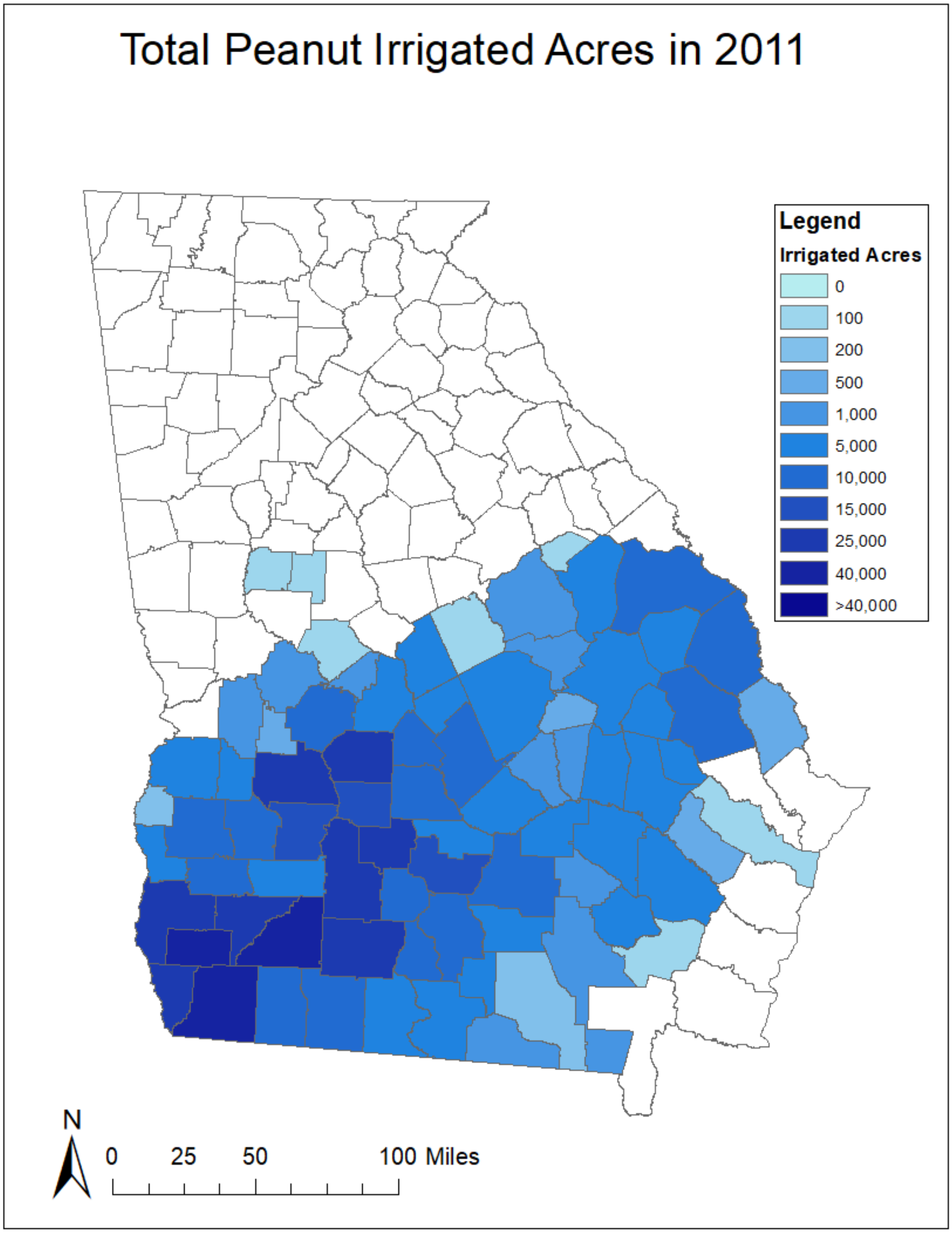
Map A.53 All Peanut Irrigated Acres in Georgia for 2008



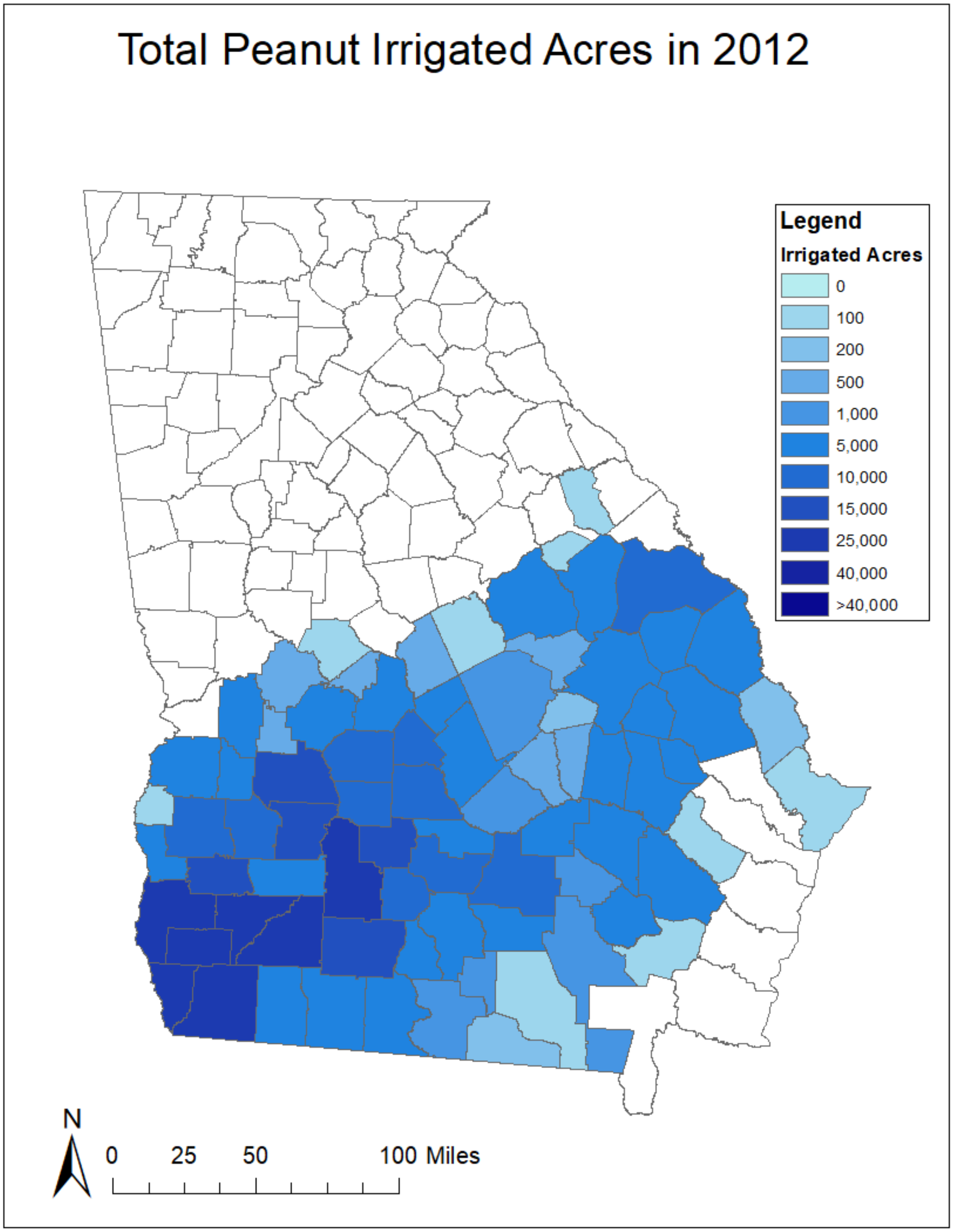
Map A.54 All Peanut Irrigated Acres in Georgia for 2009



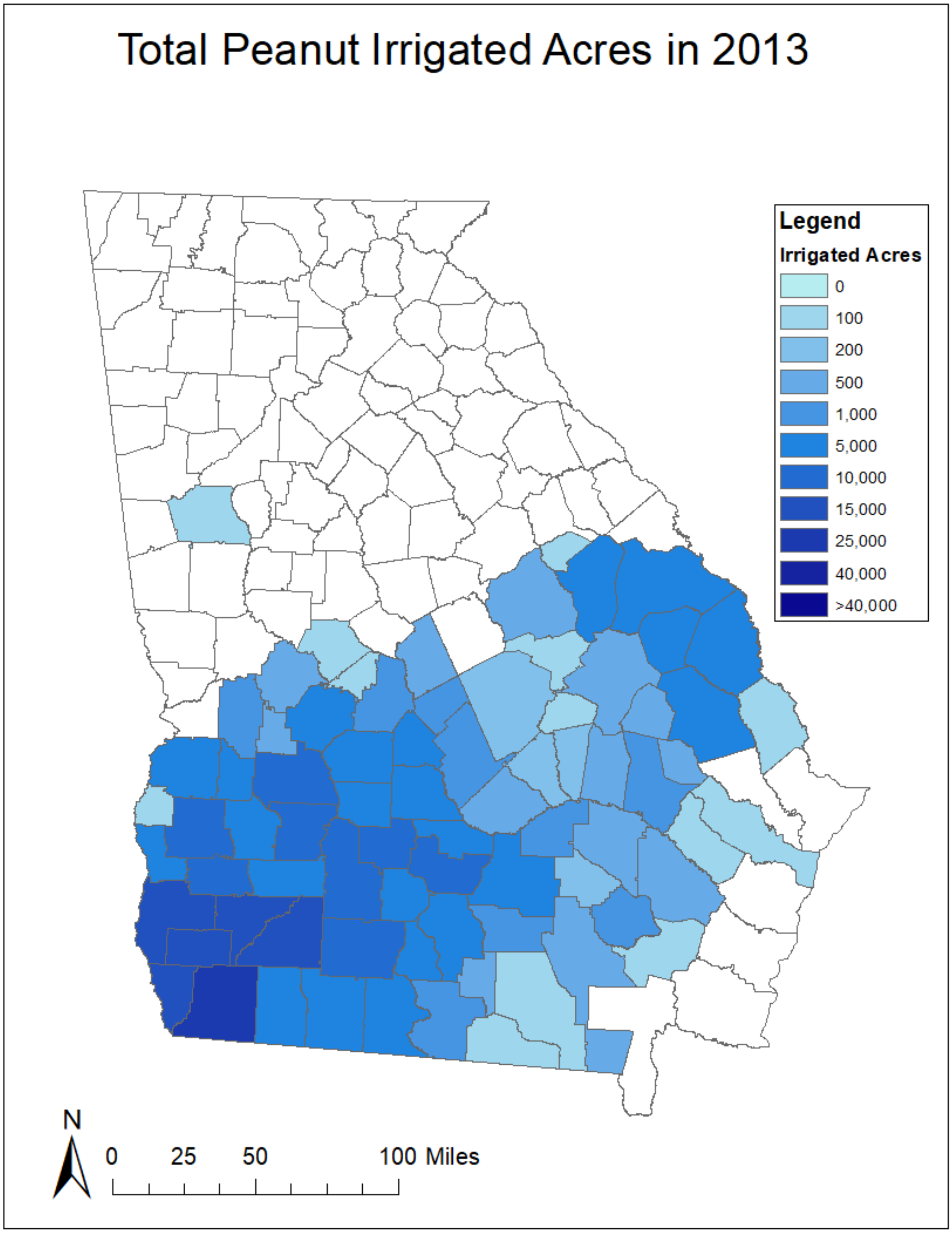
Map A.55 All Peanut Irrigated Acres in Georgia for 2010



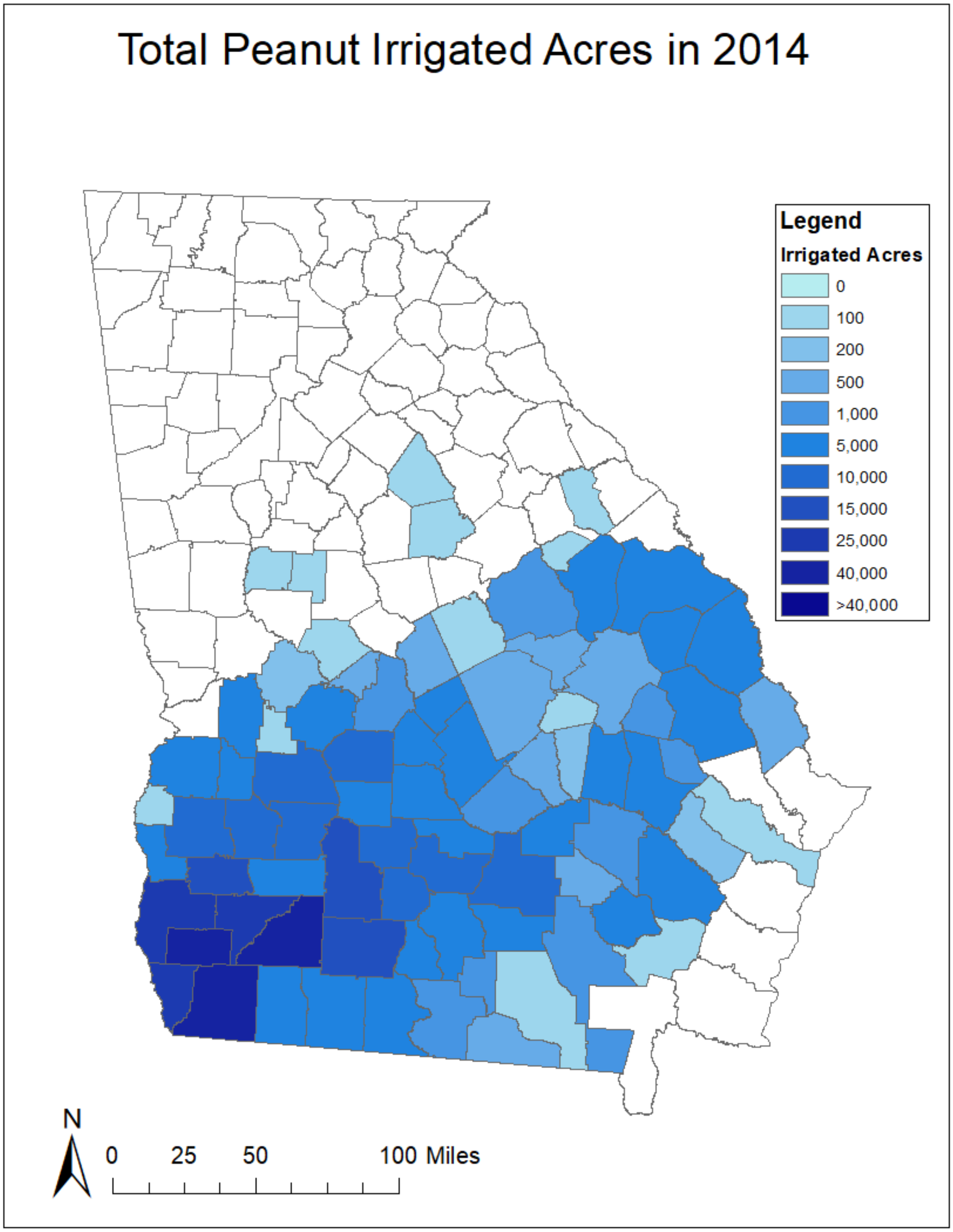
Map A.56 All Peanut Irrigated Acres in Georgia for 2011



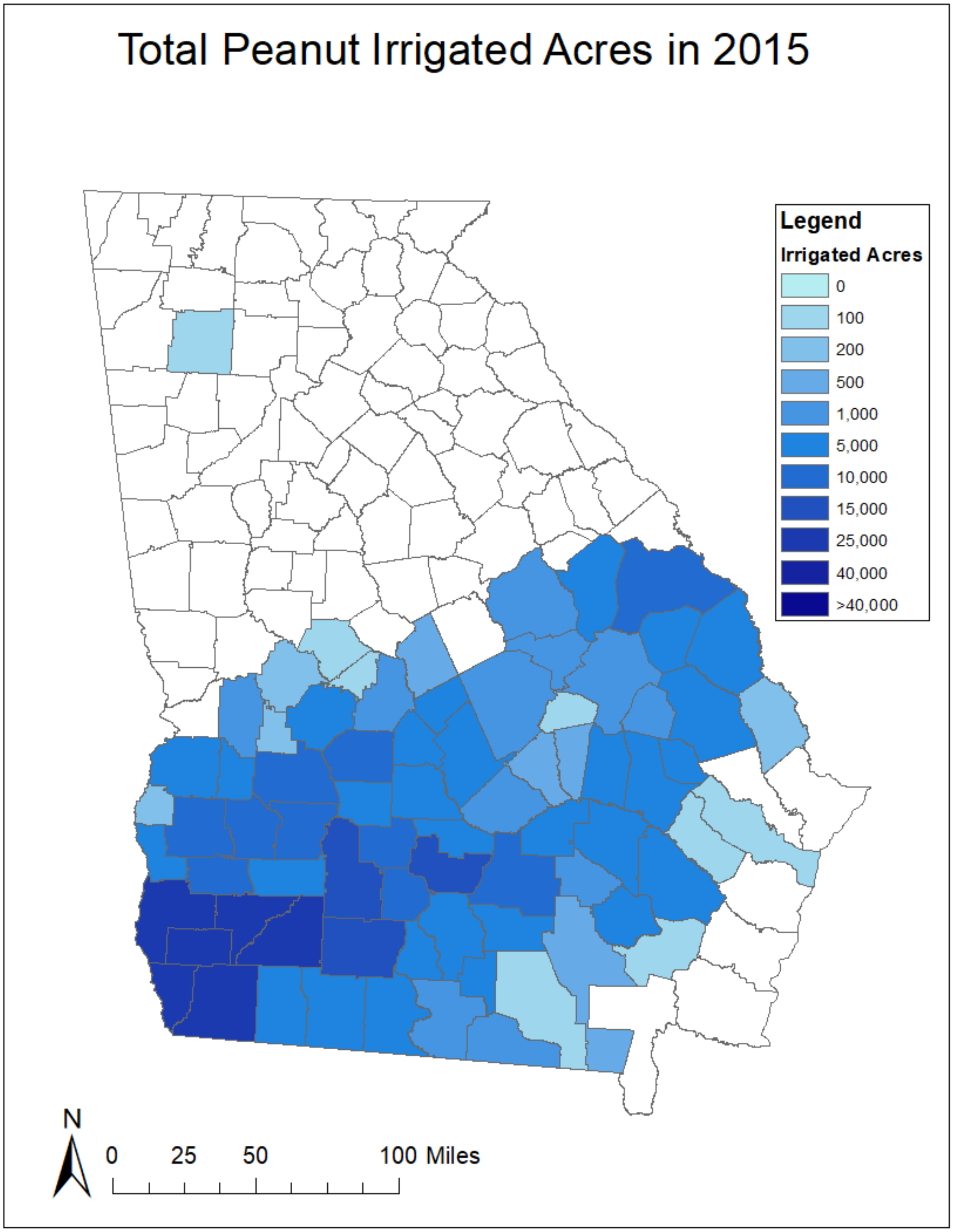
Map A.57 All Peanut Irrigated Acres in Georgia for 2012



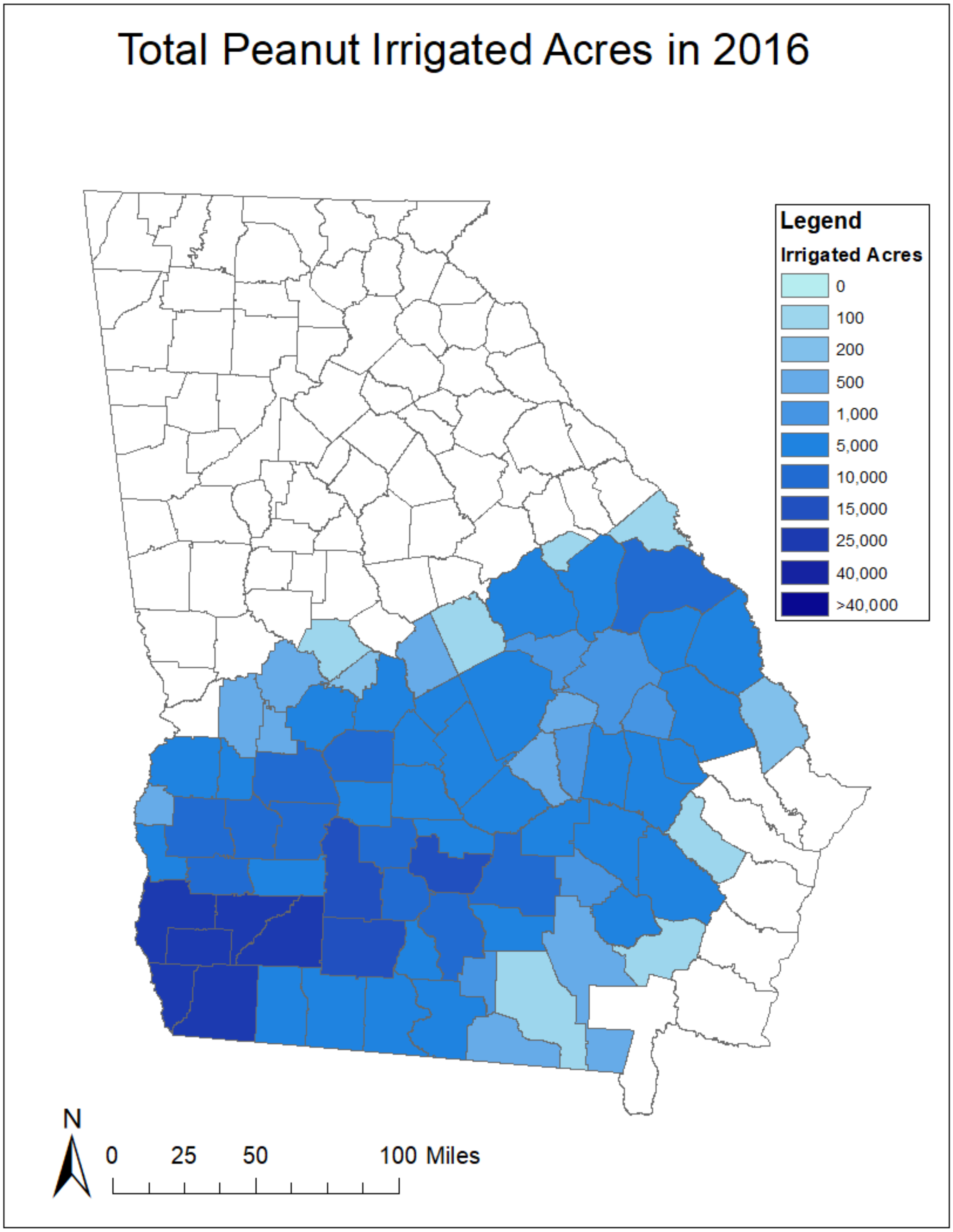
Map A.58 All Peanut Irrigated Acres in Georgia for 2013



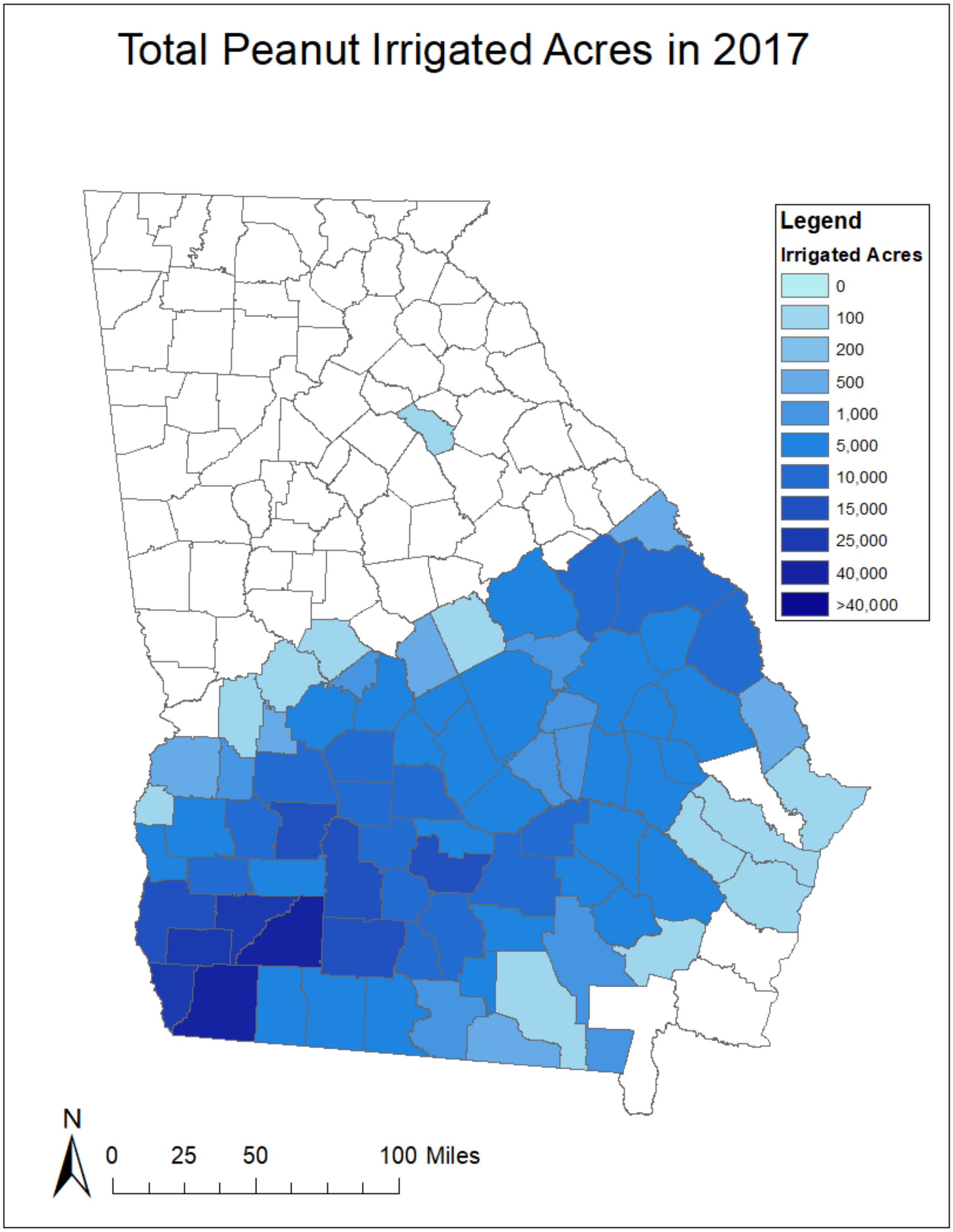
Map A.59 All Peanut Irrigated Acres in Georgia for 2014



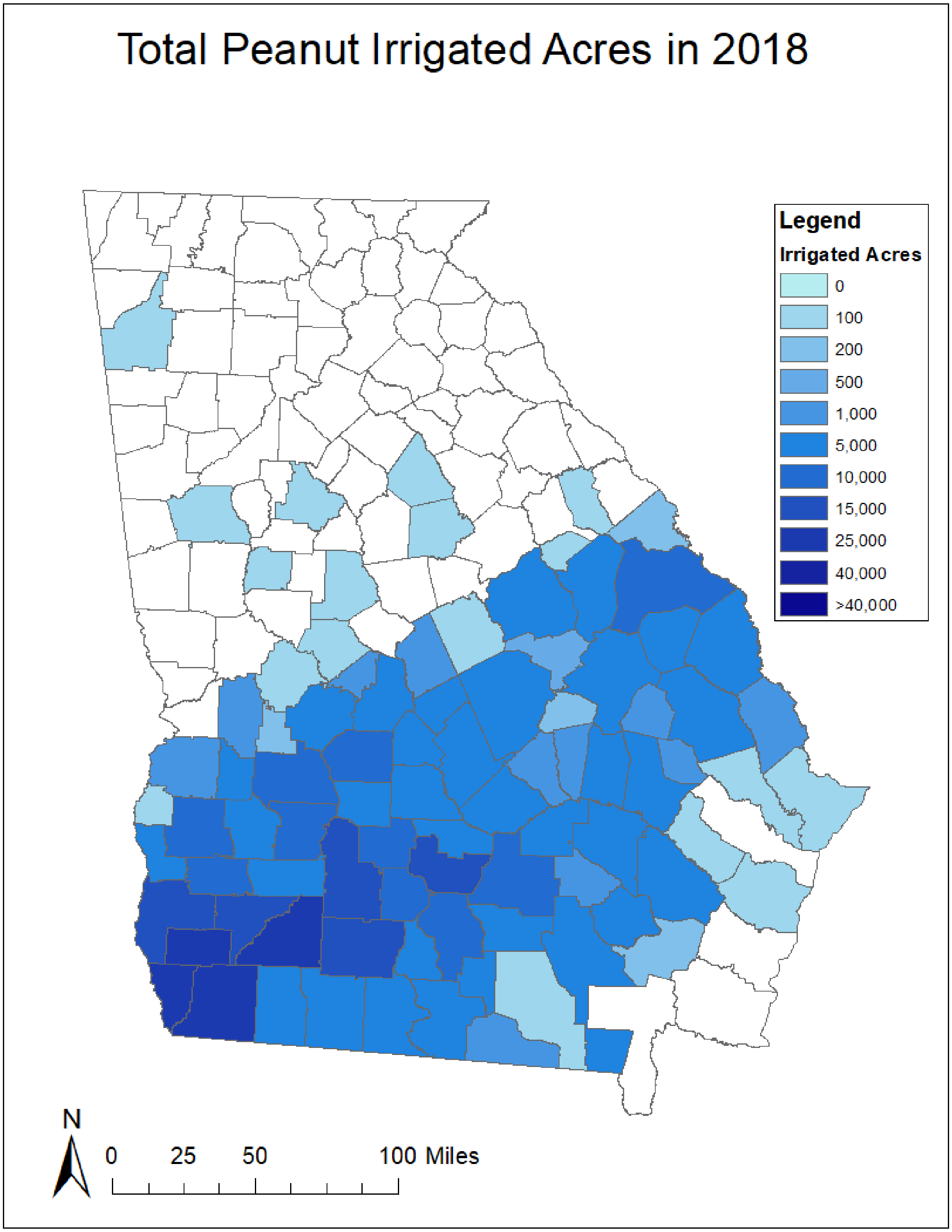
Map A.60 All Peanut Irrigated Acres in Georgia for 2015



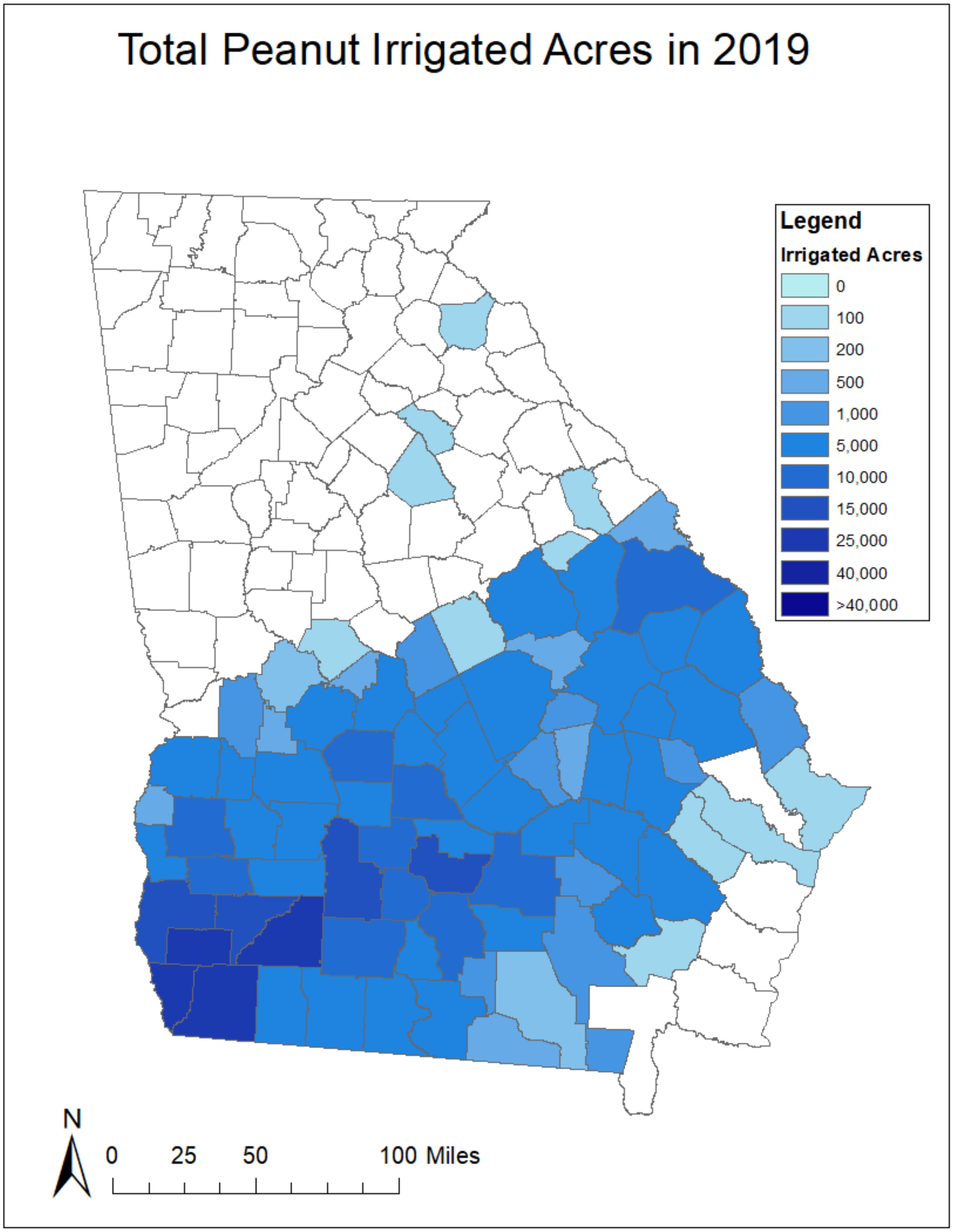
Map A.61 All Peanut Irrigated Acres in Georgia for 2016



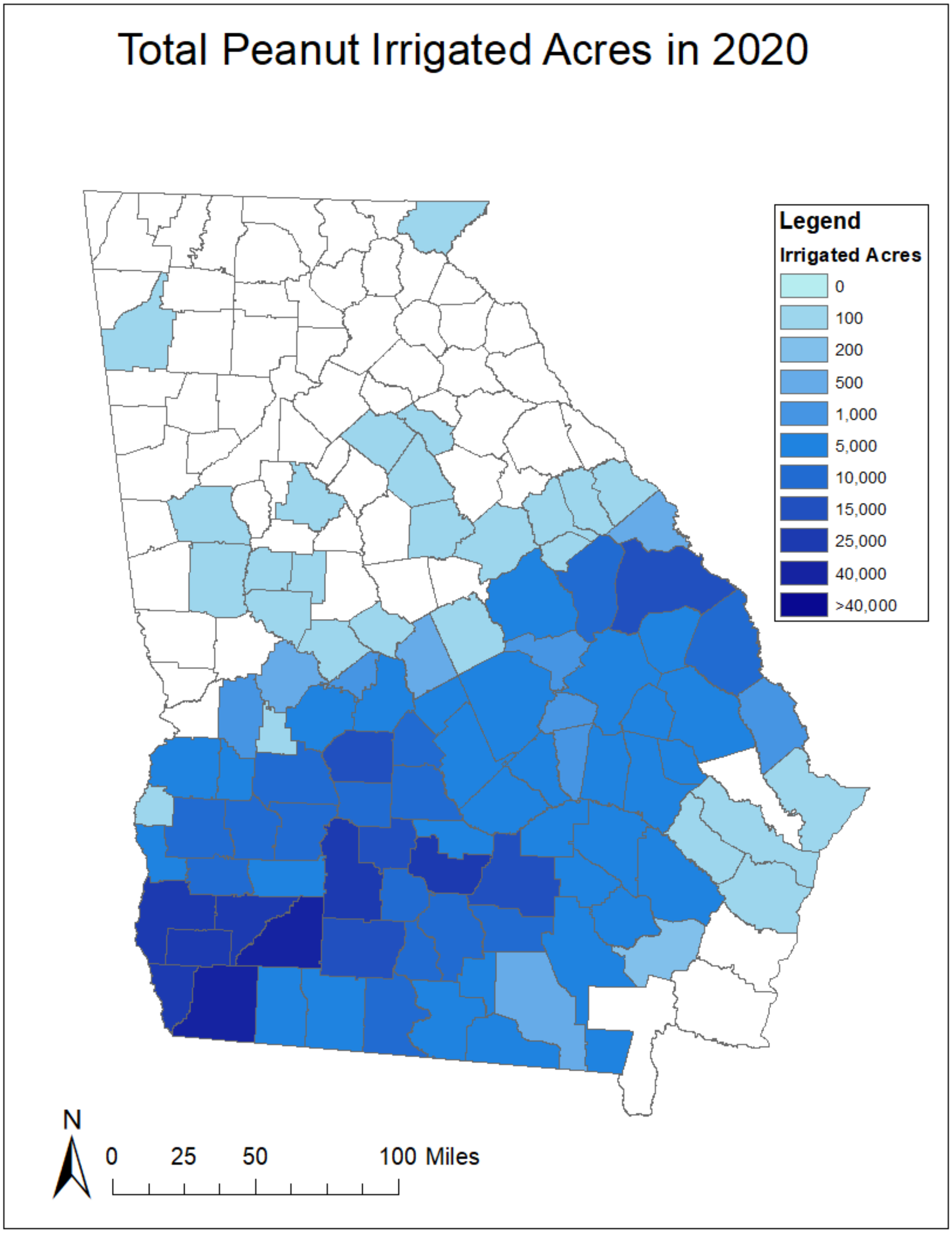
Map A.62 All Peanut Irrigated Acres in Georgia for 2017



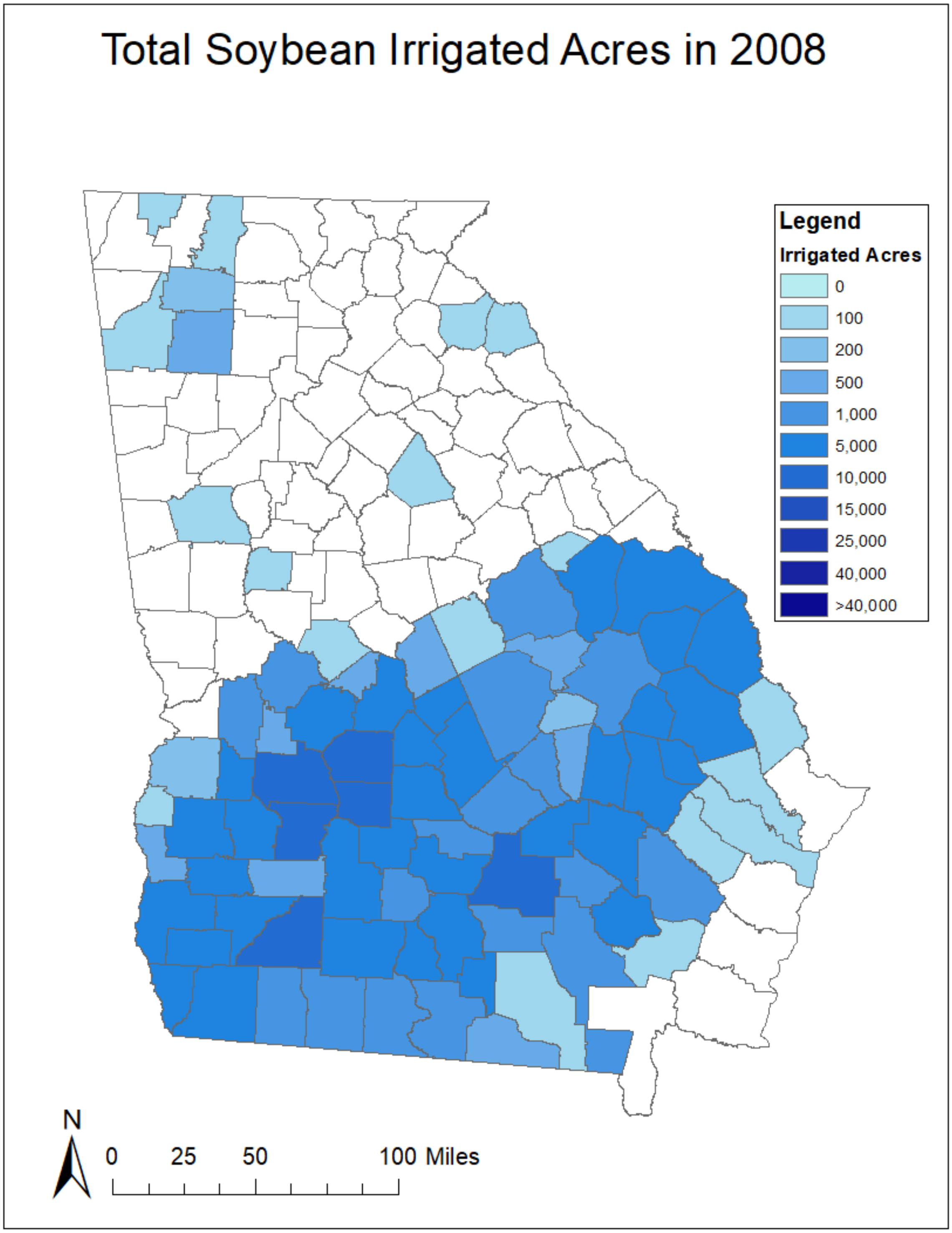
Map A.63 All Peanut Irrigated Acres in Georgia for 2018



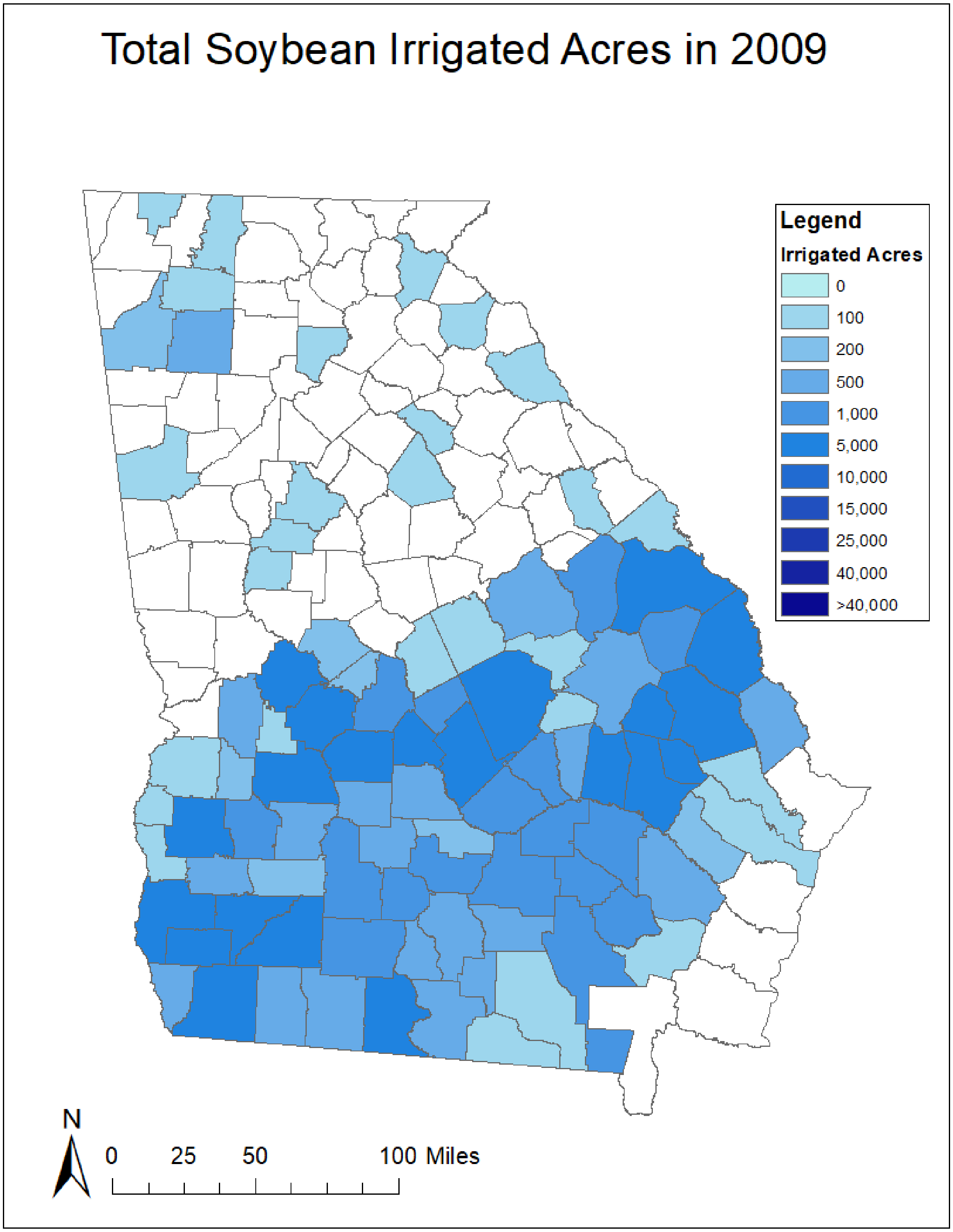
Map A.64 All Peanut Irrigated Acres in Georgia for 2019



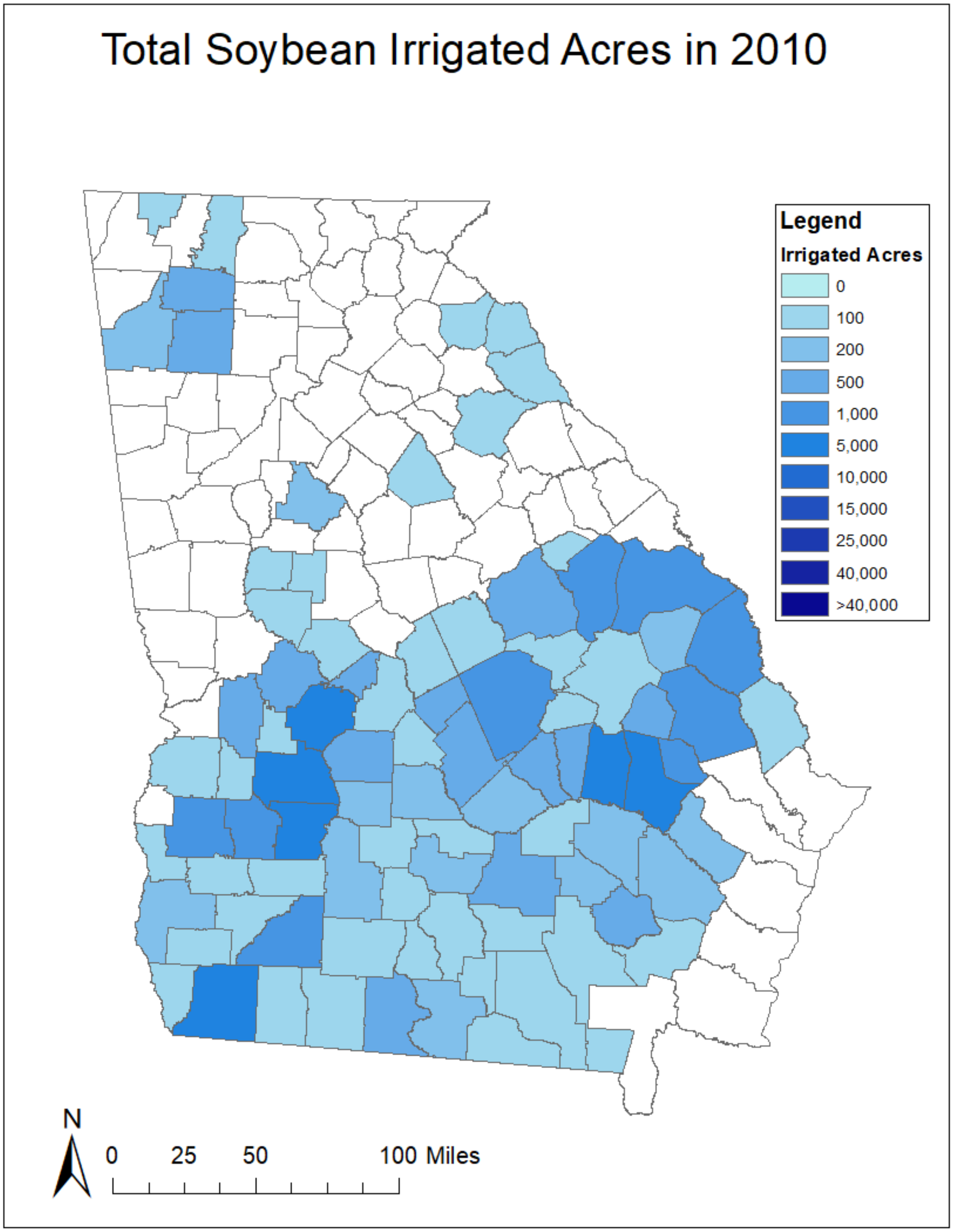
Map A.65 All Peanut Irrigated Acres in Georgia for 2020



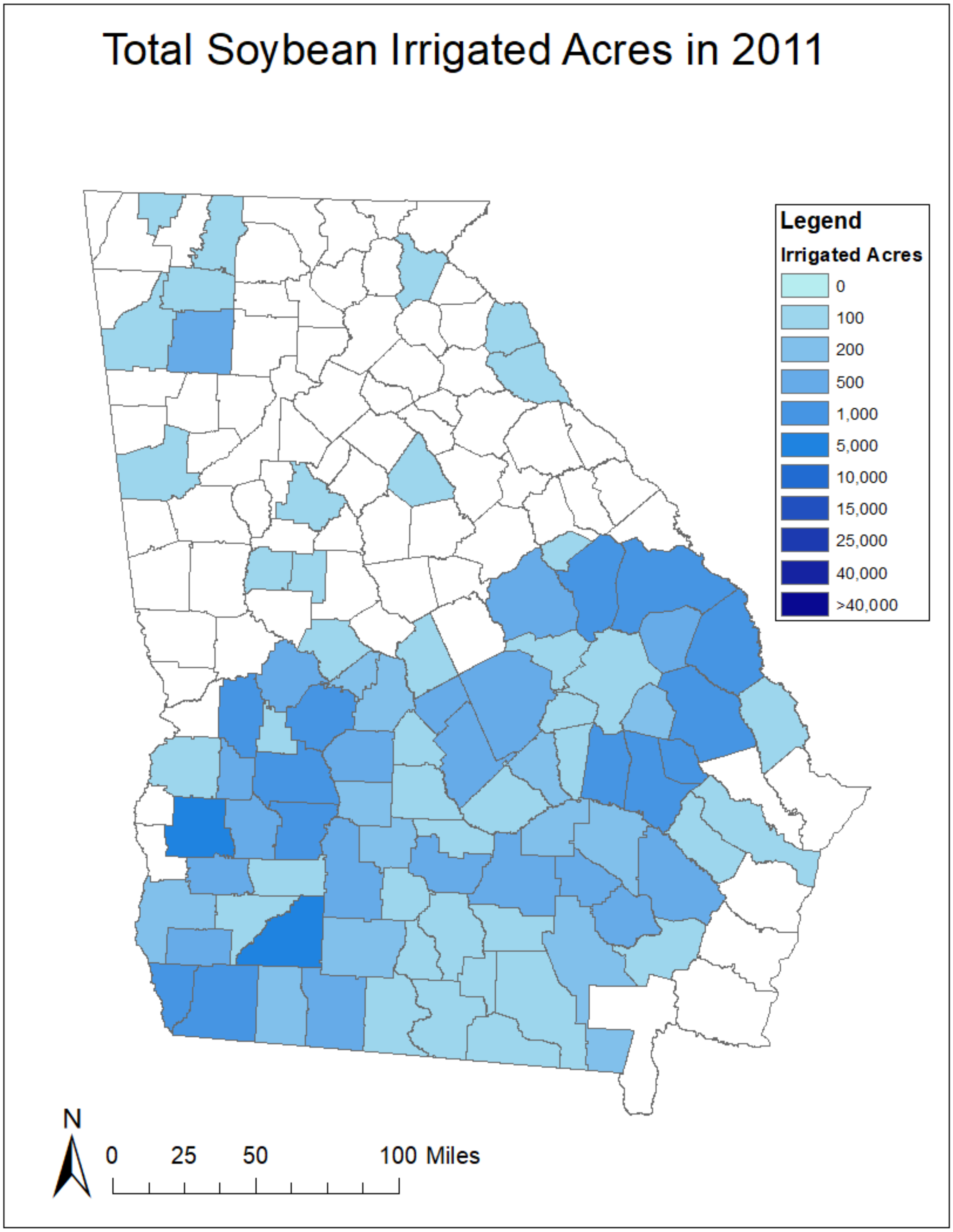
Map A.66 All Soybean Irrigated Acres in Georgia for 2008



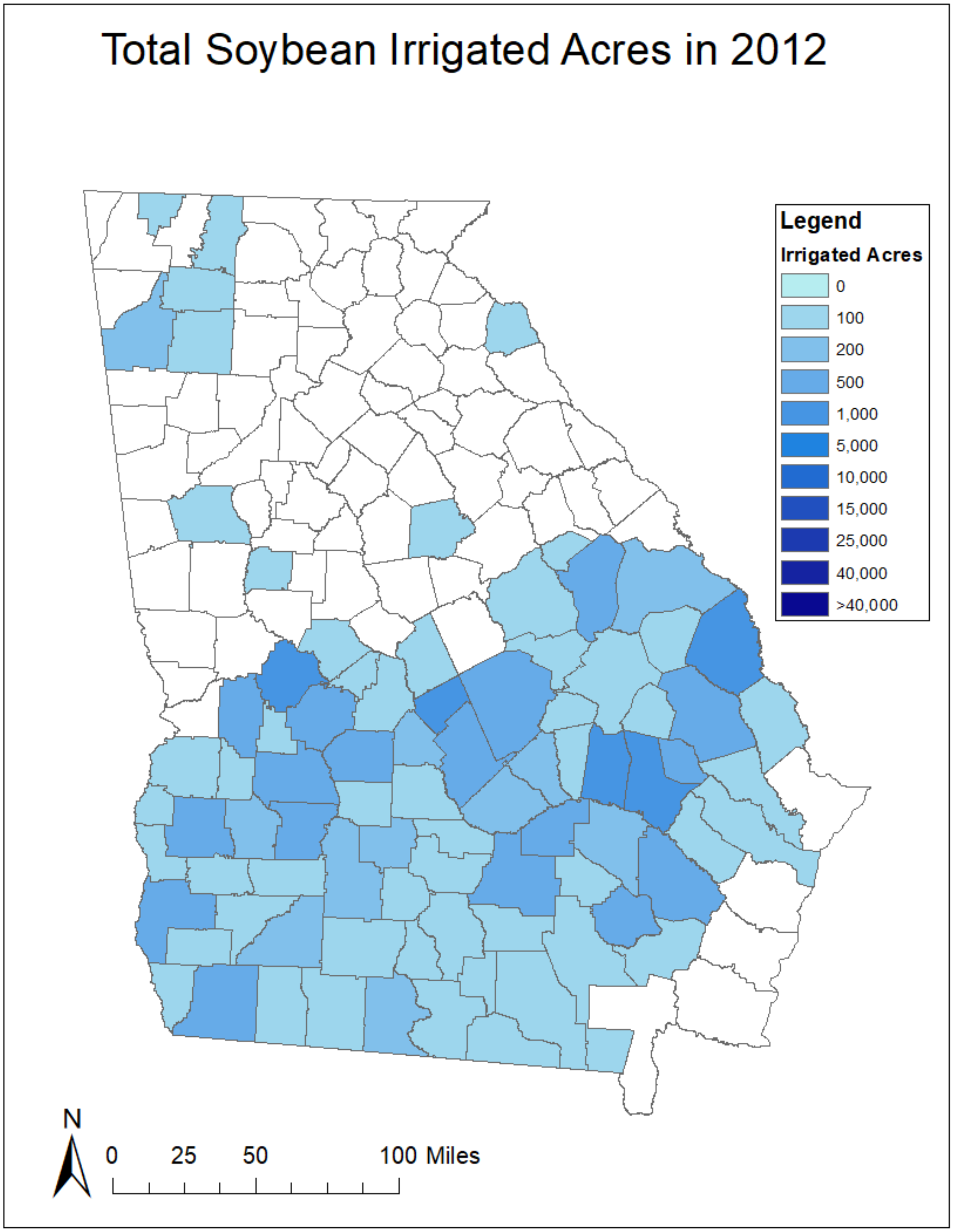
Map A.67 All Soybean Irrigated Acres in Georgia for 2009



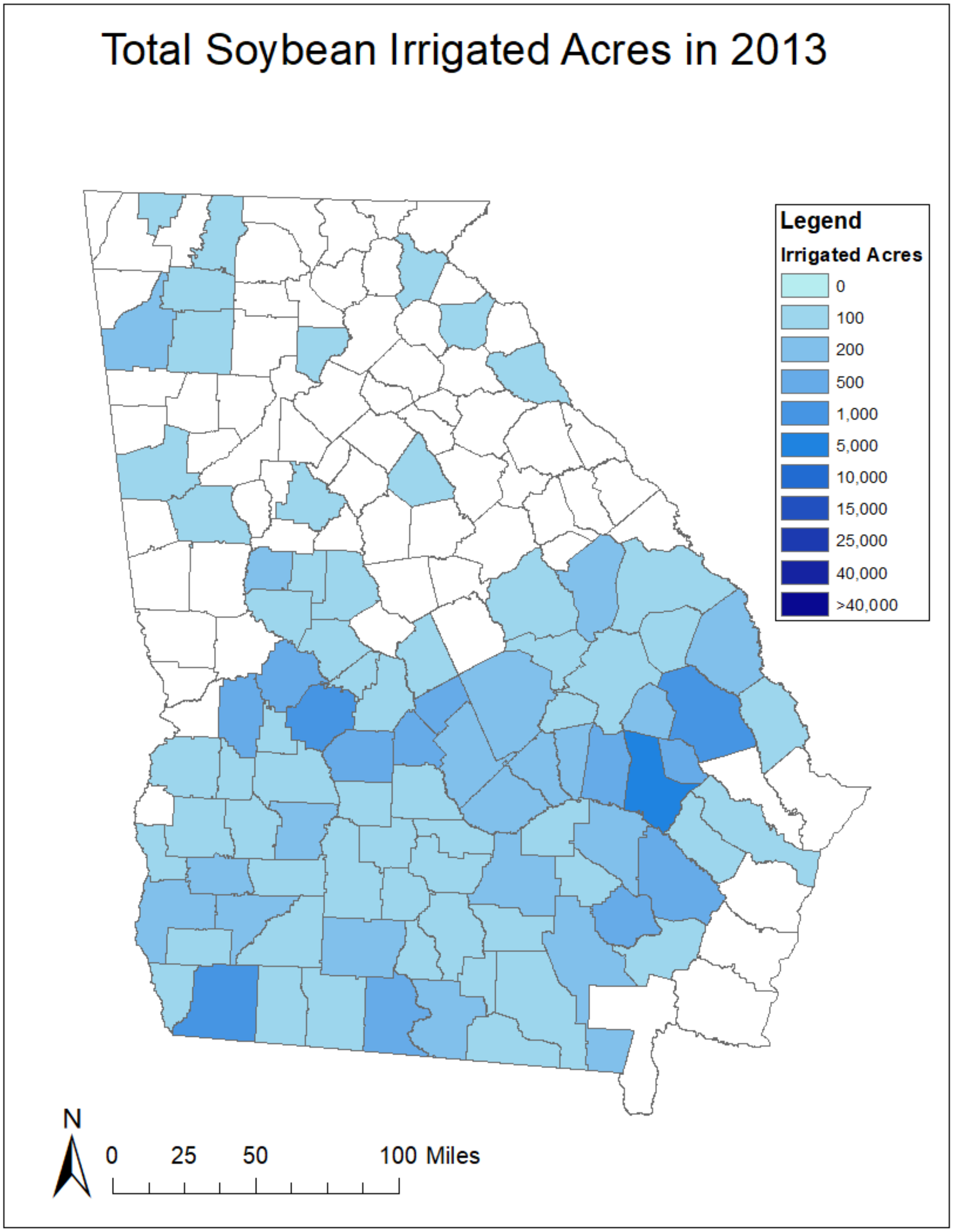
Map A.68 All Soybean Irrigated Acres in Georgia for 2010



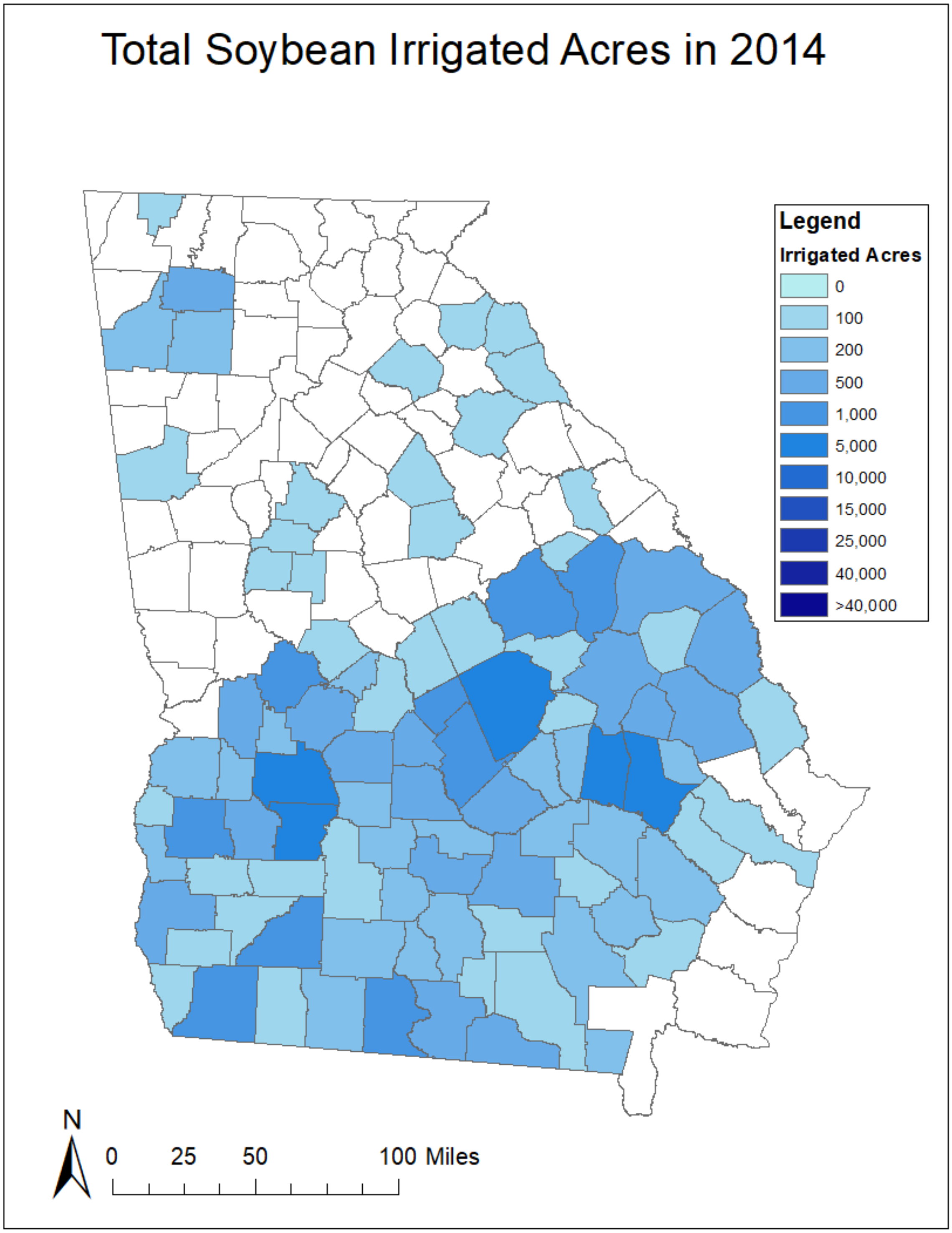
Map A.69 All Soybean Irrigated Acres in Georgia for 2011



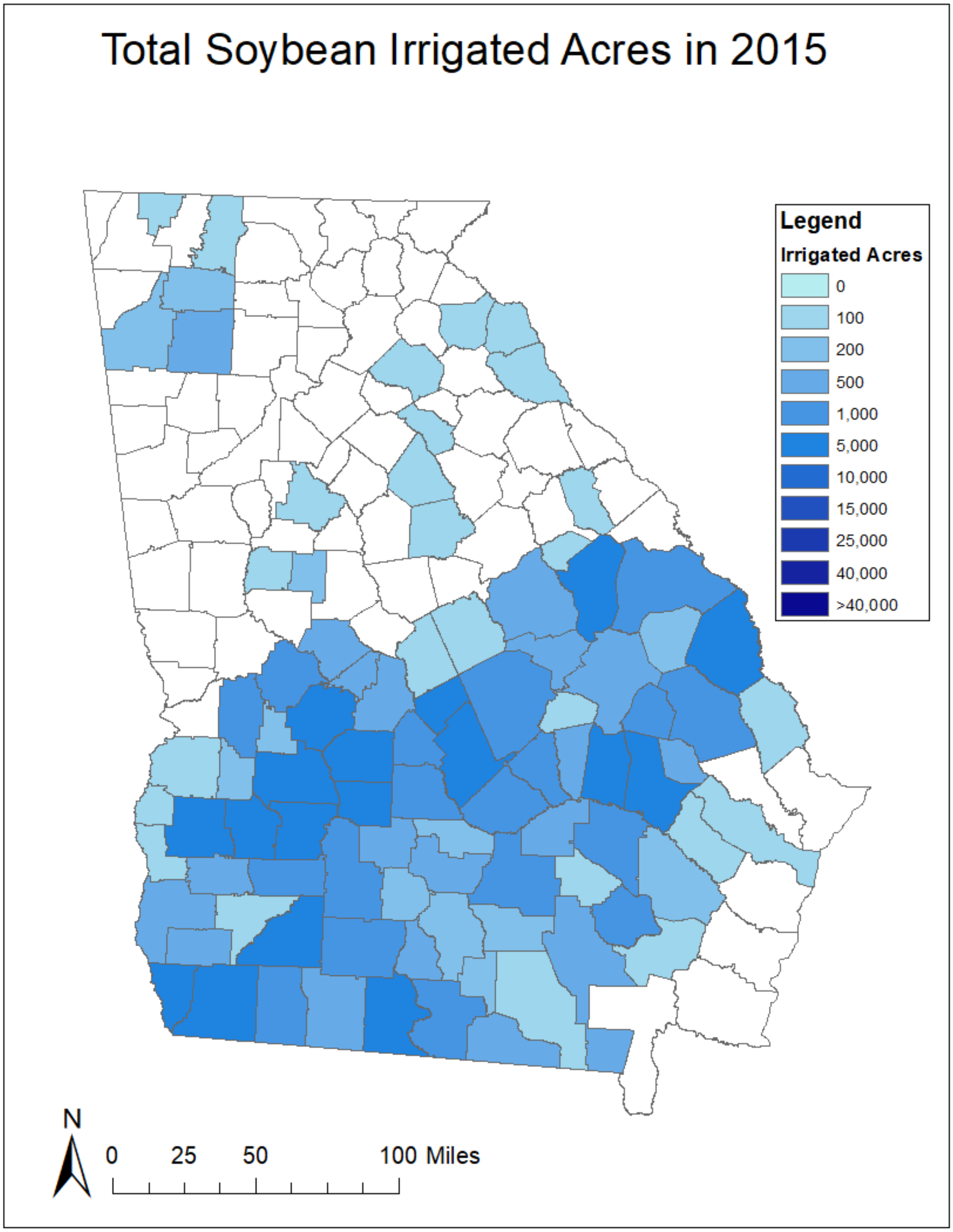
Map A.70 All Soybean Irrigated Acres in Georgia for 2012



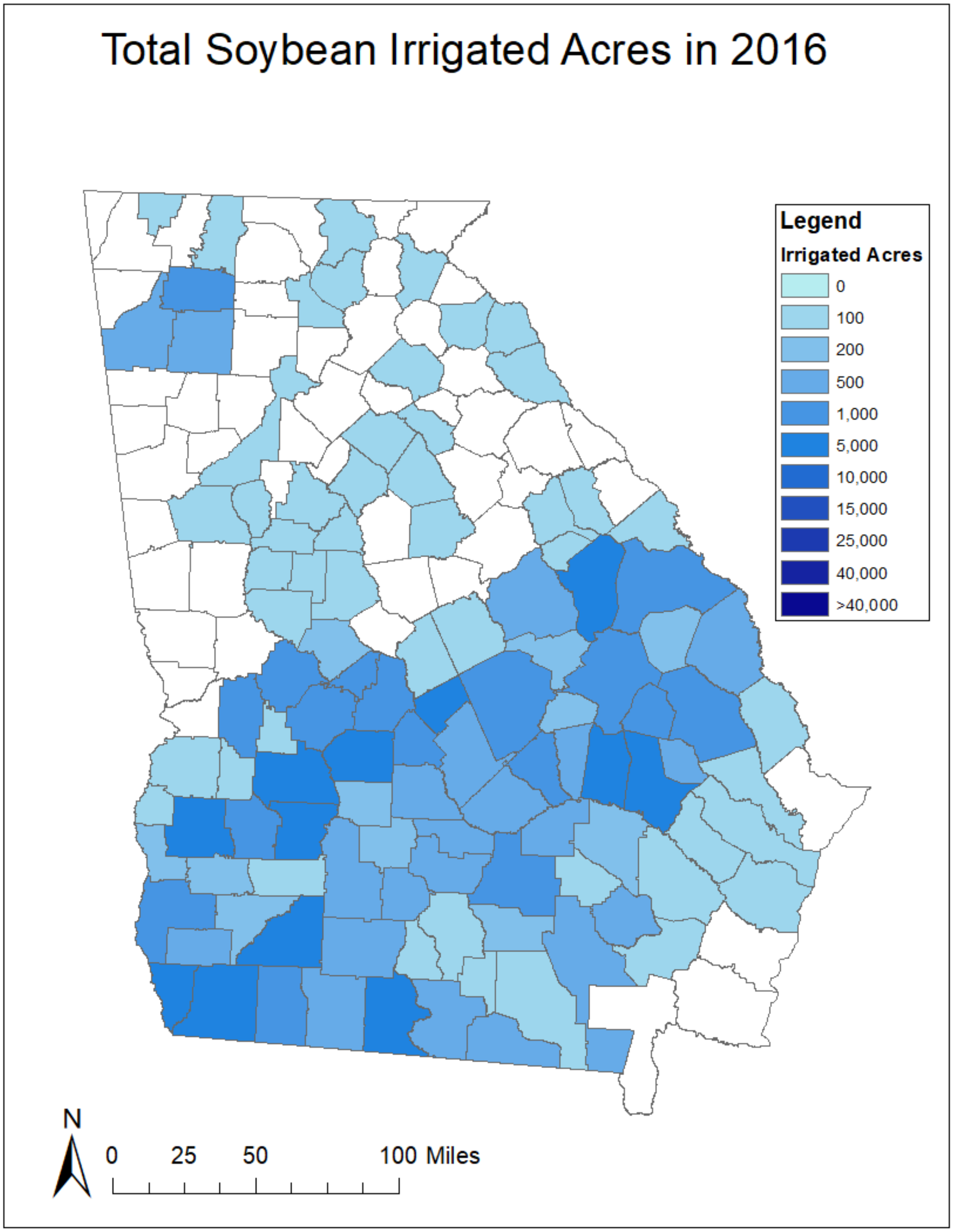
Map A.71 All Soybean Irrigated Acres in Georgia for 2013



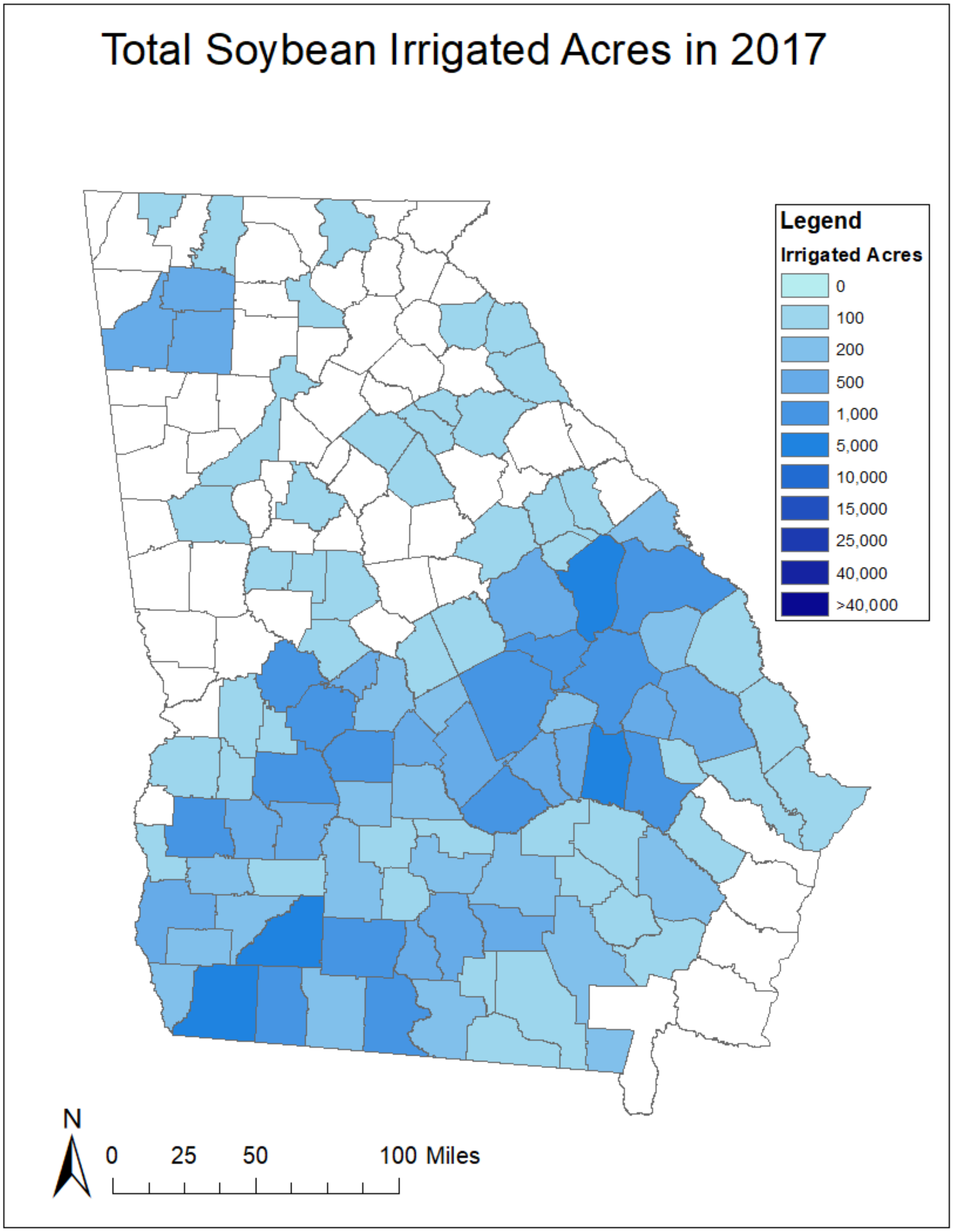
Map A.72 All Soybean Irrigated Acres in Georgia for 2014



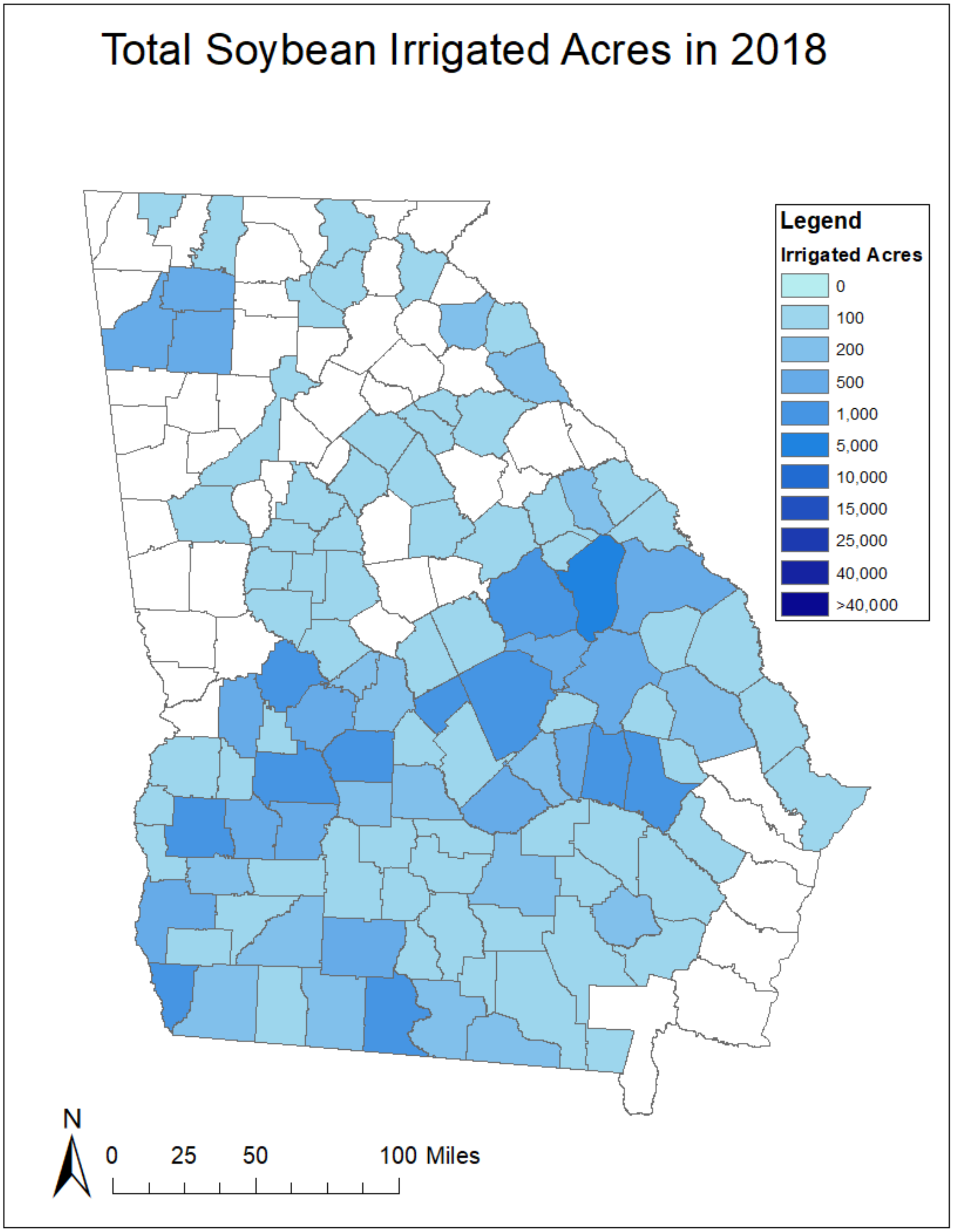
Map A.73 All Soybean Irrigated Acres in Georgia for 2015



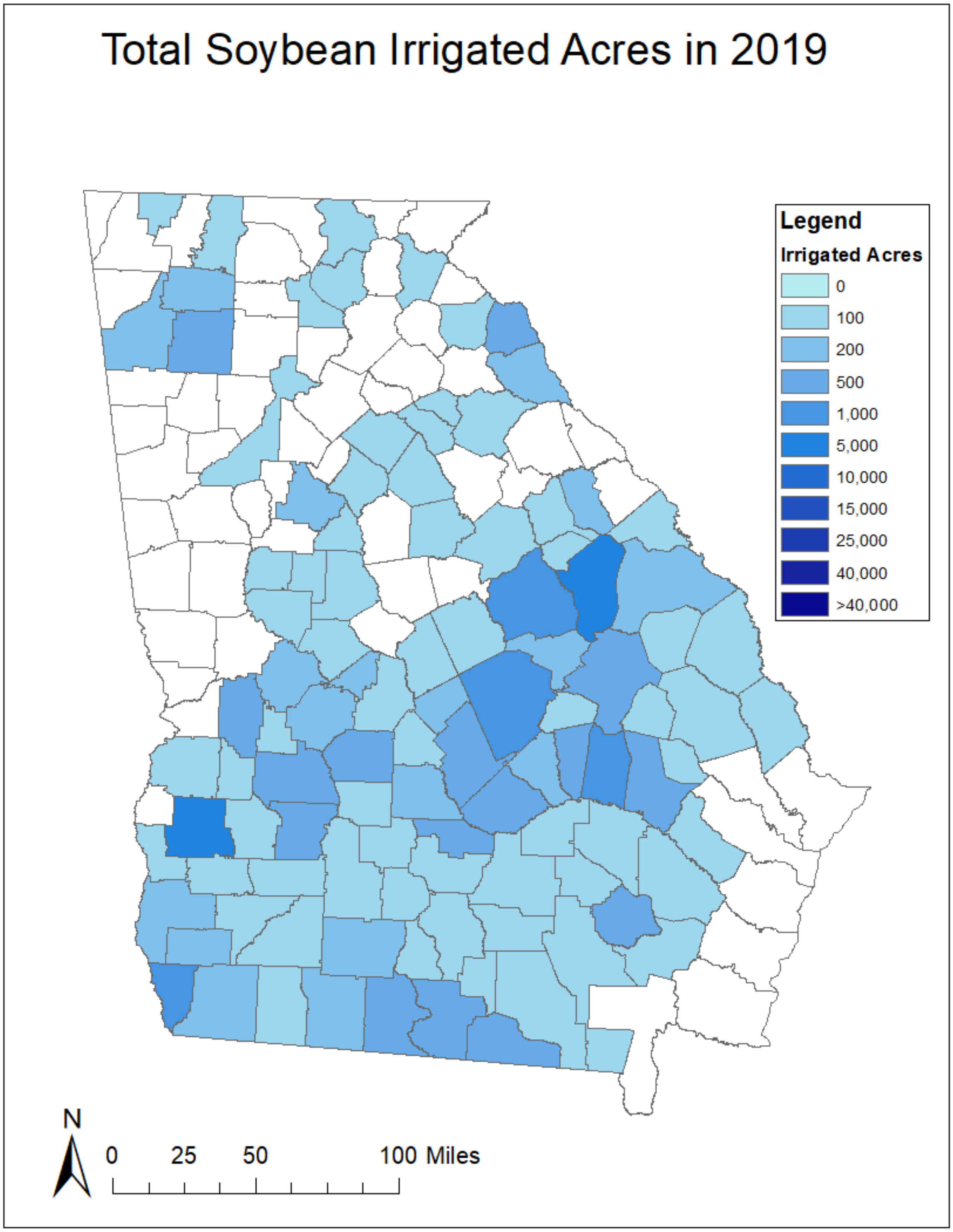
Map A.74 All Soybean Irrigated Acres in Georgia for 2016



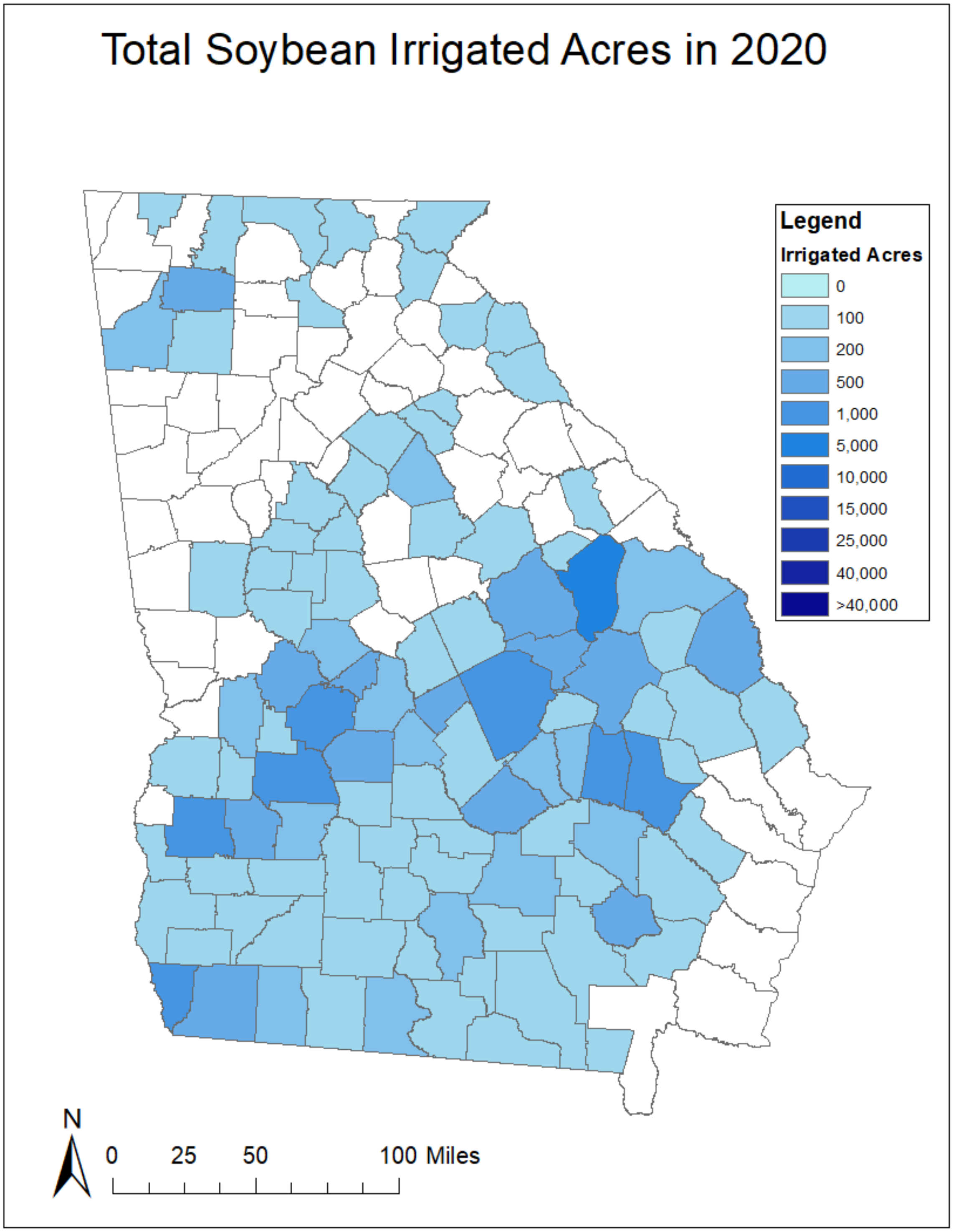
Map A.75 All Soybean Irrigated Acres in Georgia for 2017



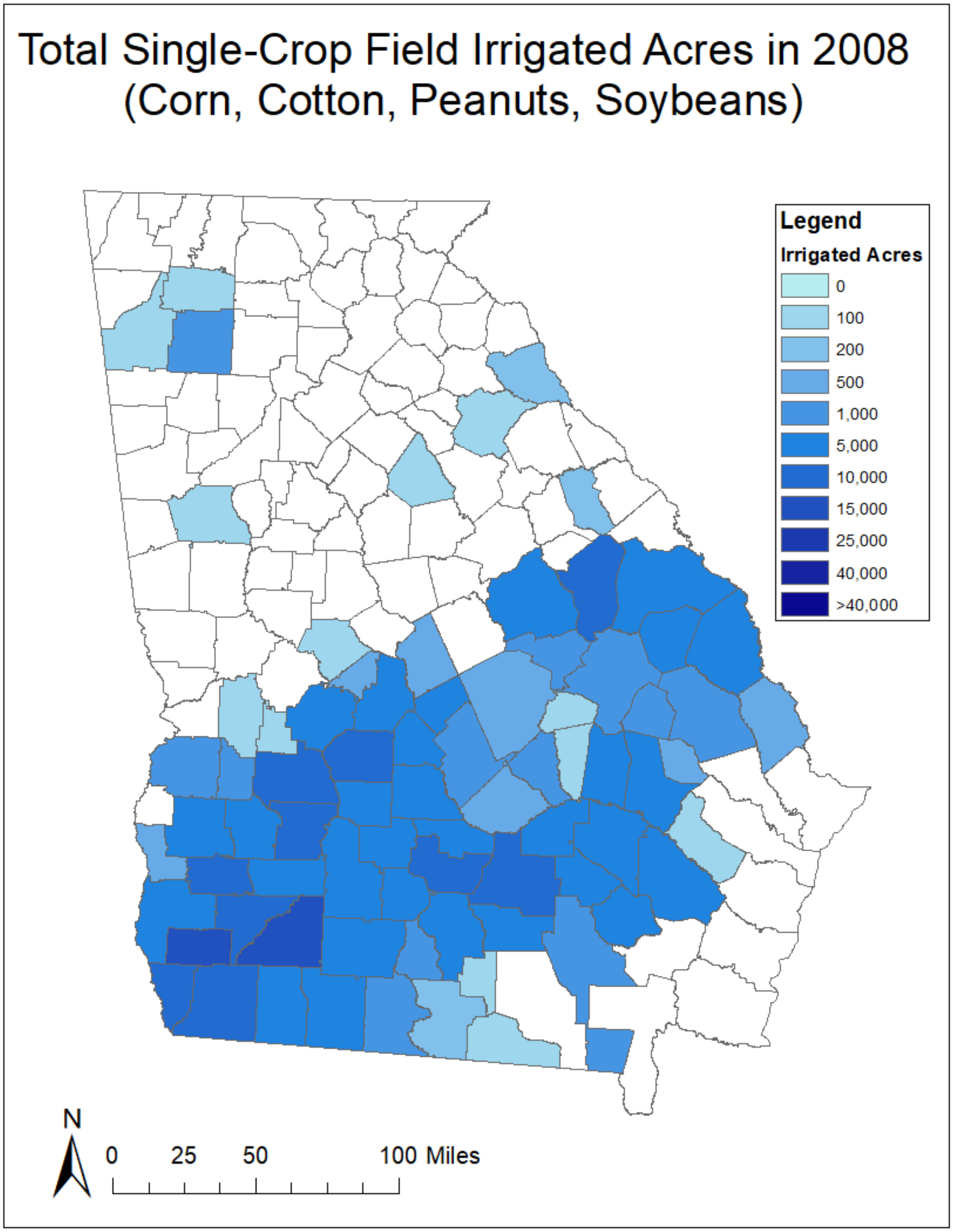
Map A.76 All Soybean Irrigated Acres in Georgia for 2018



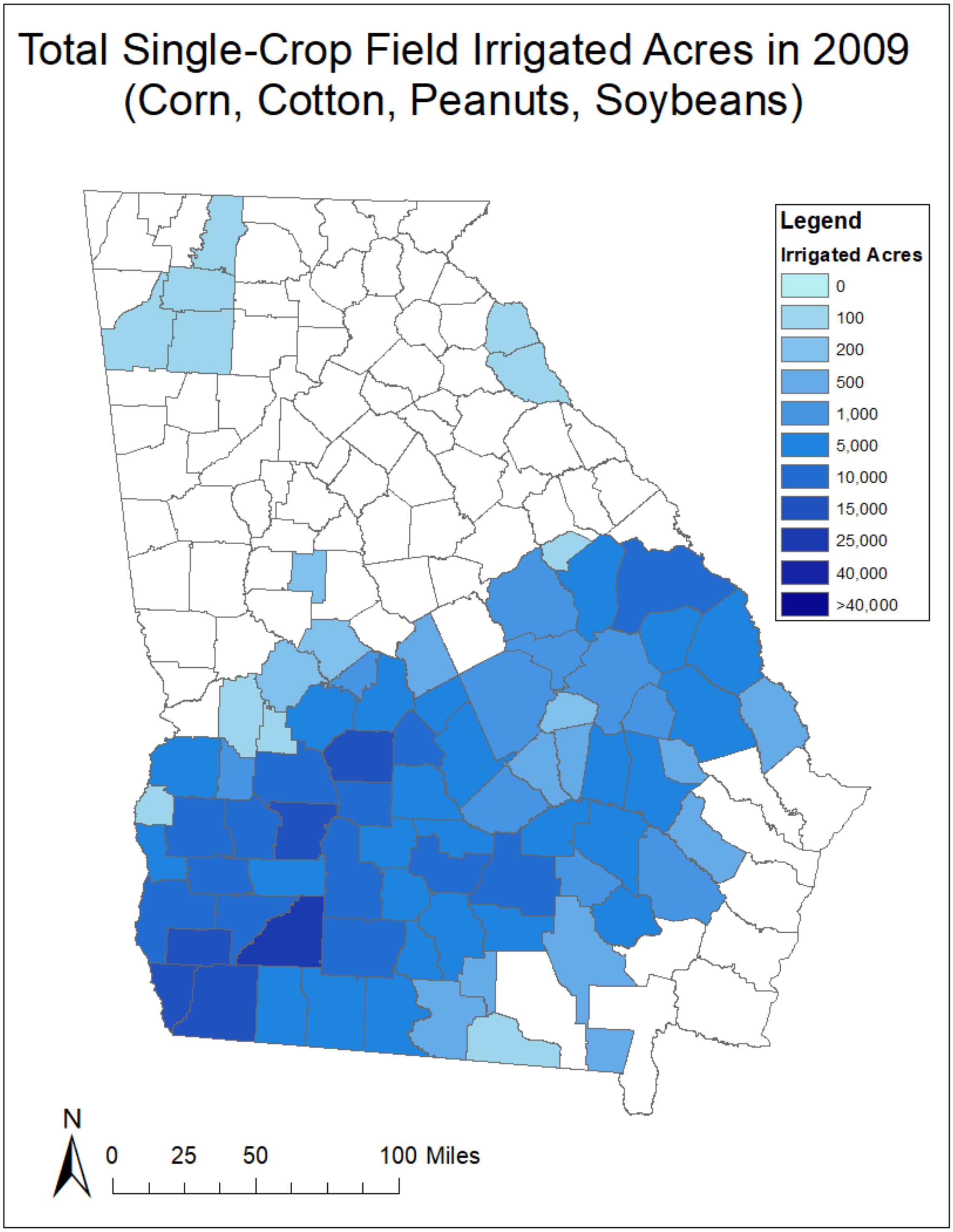
Map A.77 All Soybean Irrigated Acres in Georgia for 2019



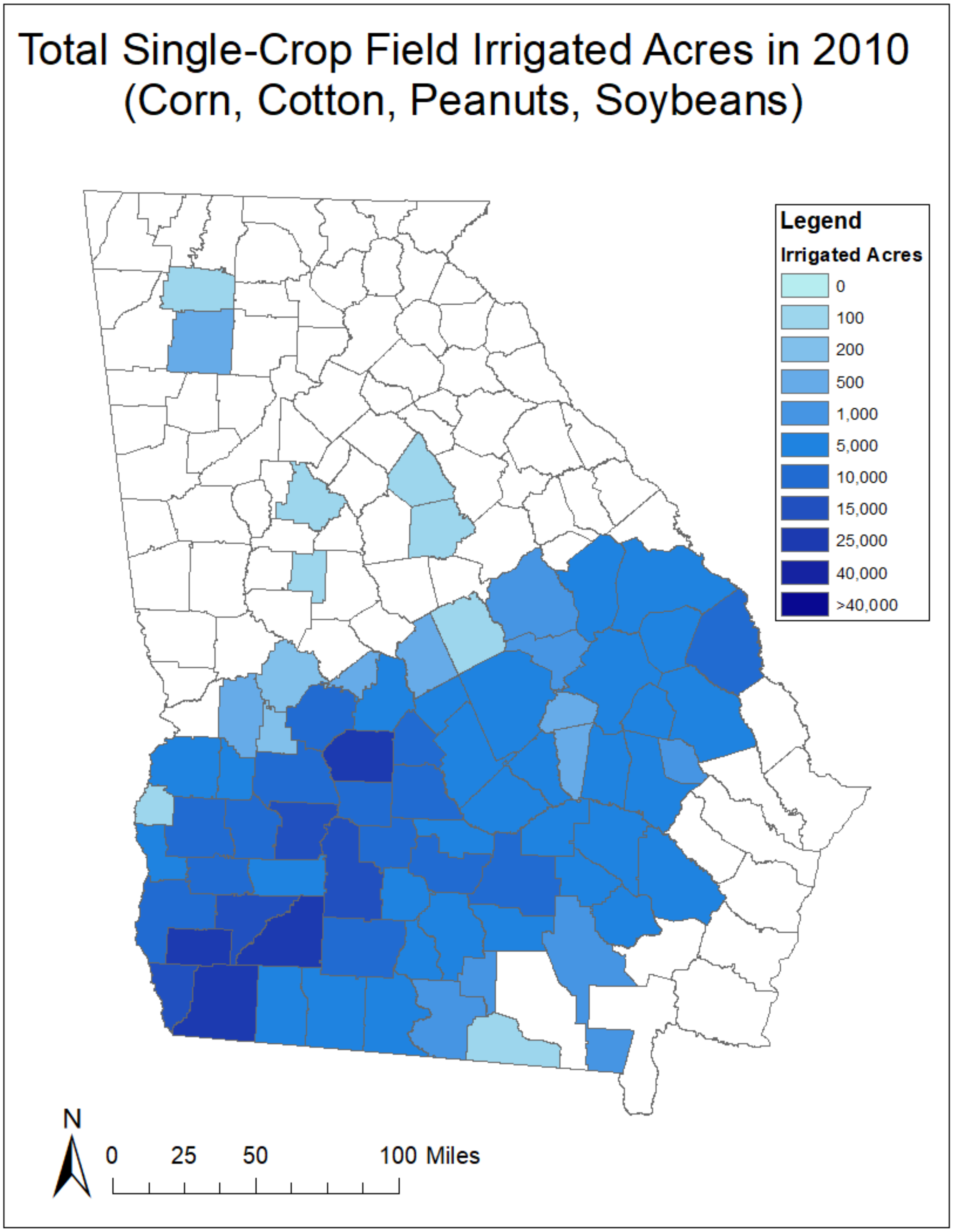
Map A.78 All Soybean Irrigated Acres in Georgia for 2020



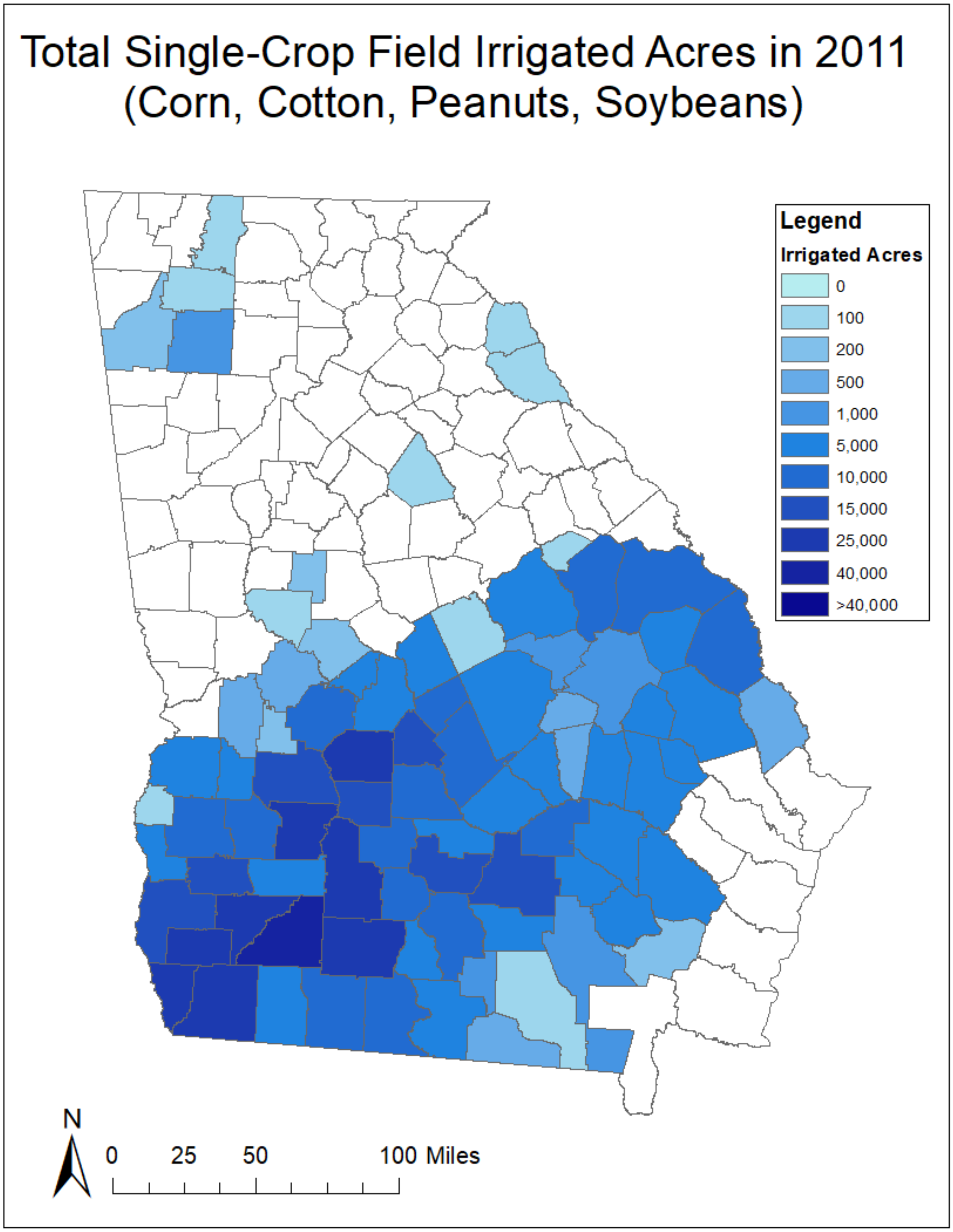
Map A.79 Total Single-Crop Field Irrigated Acres in Georgia for 2008



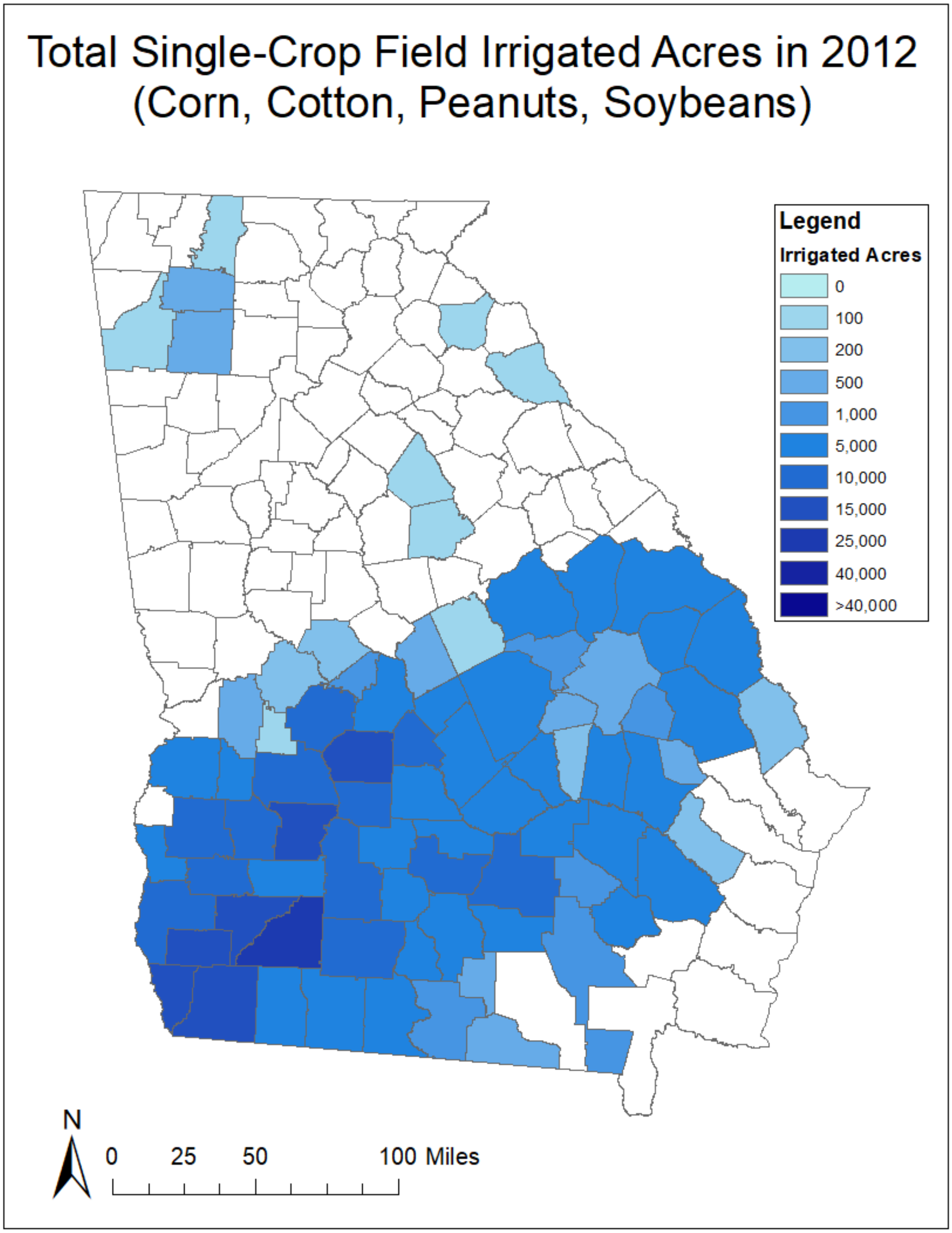
Map A.80 Total Single-Crop Field Irrigated Acres in Georgia for 2009



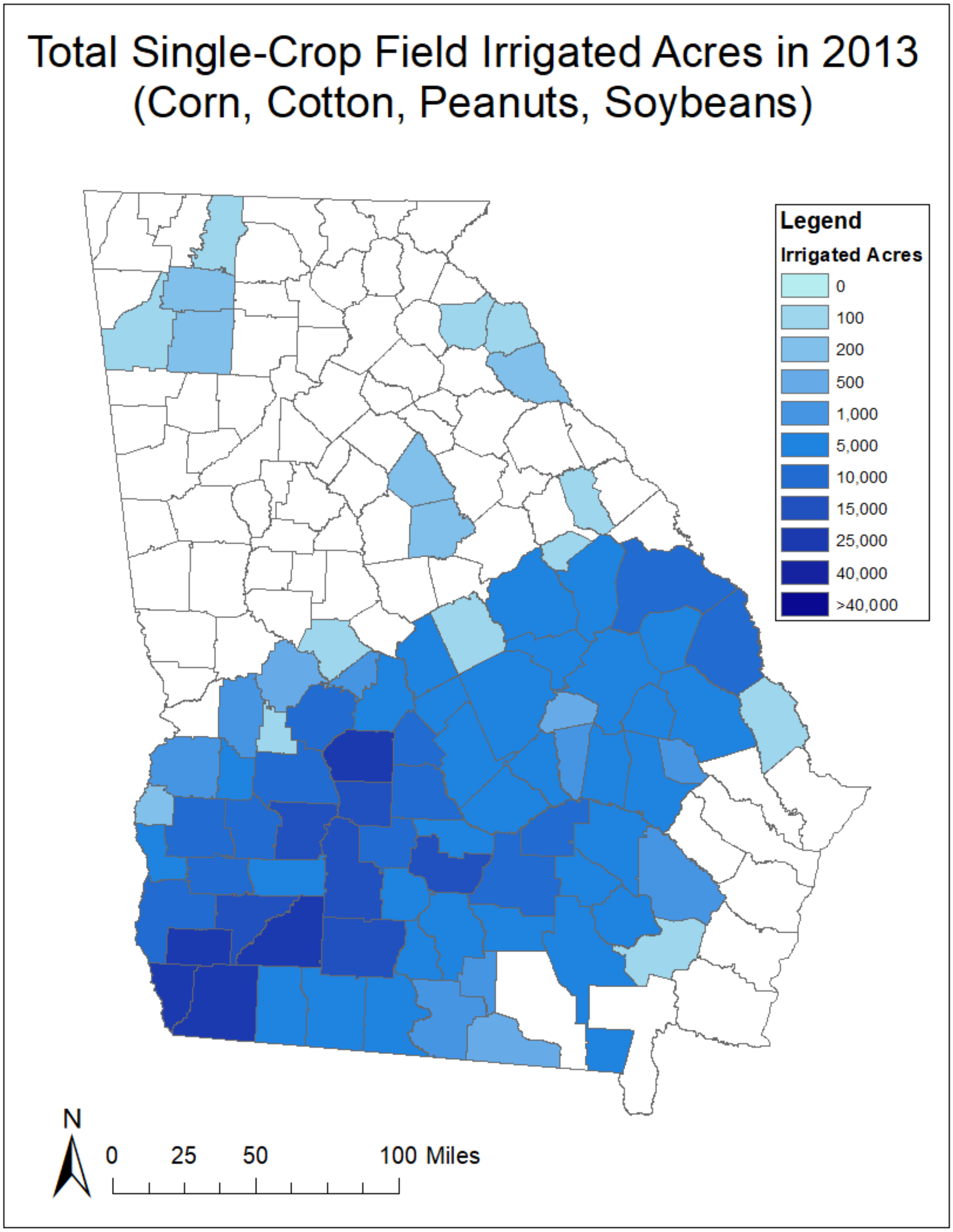
Map A.81 Total Single-Crop Field Irrigated Acres in Georgia for 2010



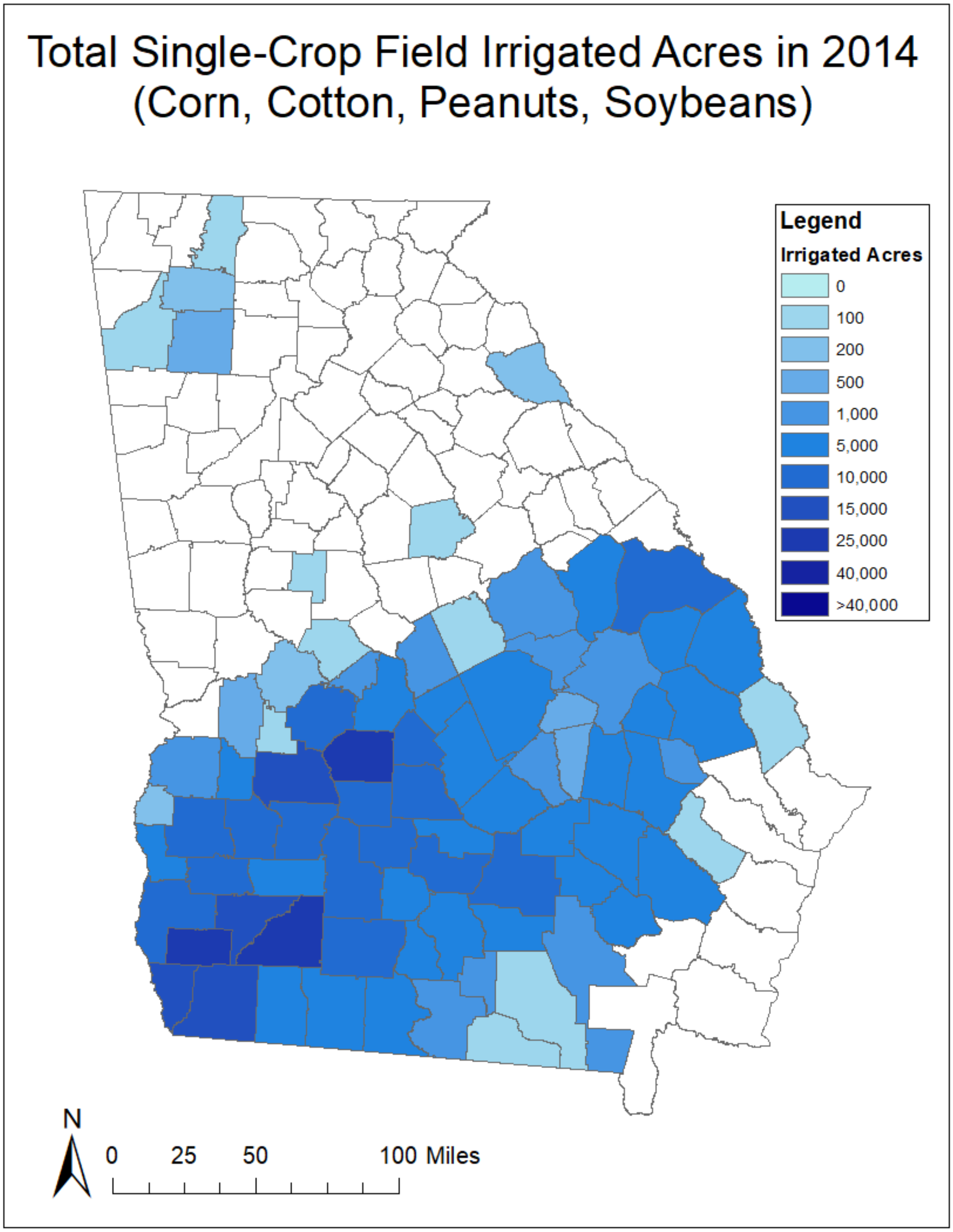
Map A.82 Total Single-Crop Field Irrigated Acres in Georgia for 2011



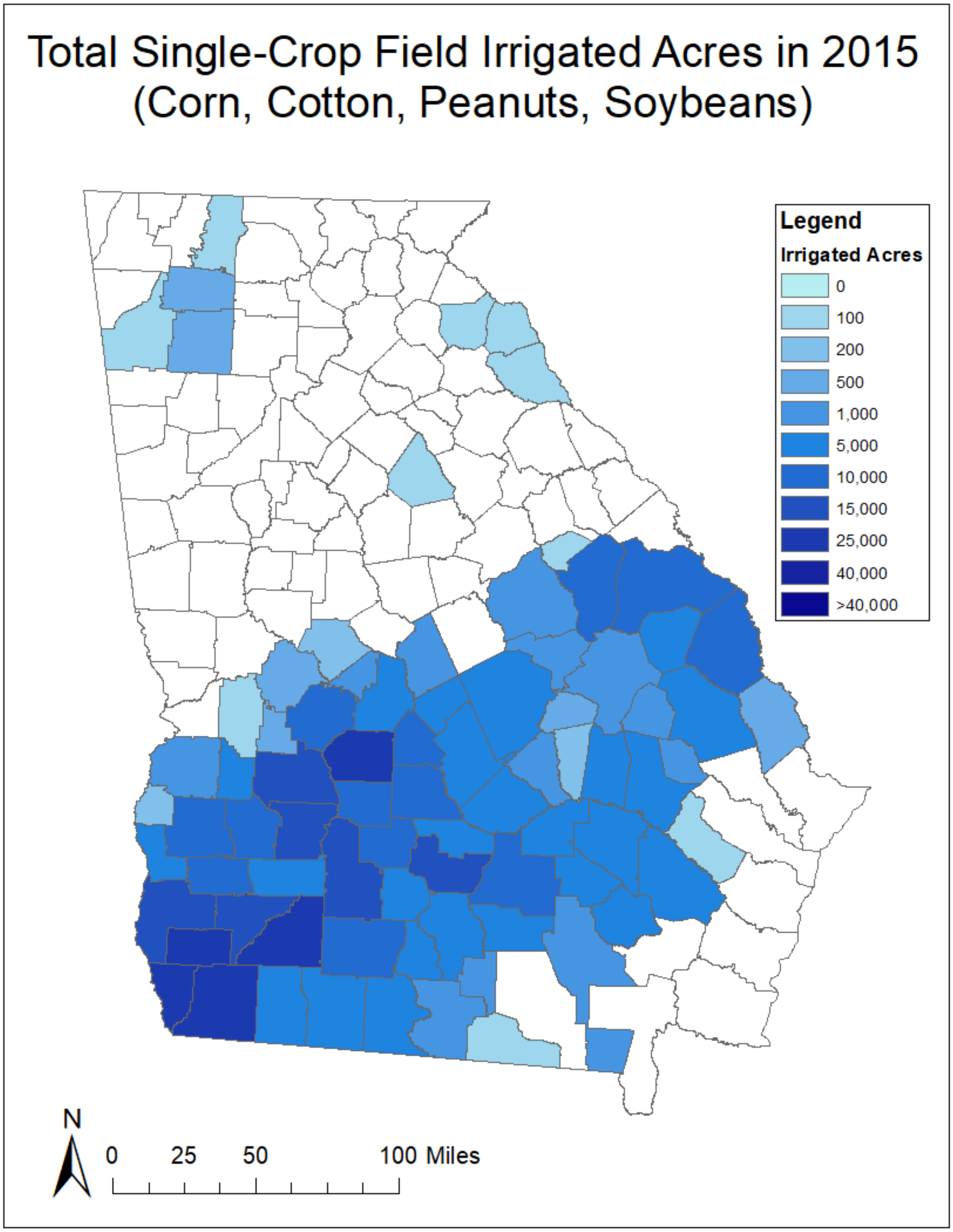
Map A.83 Total Single-Crop Field Irrigated Acres in Georgia for 2012



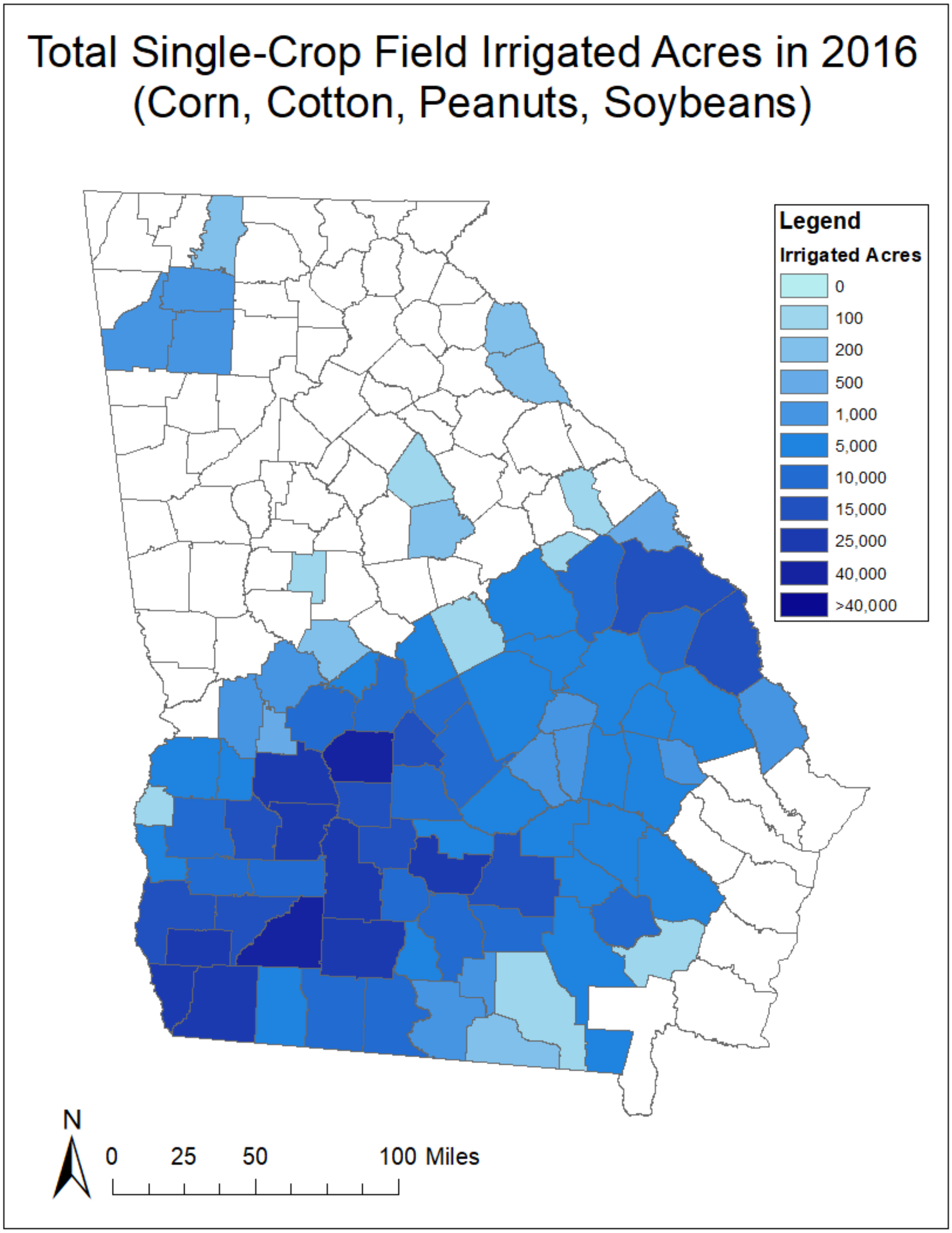
Map A.84 Total Single-Crop Field Irrigated Acres in Georgia for 2013



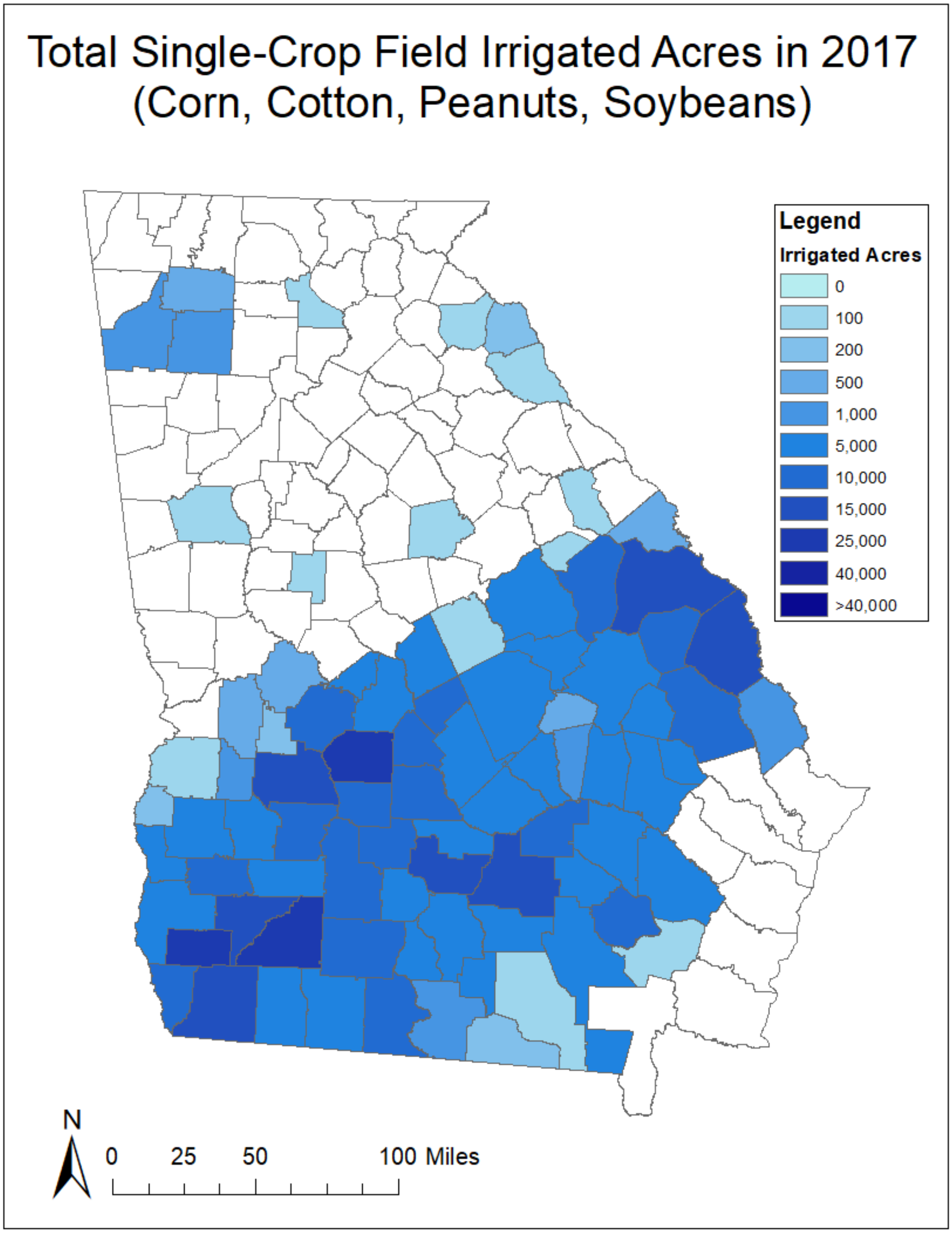
Map A.85 Total Single-Crop Field Irrigated Acres in Georgia for 2014



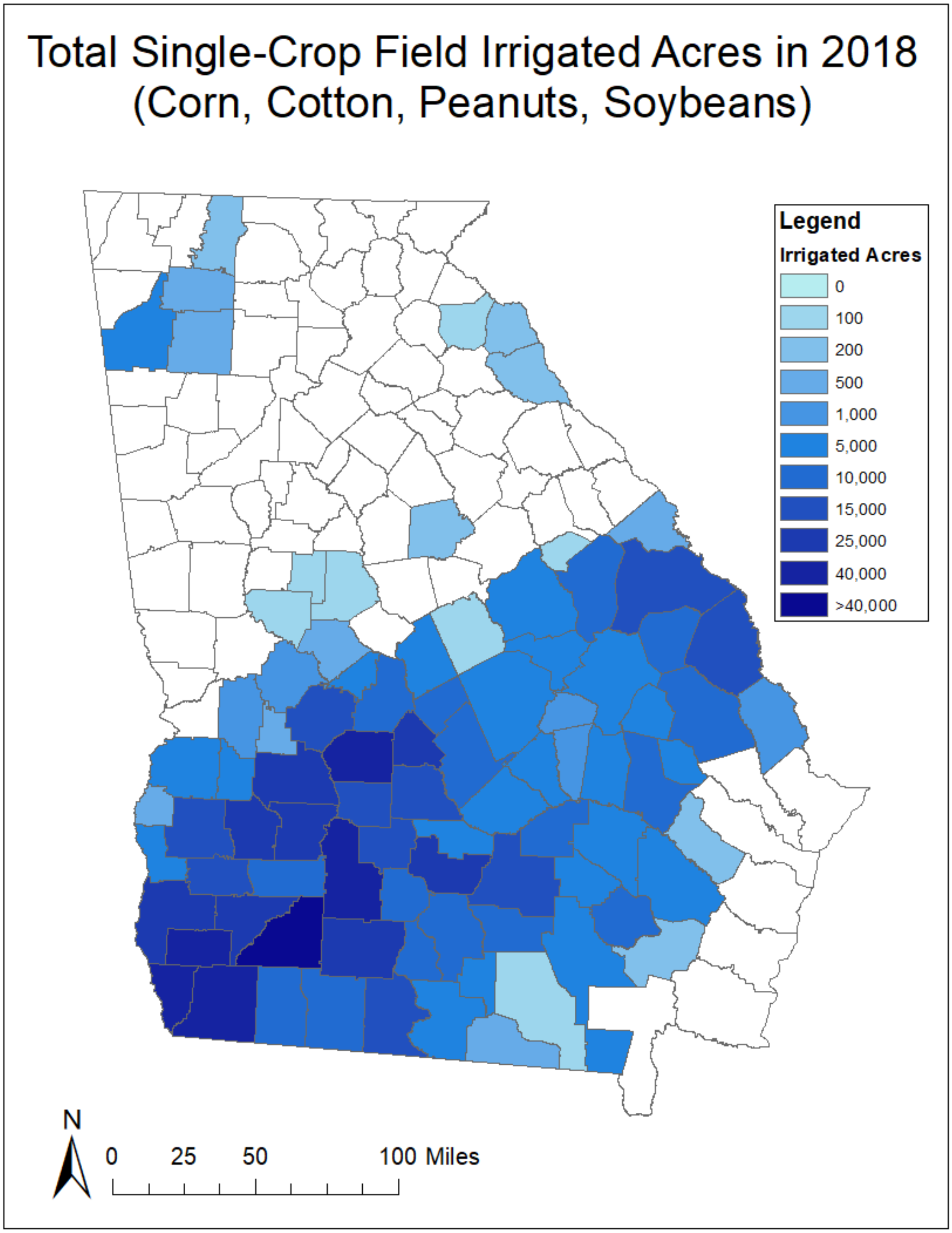
Map A.86 Total Single-Crop Field Irrigated Acres in Georgia for 2015



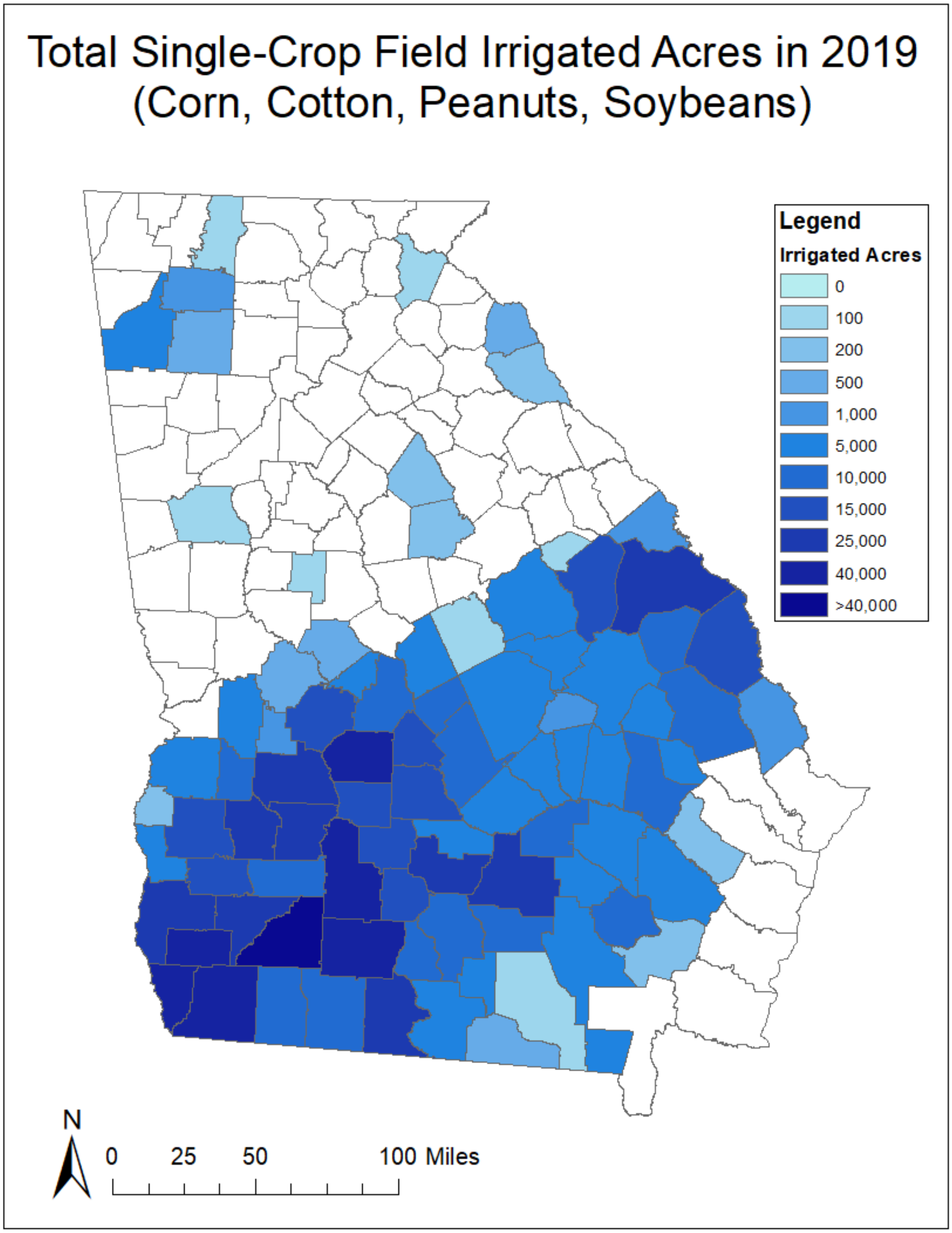
Map A.87 Total Single-Crop Field Irrigated Acres in Georgia for 2016



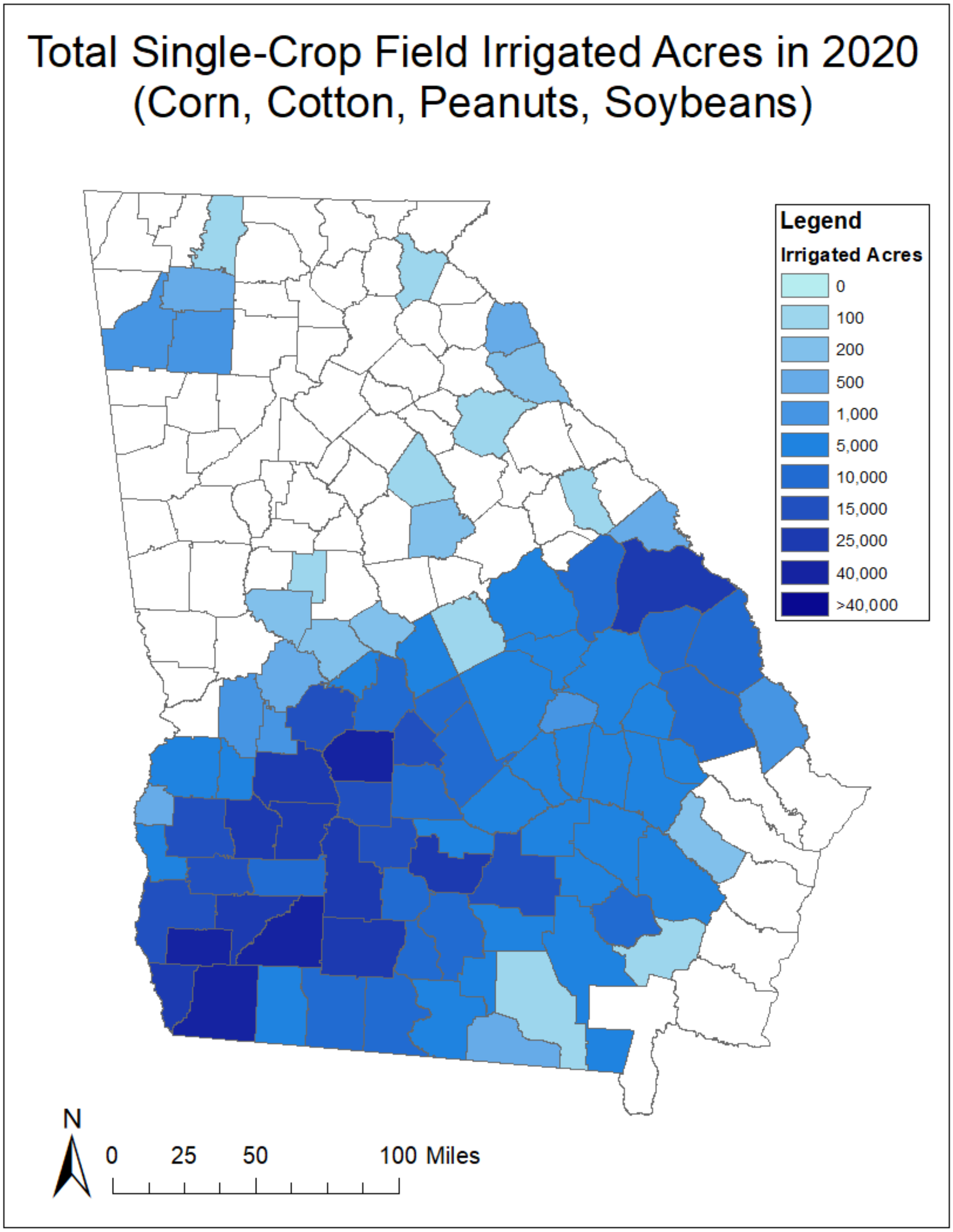
Map A.88 Total Single-Crop Field Irrigated Acres in Georgia for 2017



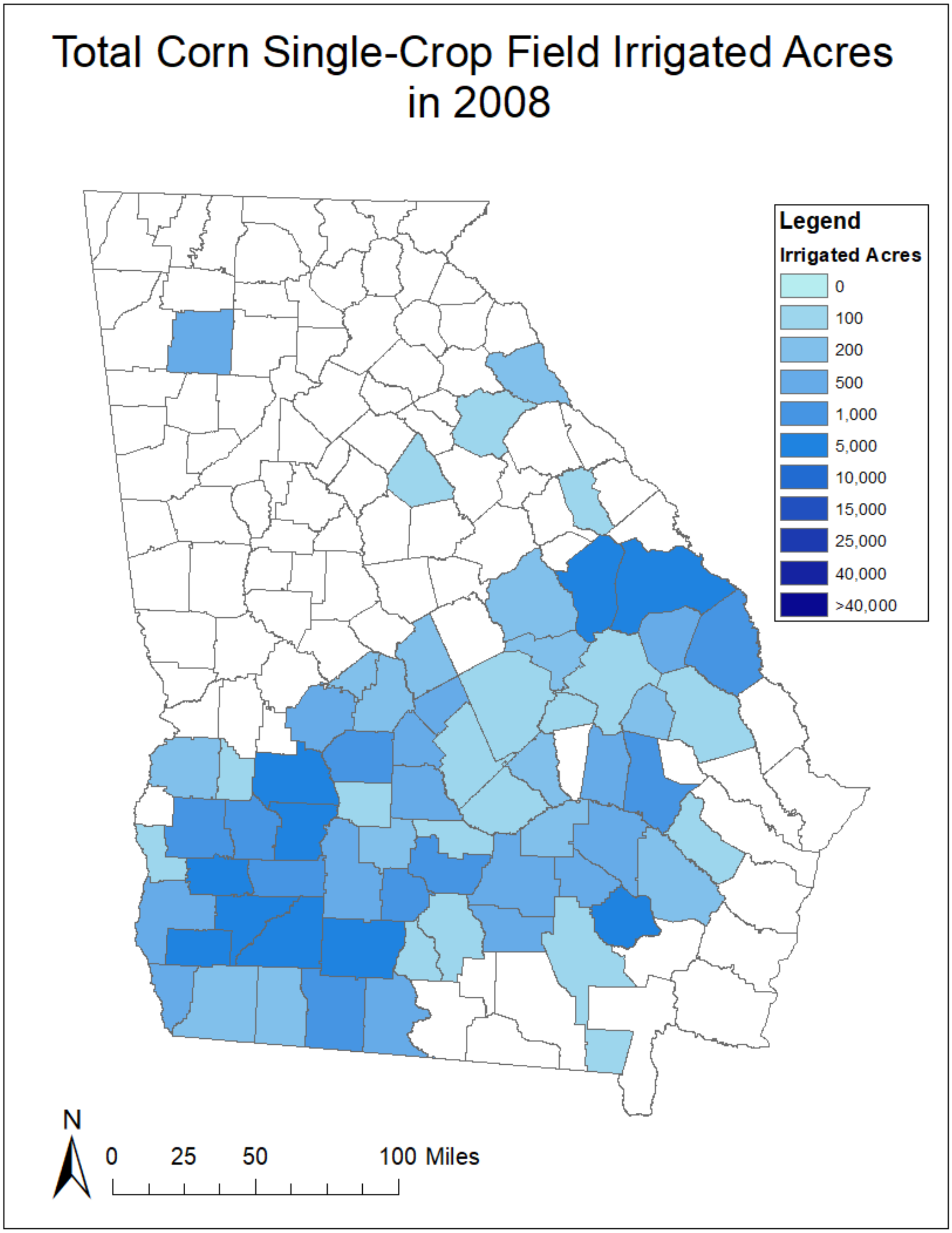
Map A.89 Total Single-Crop Field Irrigated Acres in Georgia for 2018



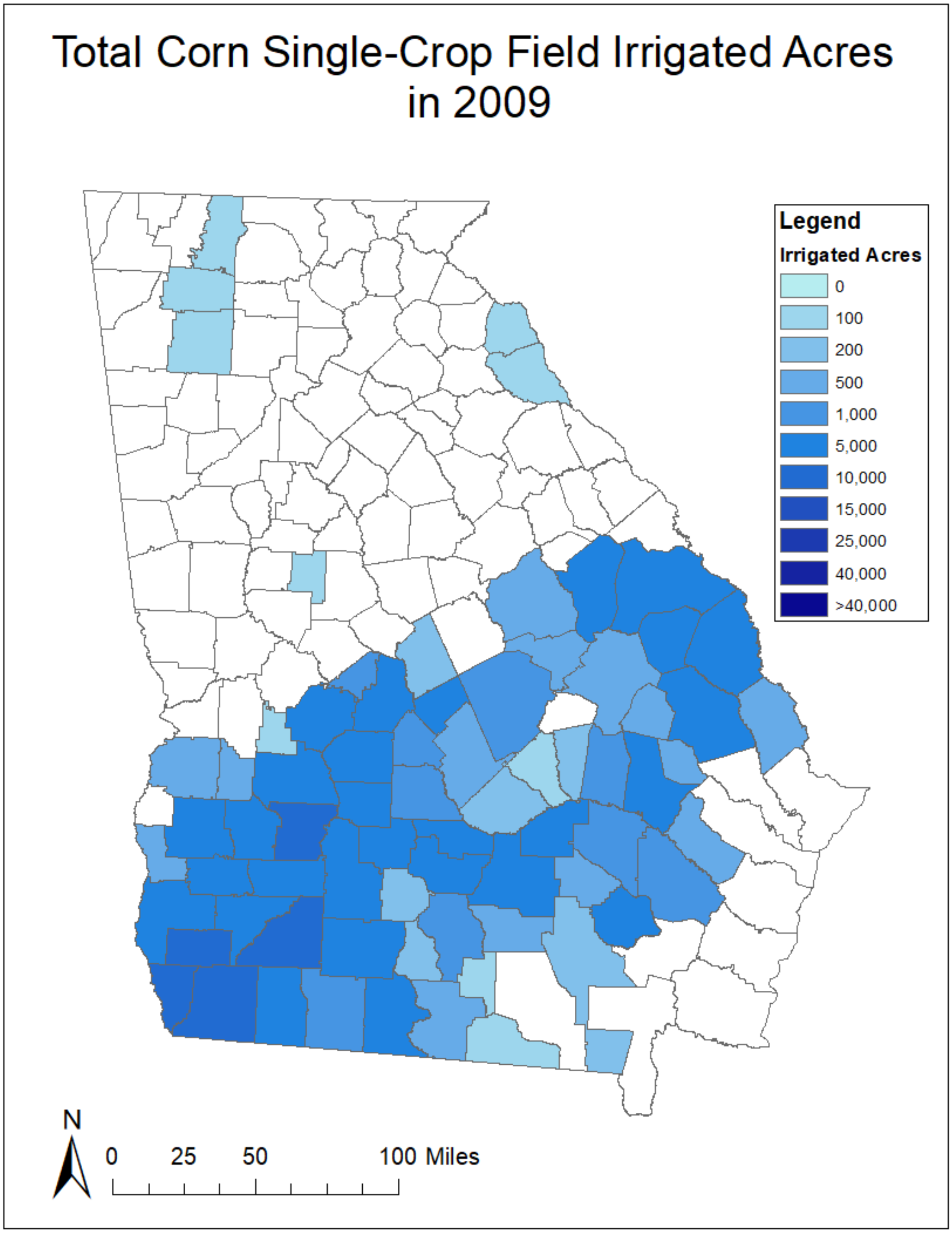
Map A.90 Total Single-Crop Field Irrigated Acres in Georgia for 2019



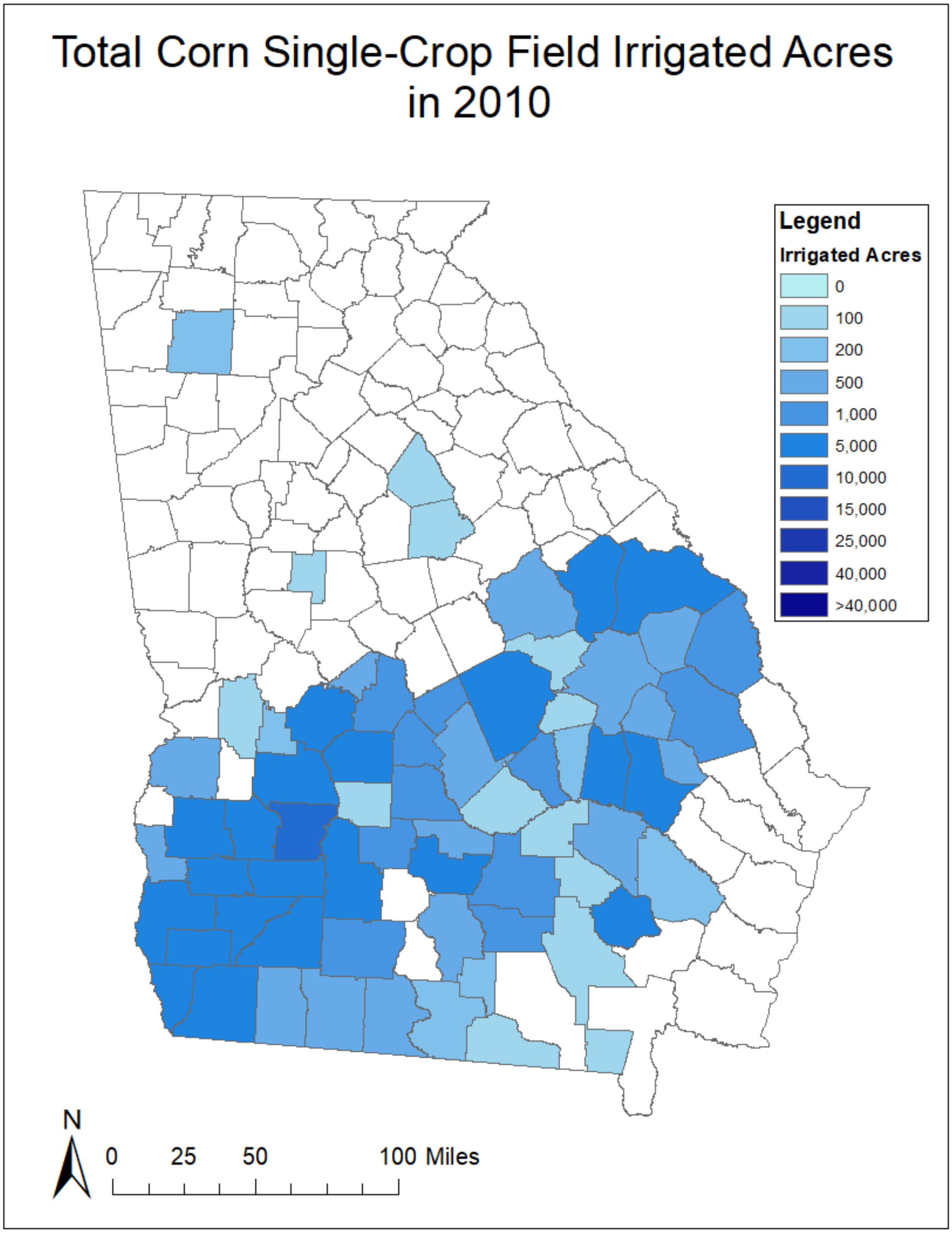
Map A.91 Total Single-Crop Field Irrigated Acres in Georgia for 2020



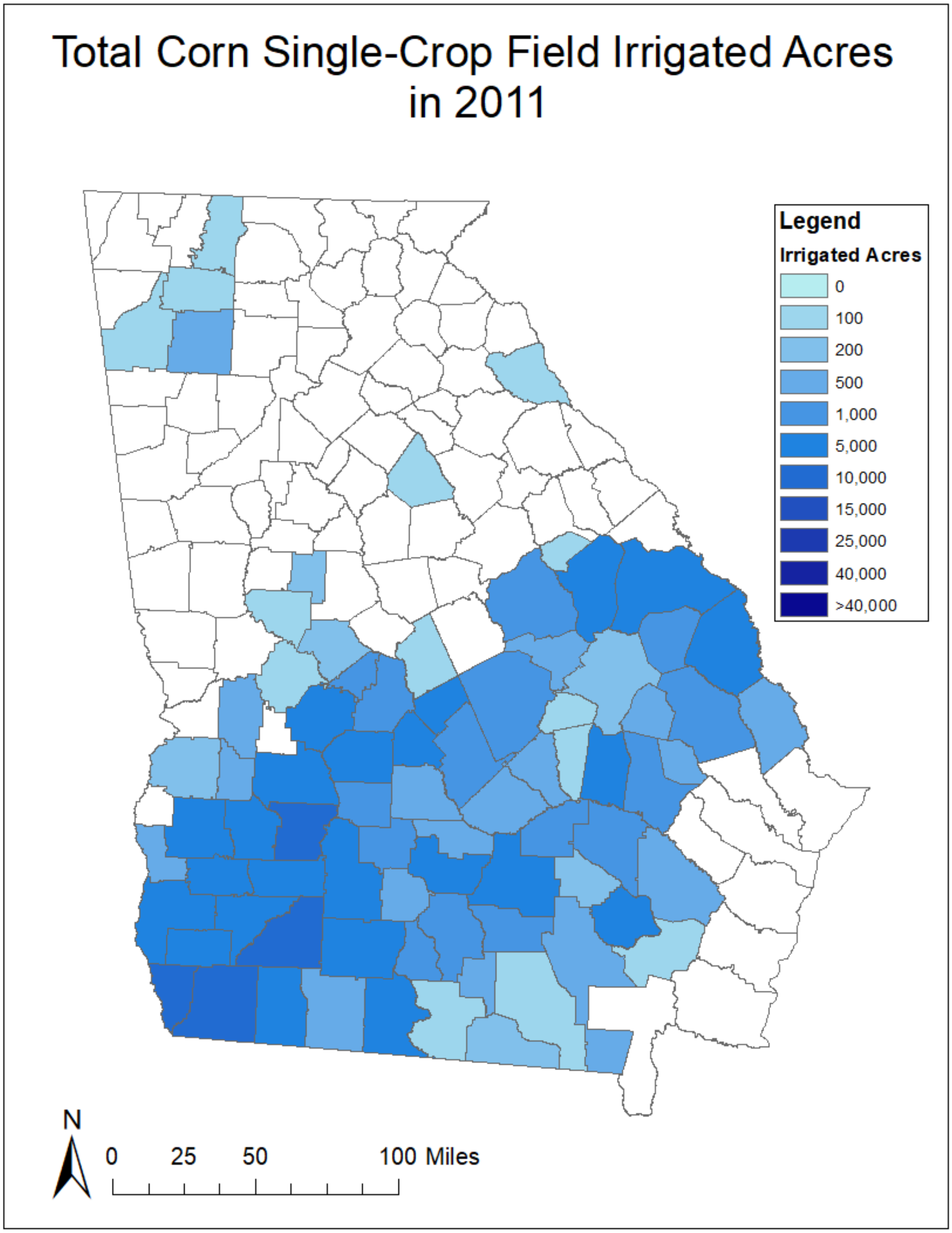
Map A.92 Total Corn Single-Crop Field Irrigated Acres in Georgia for 2008



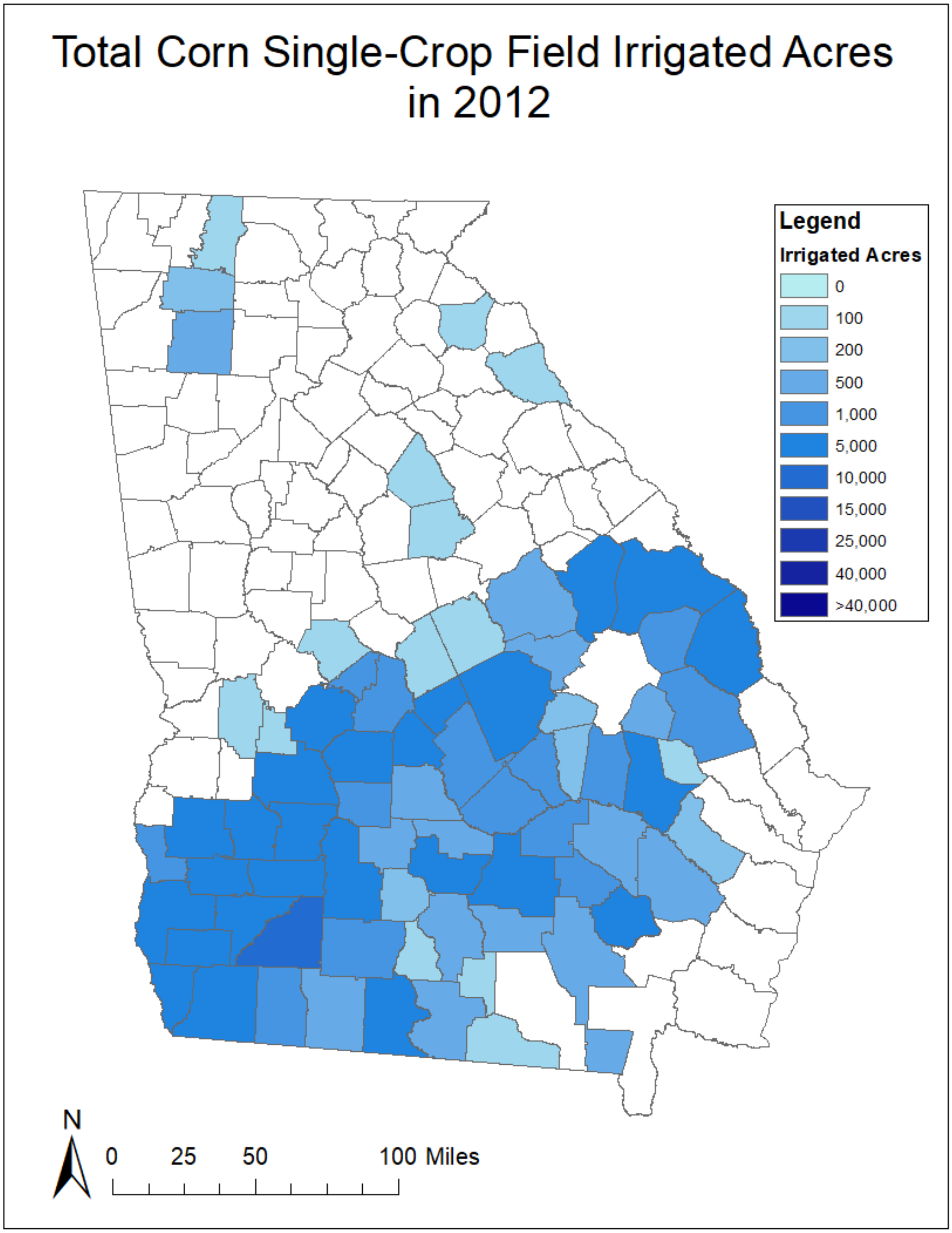
Map A.93 Total Corn Single-Crop Field Irrigated Acres in Georgia for 2009



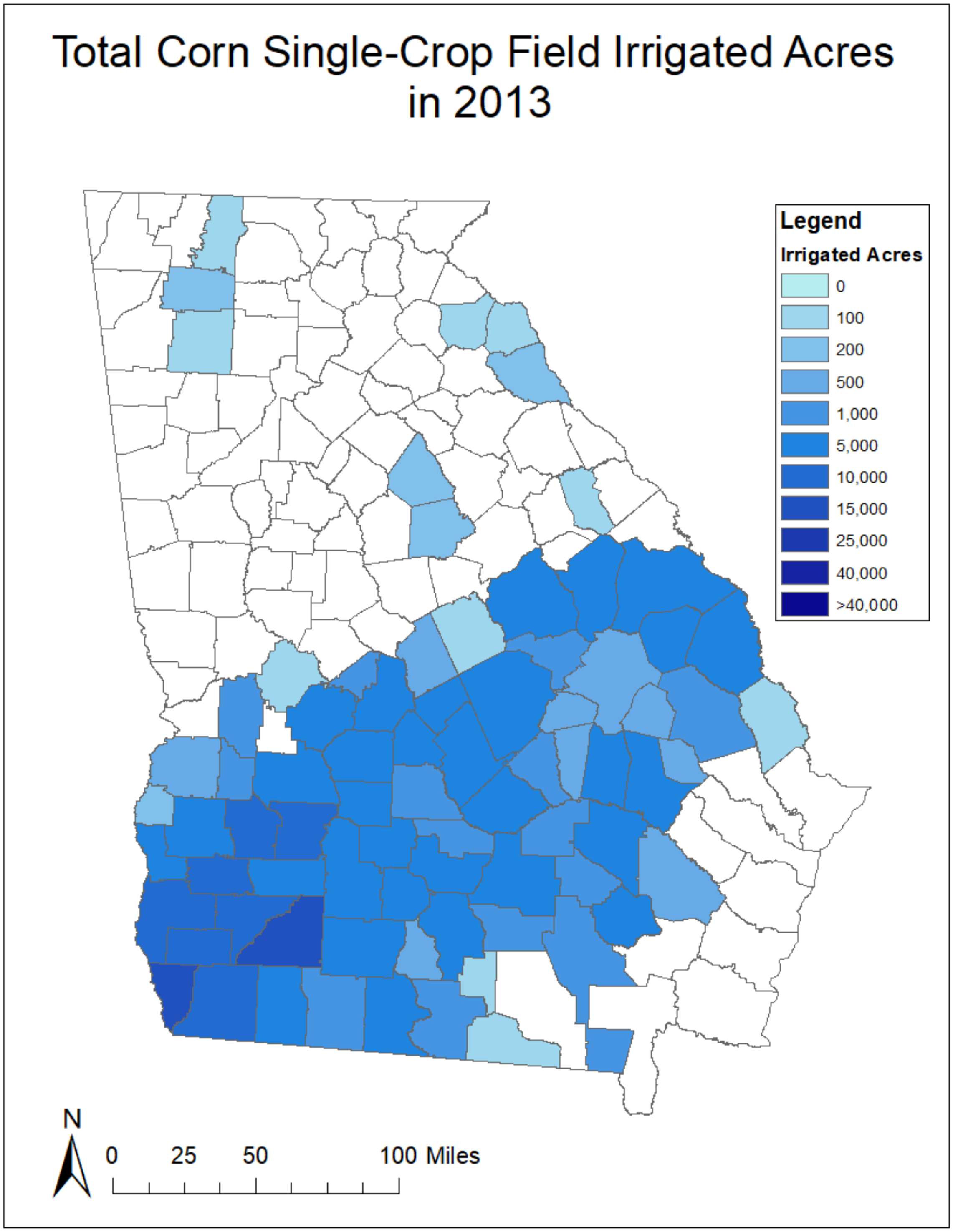
Map A.94 Total Corn Single-Crop Field Irrigated Acres in Georgia for 2010



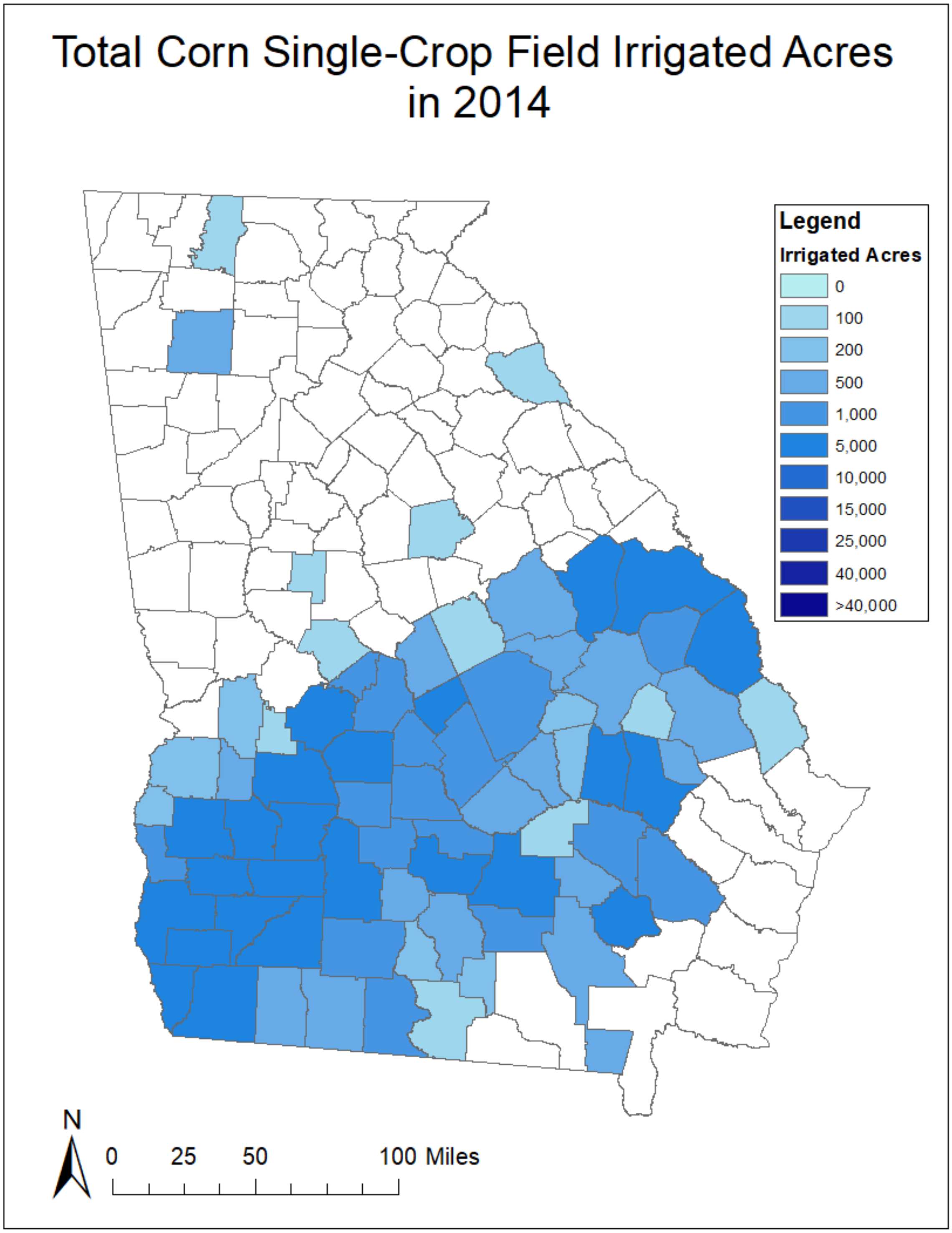
Map A.95 Total Corn Single-Crop Field Irrigated Acres in Georgia for 2011



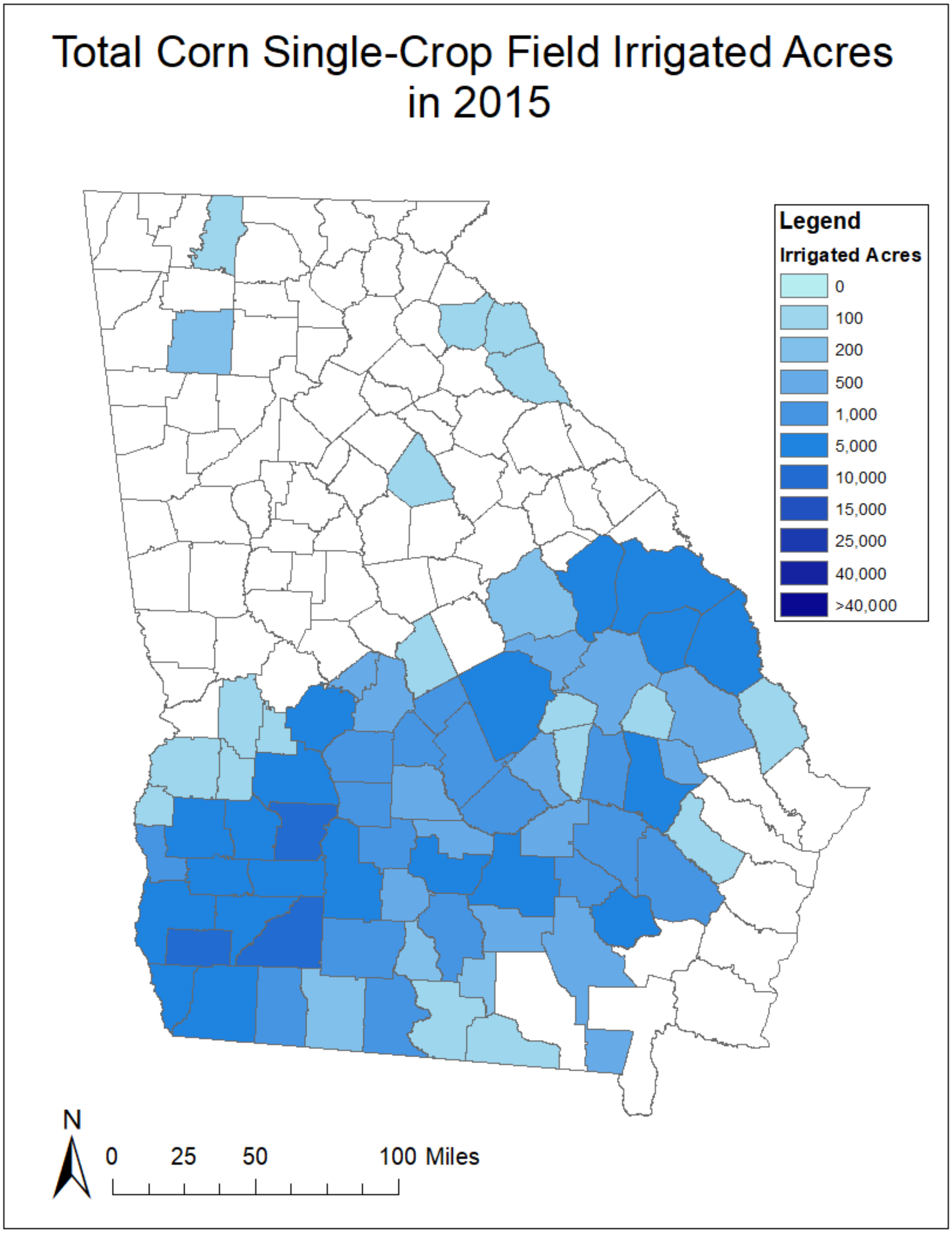
Map A.96 Total Corn Single-Crop Field Irrigated Acres in Georgia for 2012



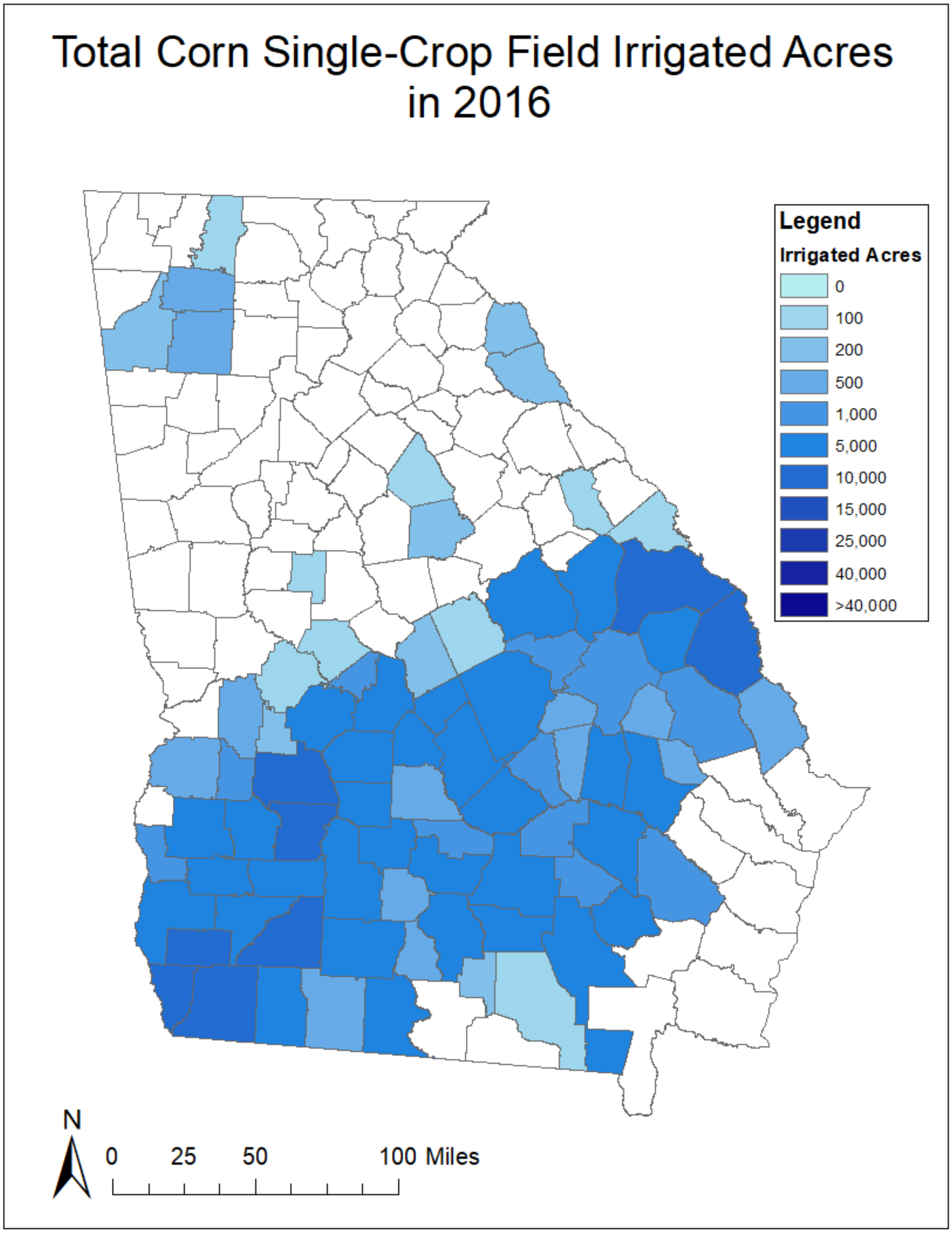
Map A.97 Total Corn Single-Crop Field Irrigated Acres in Georgia for 2013



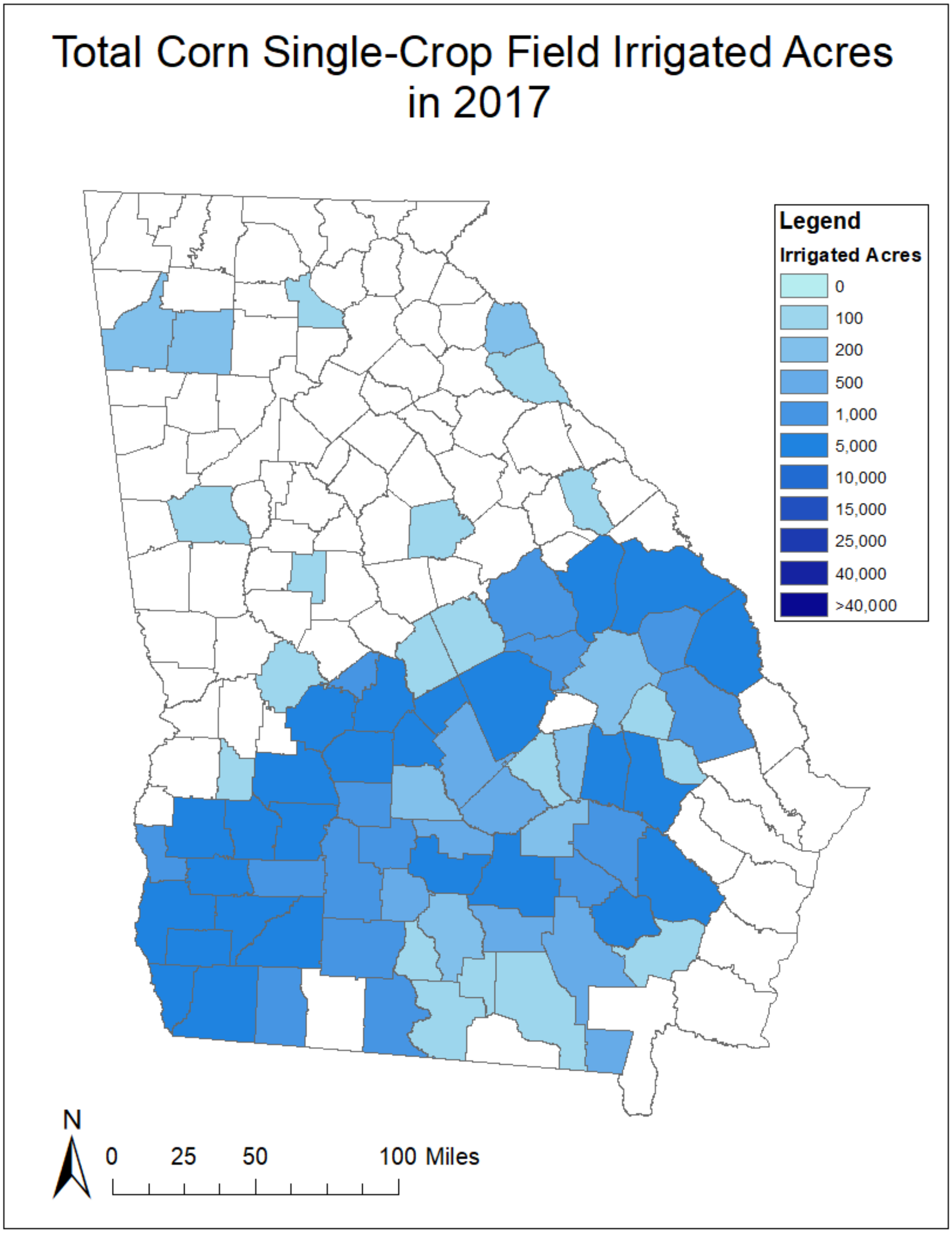
Map A.98 Total Corn Single-Crop Field Irrigated Acres in Georgia for 2014



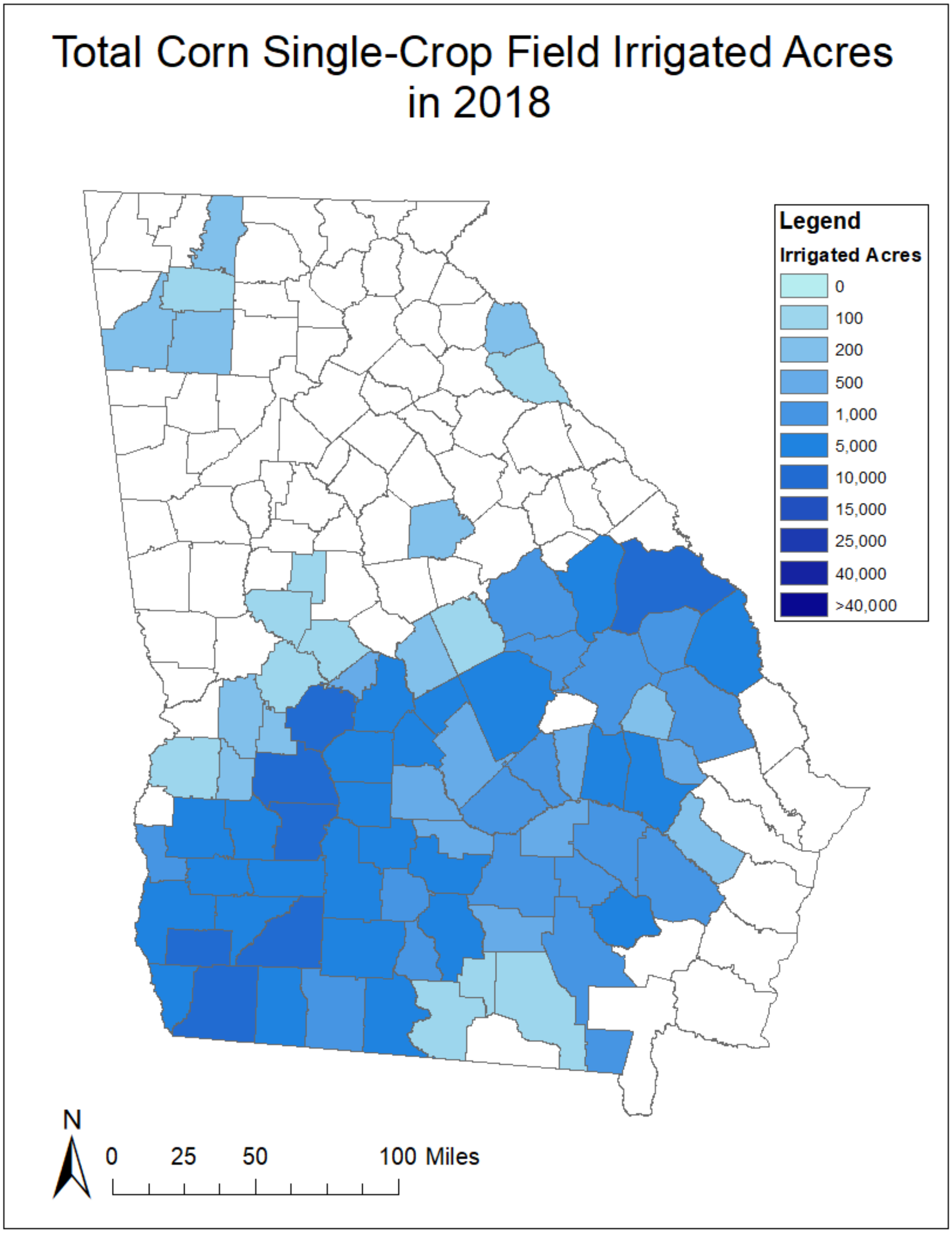
Map A.99 Total Corn Single-Crop Field Irrigated Acres in Georgia for 2015



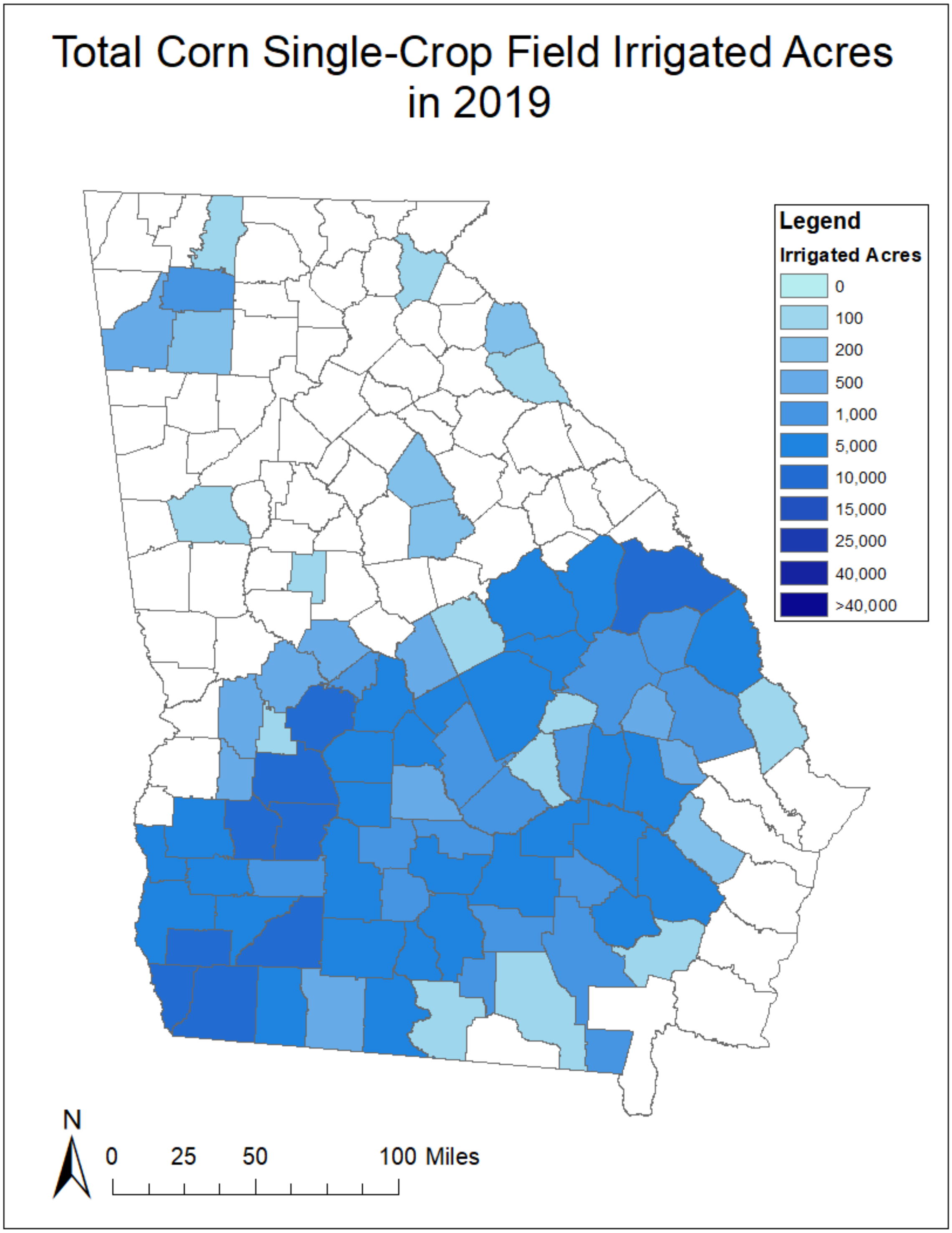
Map A.100 Total Corn Single-Crop Field Irrigated Acres in Georgia for 2016



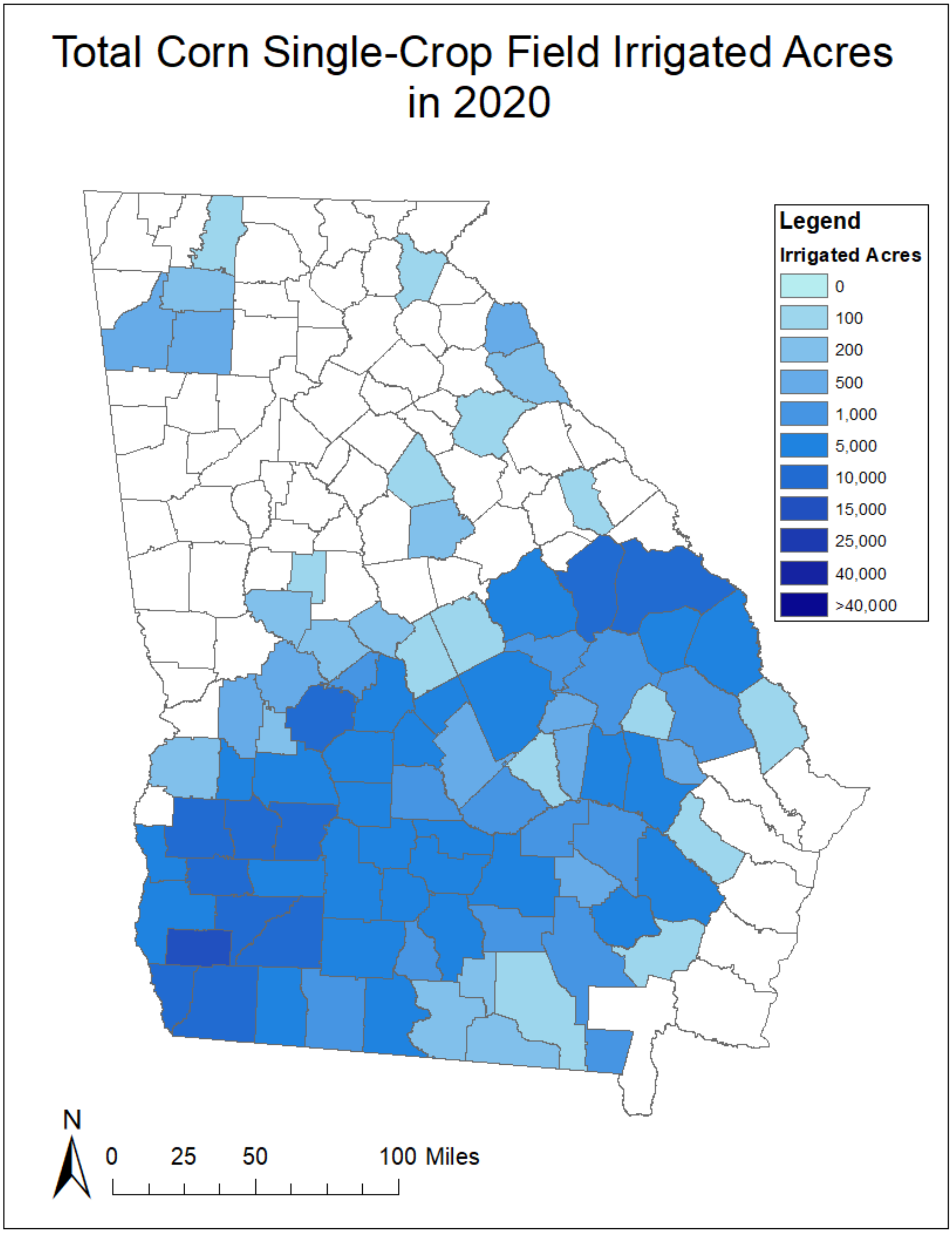
Map A.101 Total Corn Single-Crop Field Irrigated Acres in Georgia for 2017



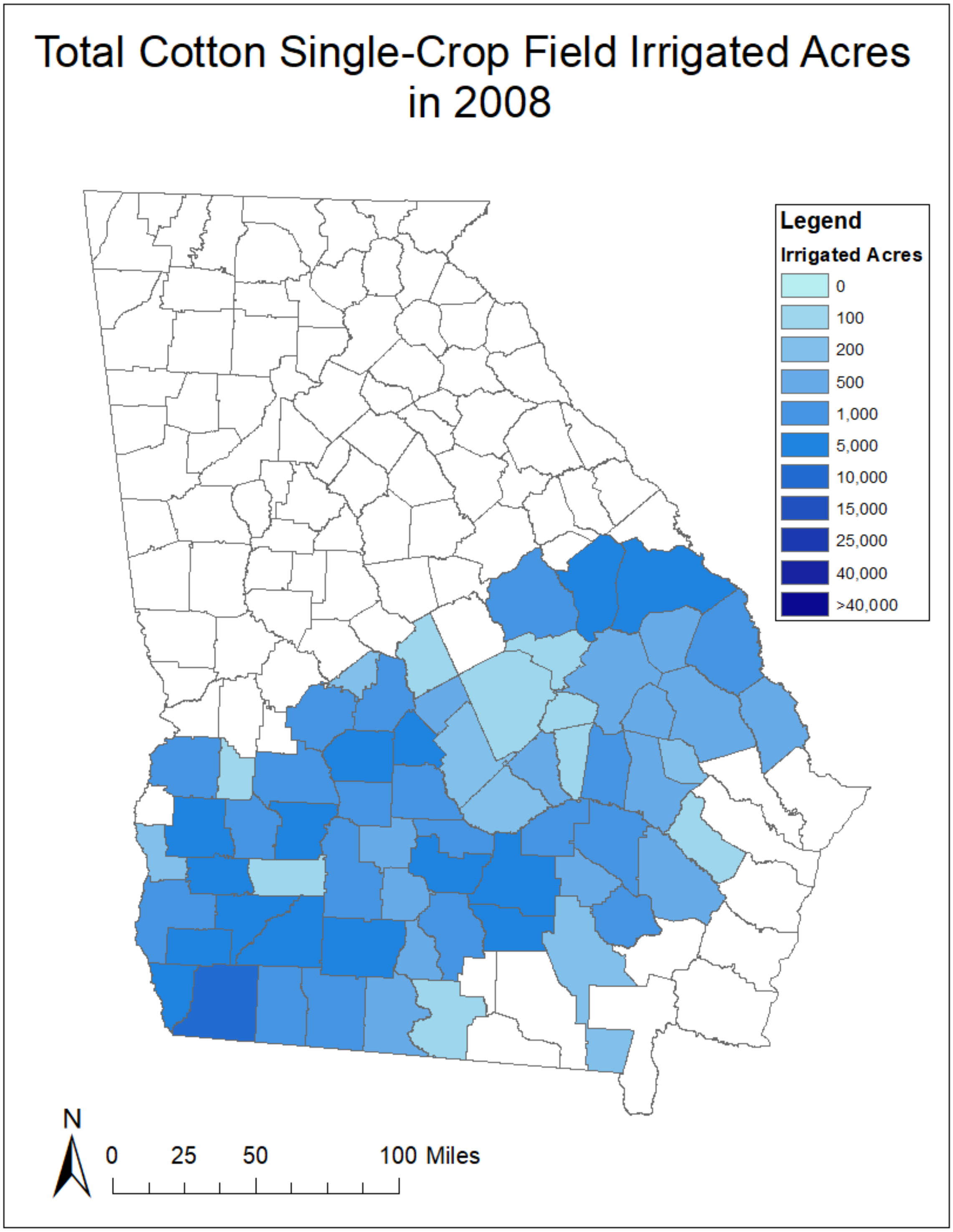
Map A.102 Total Corn Single-Crop Field Irrigated Acres in Georgia for 2018



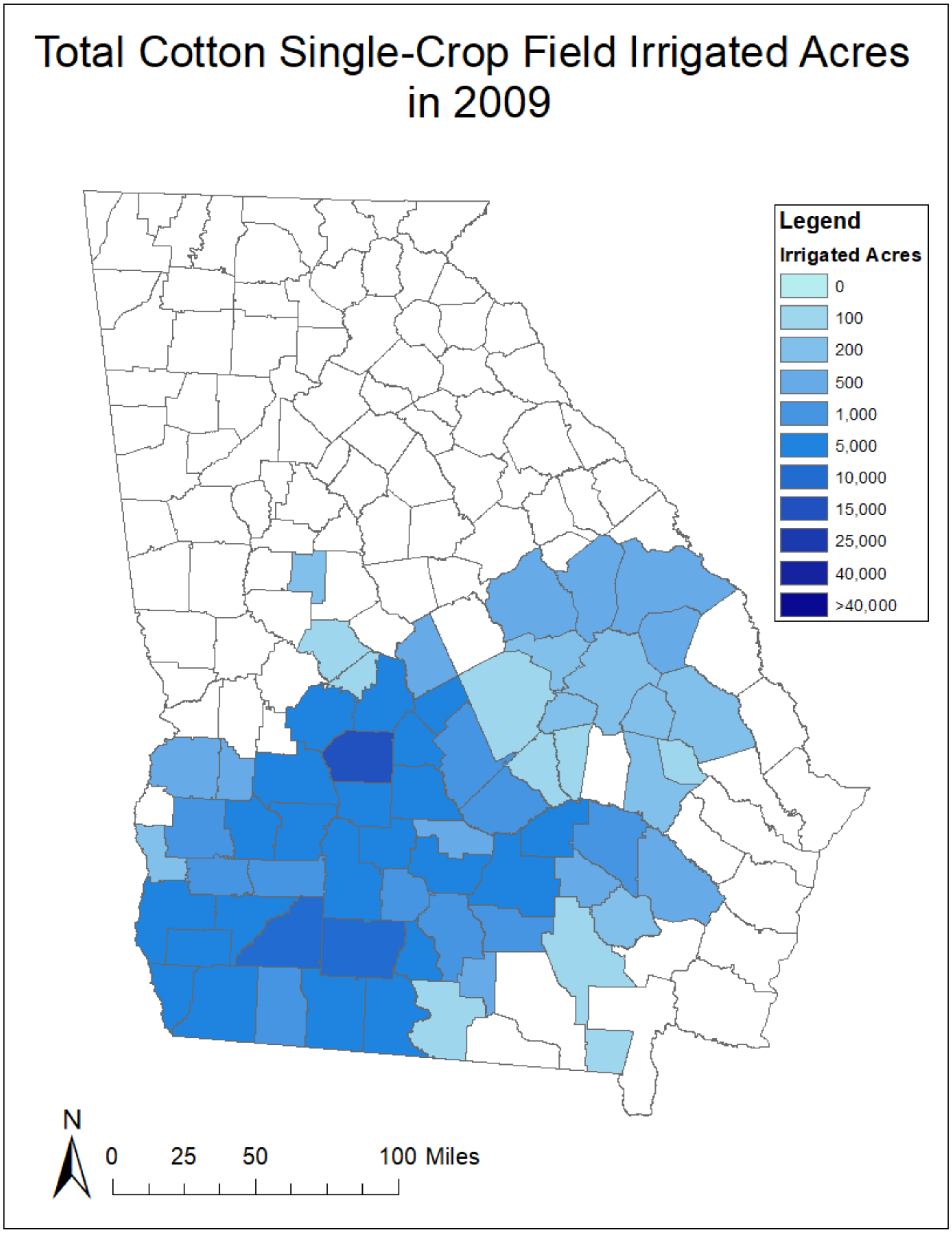
Map A.103 Total Corn Single-Crop Field Irrigated Acres in Georgia for 2019



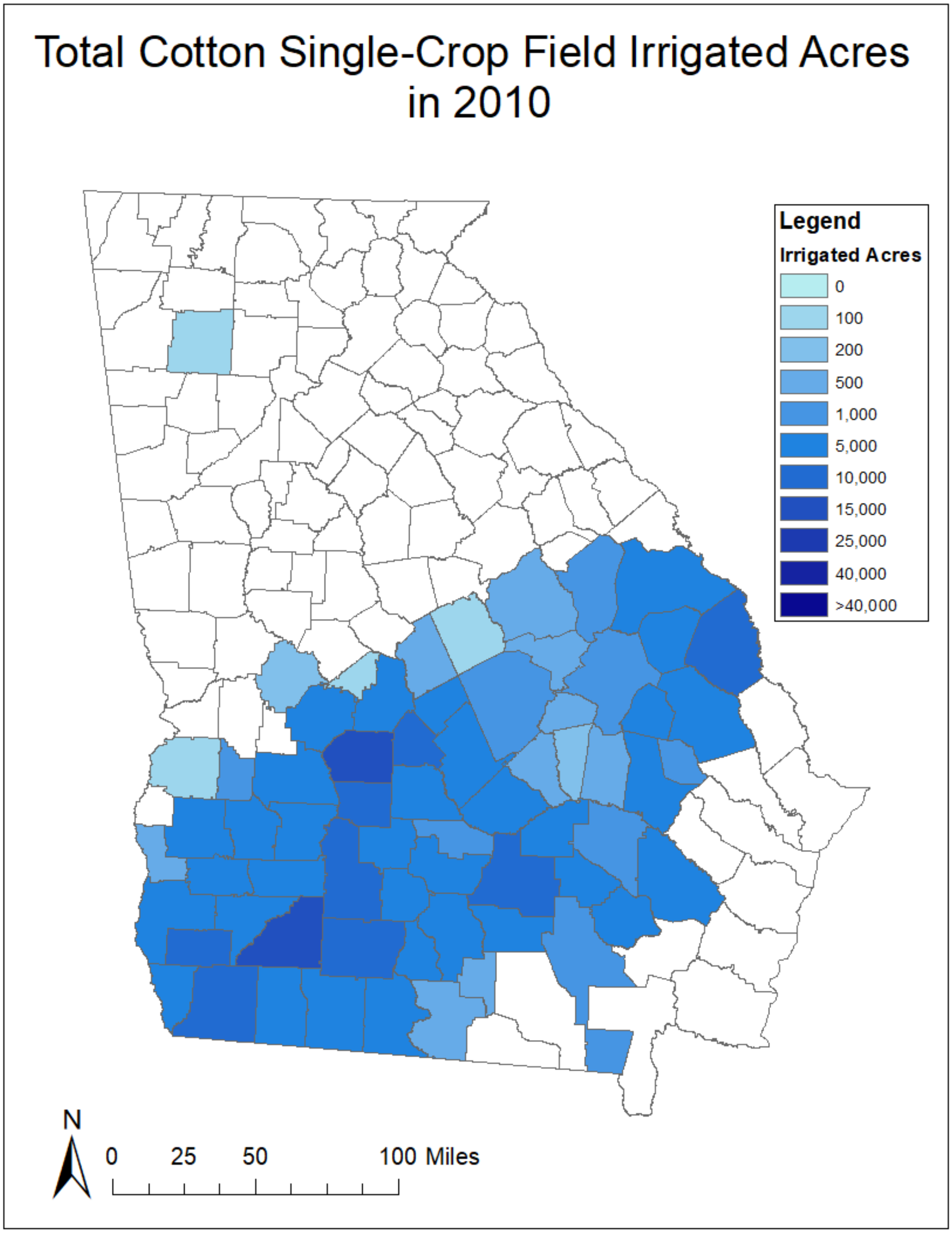
Map A.104 Total Corn Single-Crop Field Irrigated Acres in Georgia for 2020



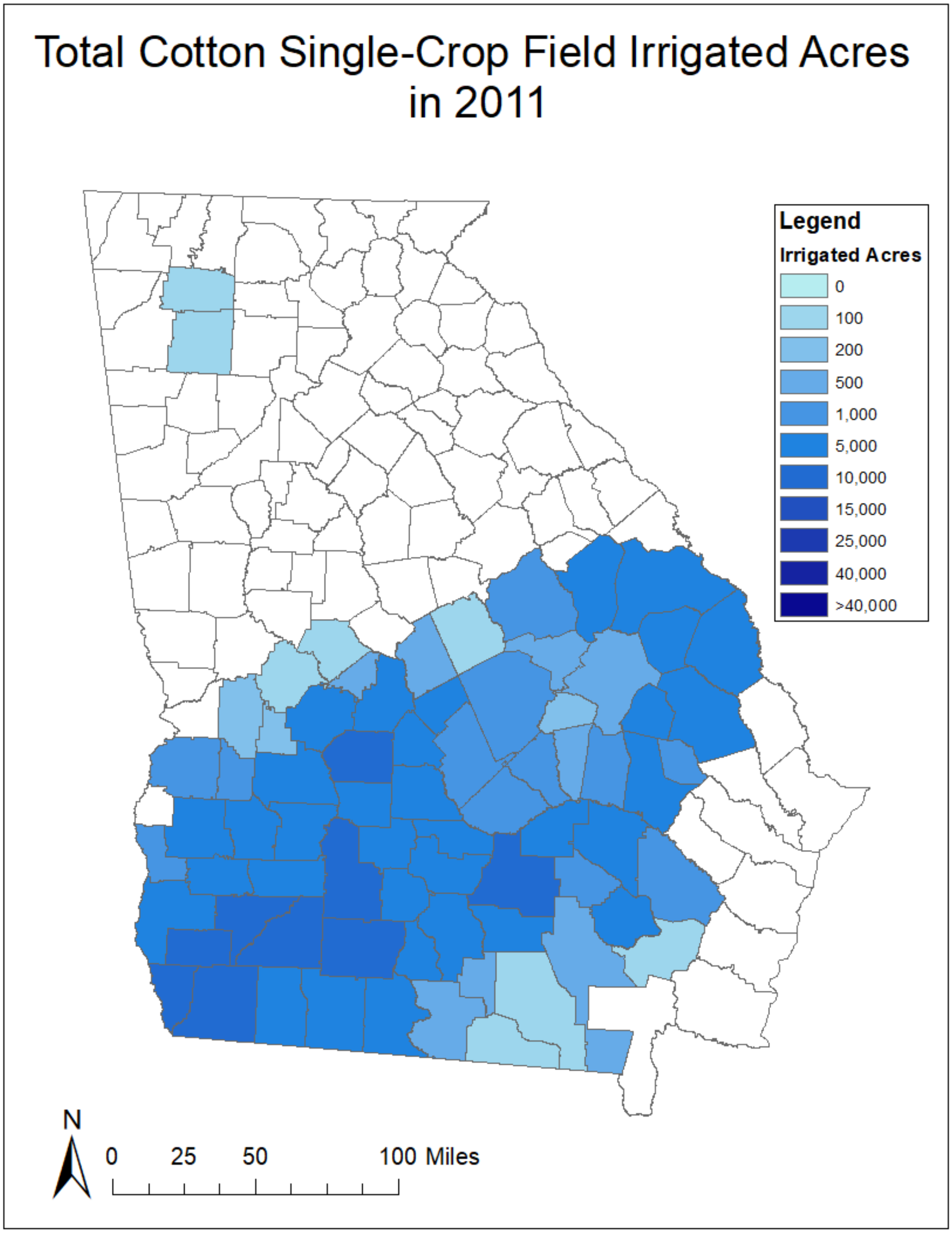
Map A.105 Total Cotton Single-Crop Field Irrigated Acres in Georgia for 2008



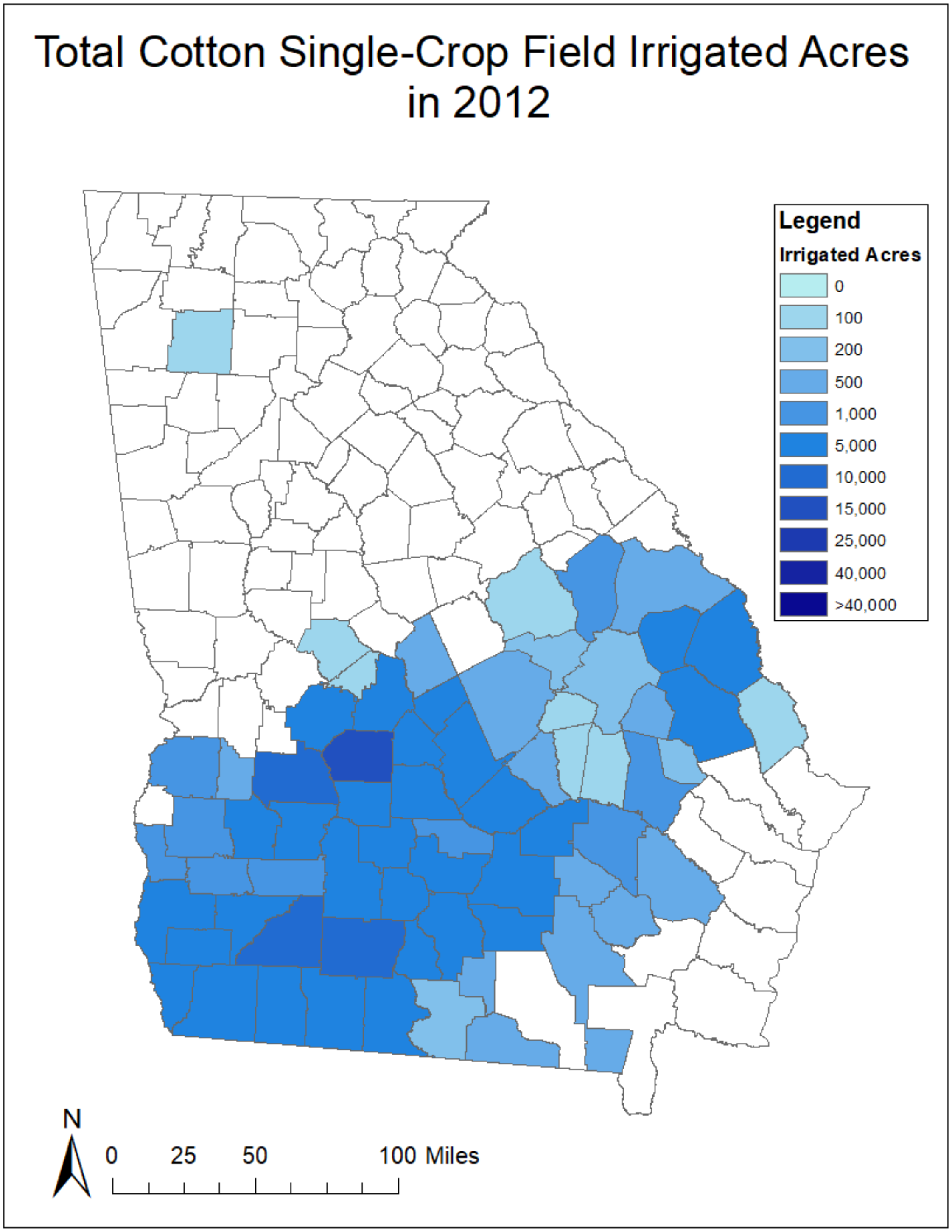
Map A.106 Total Cotton Single-Crop Field Irrigated Acres in Georgia for 2009



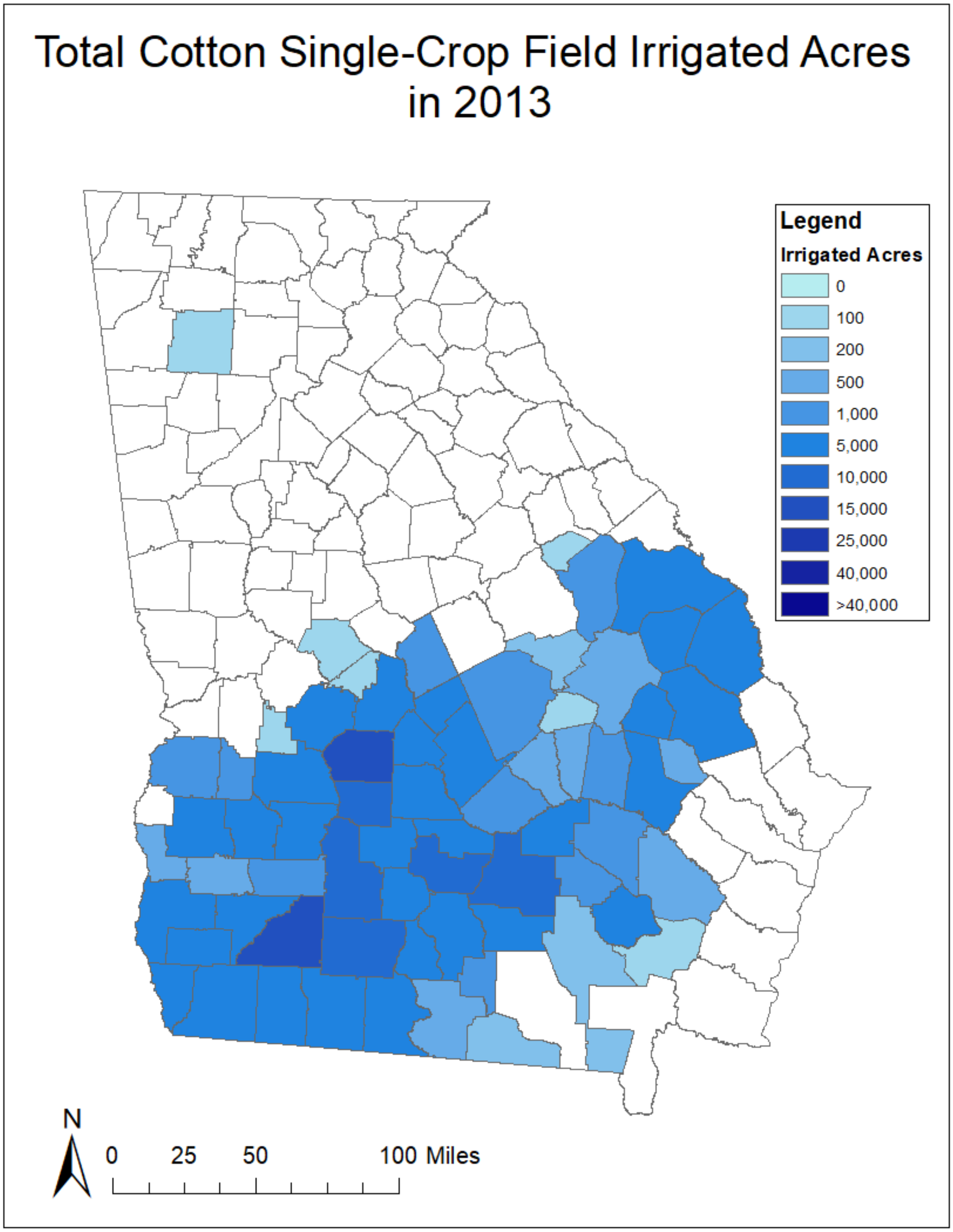
Map A.107 Total Cotton Single-Crop Field Irrigated Acres in Georgia for 2010



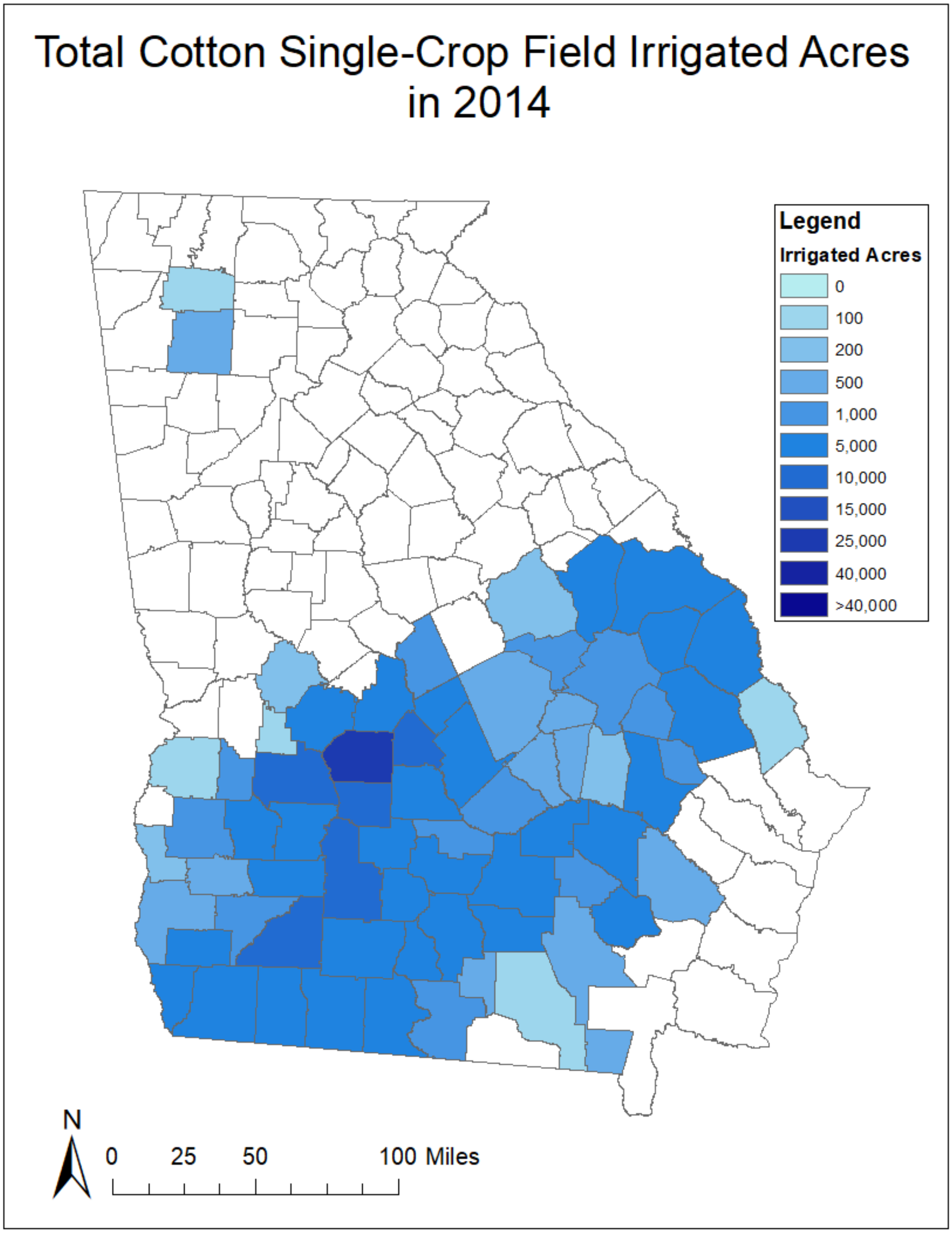
Map A.108 Total Cotton Single-Crop Field Irrigated Acres in Georgia for 2011



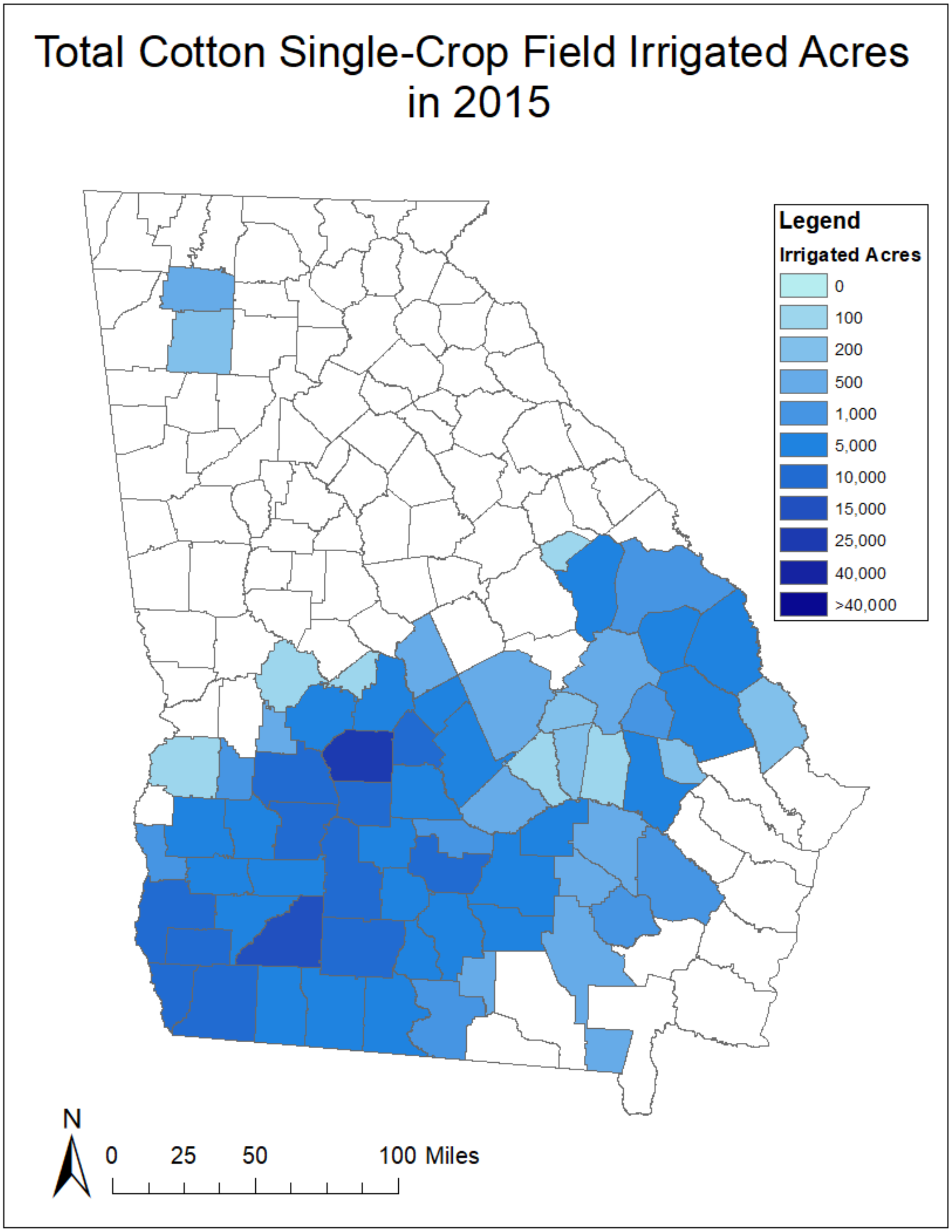
Map A.109 Total Cotton Single-Crop Field Irrigated Acres in Georgia for 2012



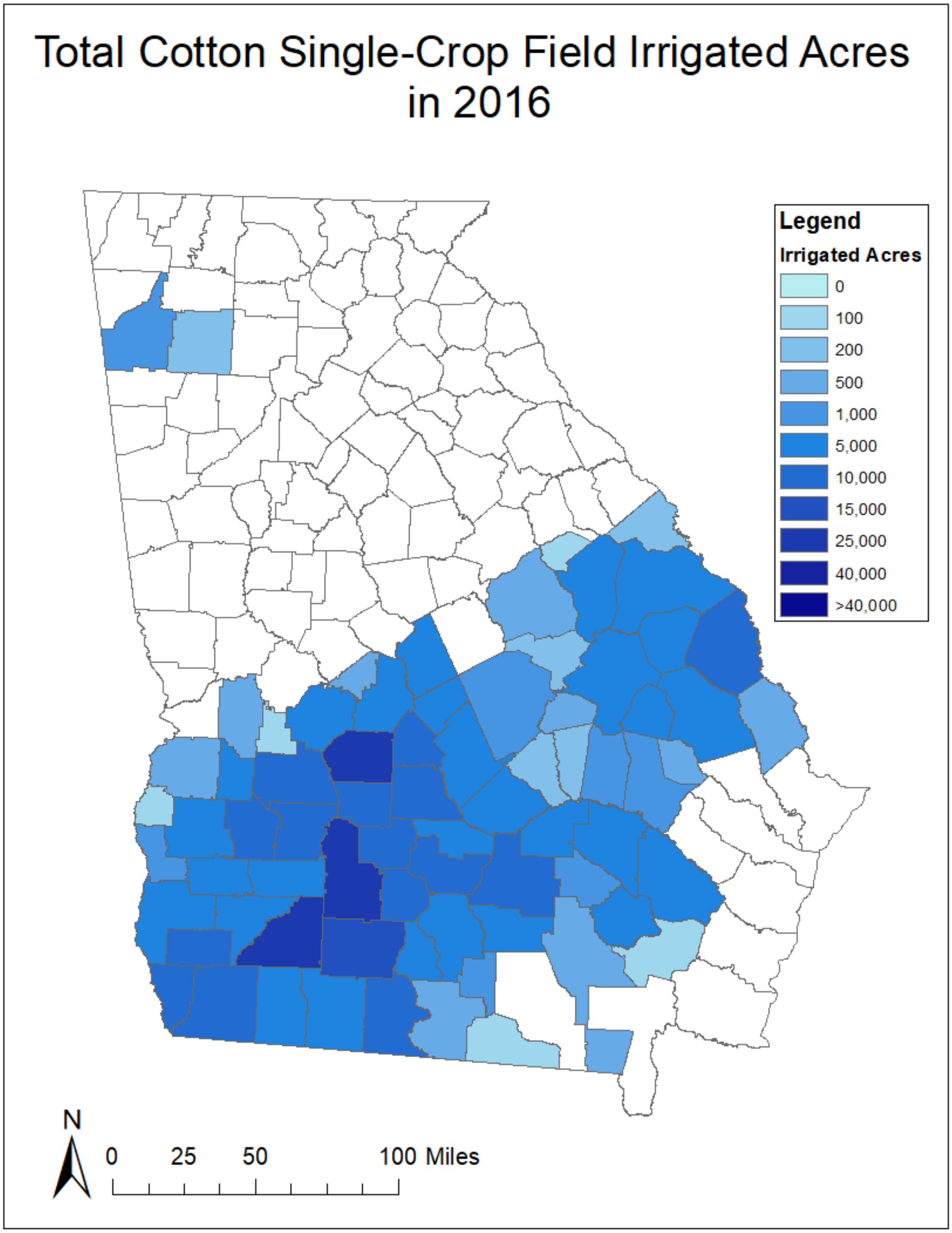
Map A.110 Total Cotton Single-Crop Field Irrigated Acres in Georgia for 2013



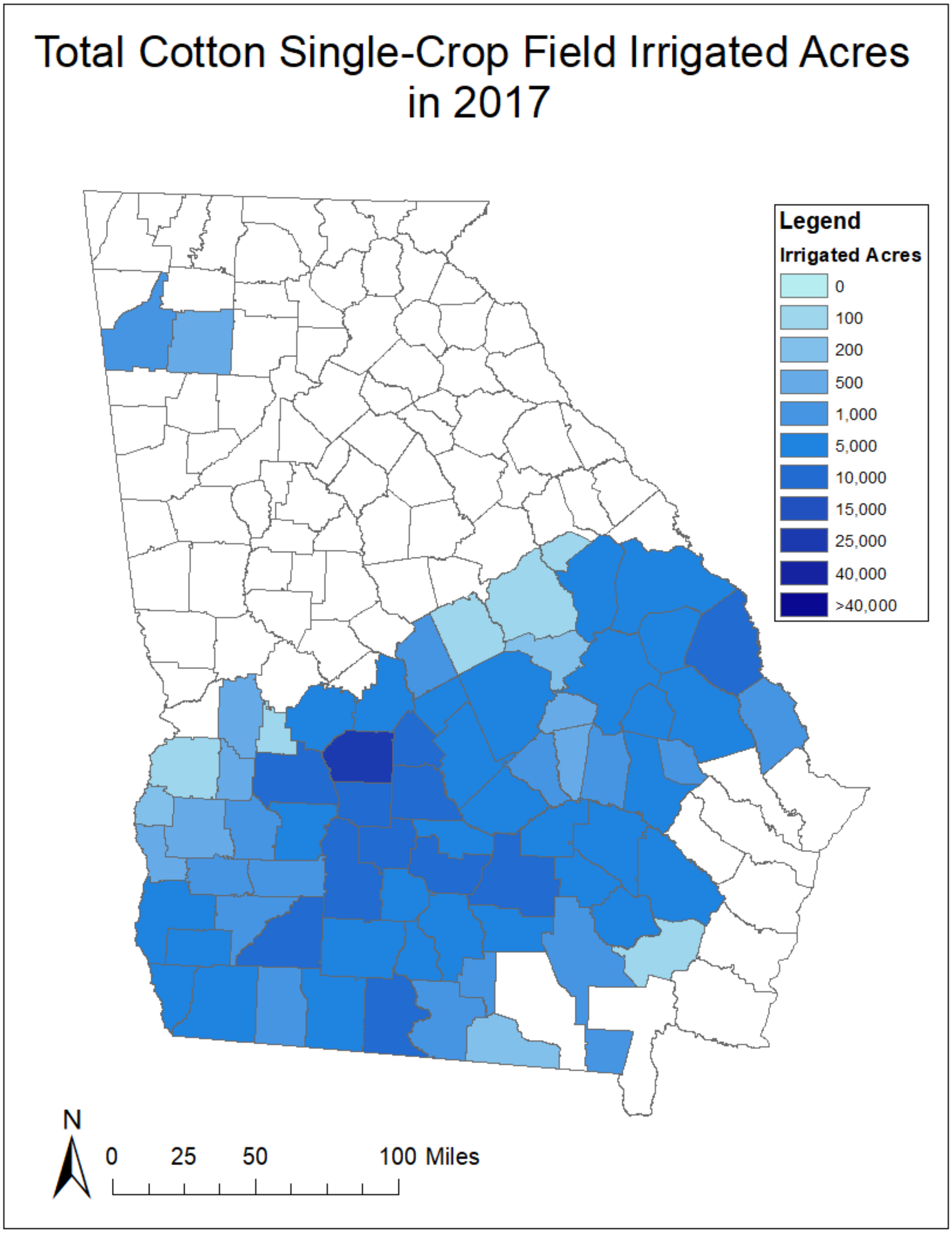
Map A.111 Total Cotton Single-Crop Field Irrigated Acres in Georgia for 2014



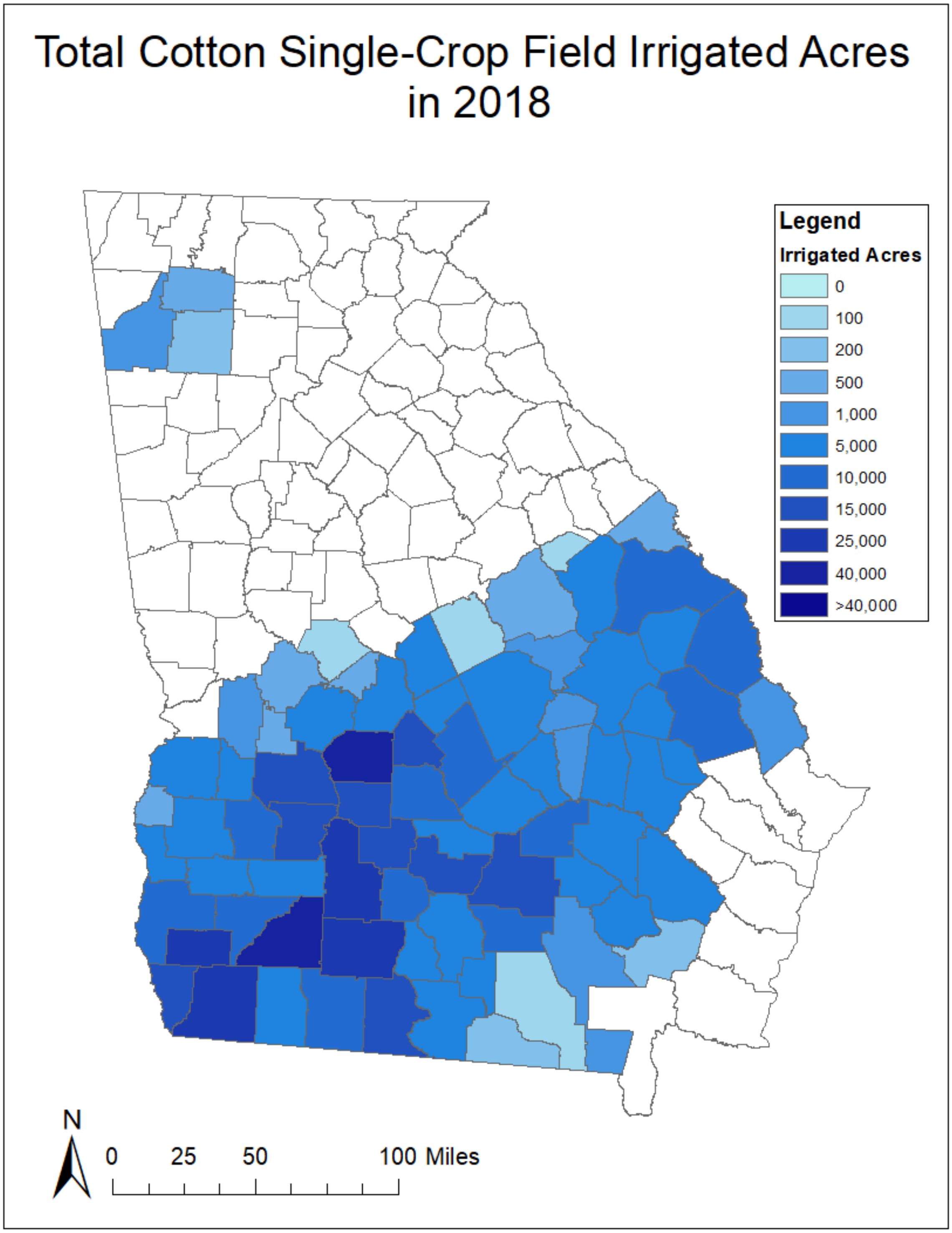
Map A.112 Total Cotton Single-Crop Field Irrigated Acres in Georgia for 2015



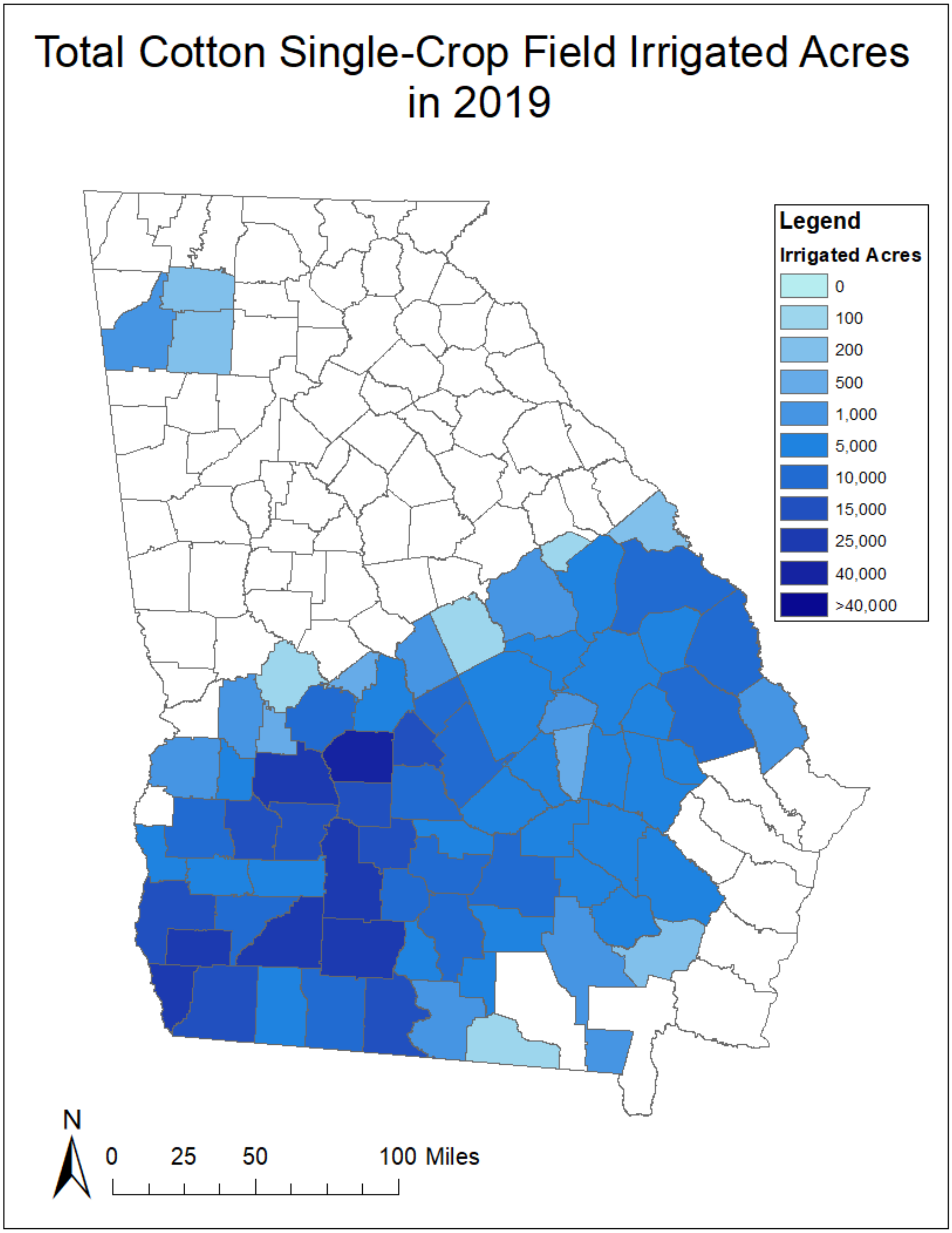
Map A.113 Total Cotton Single-Crop Field Irrigated Acres in Georgia for 2016



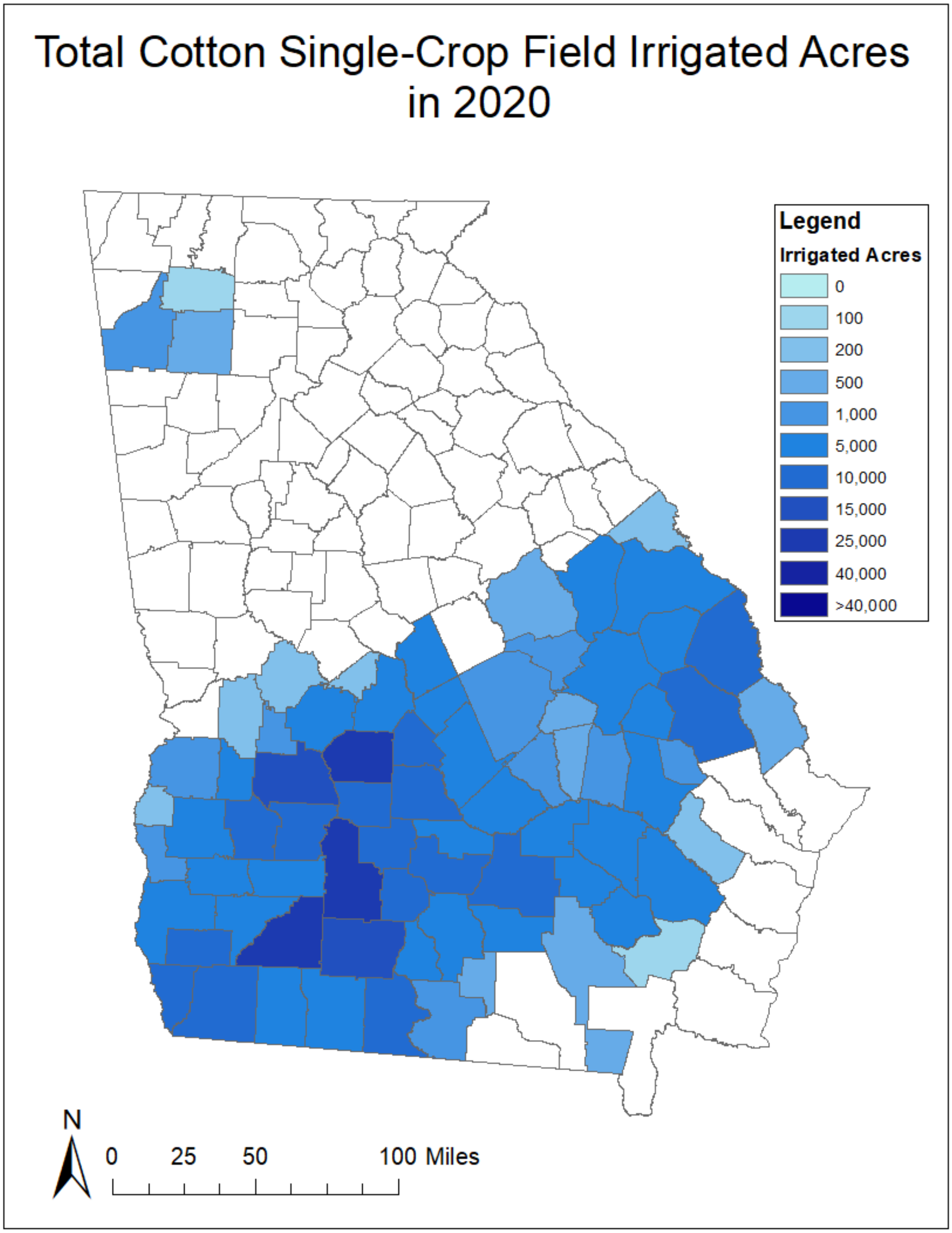
Map A.114 Total Cotton Single-Crop Field Irrigated Acres in Georgia for 2017



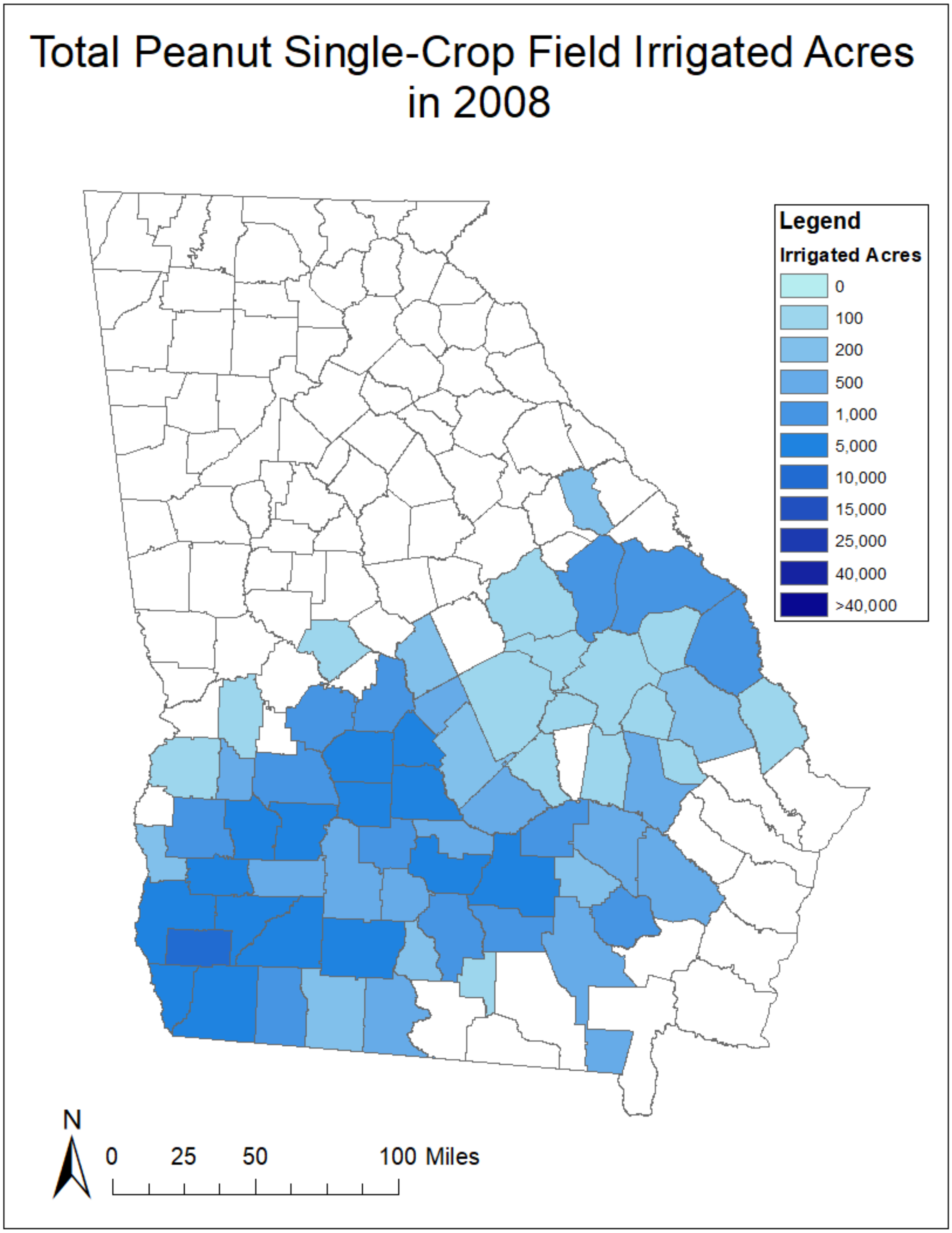
Map A.115 Total Cotton Single-Crop Field Irrigated Acres in Georgia for 2018



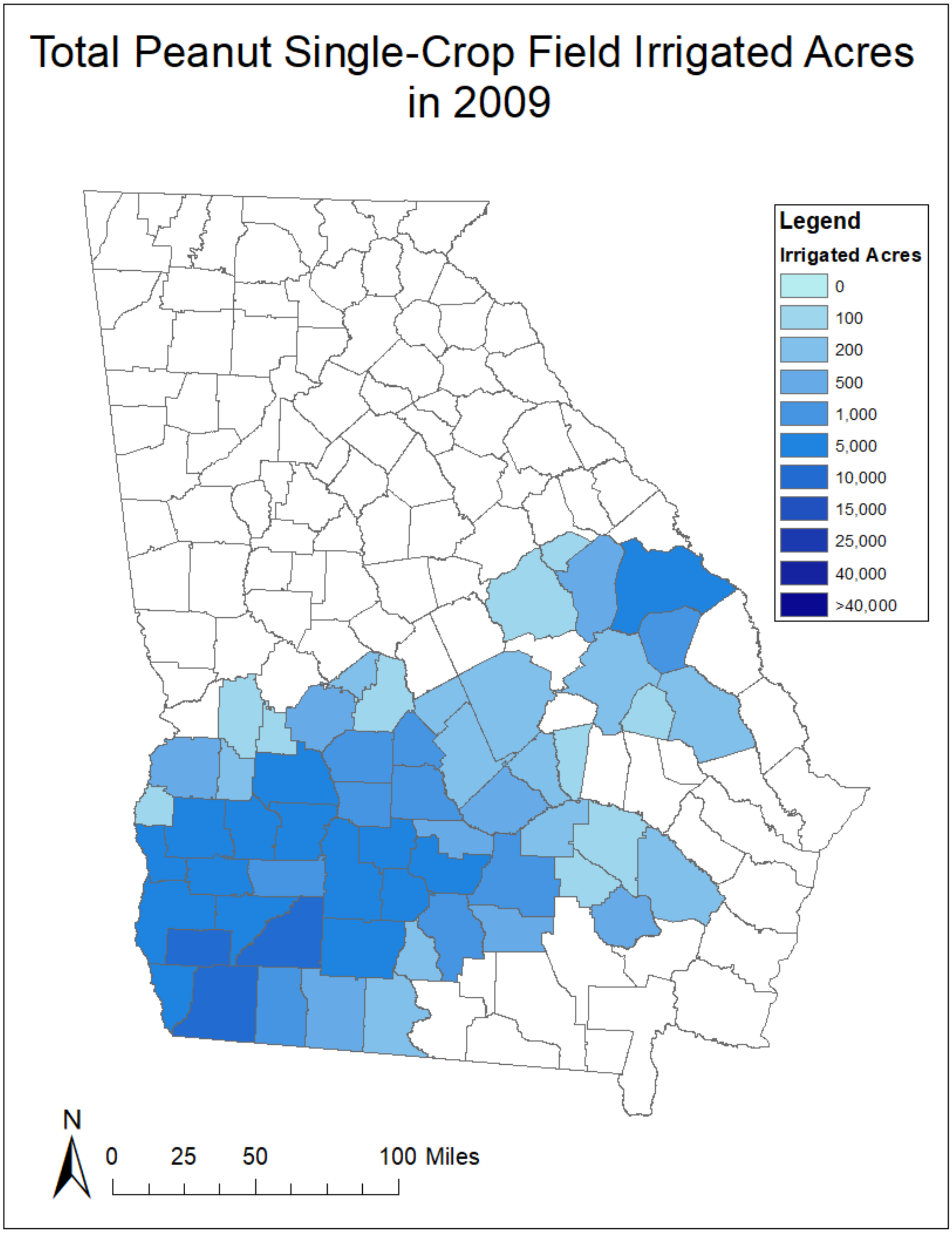
Map A.116 Total Cotton Single-Crop Field Irrigated Acres in Georgia for 2019



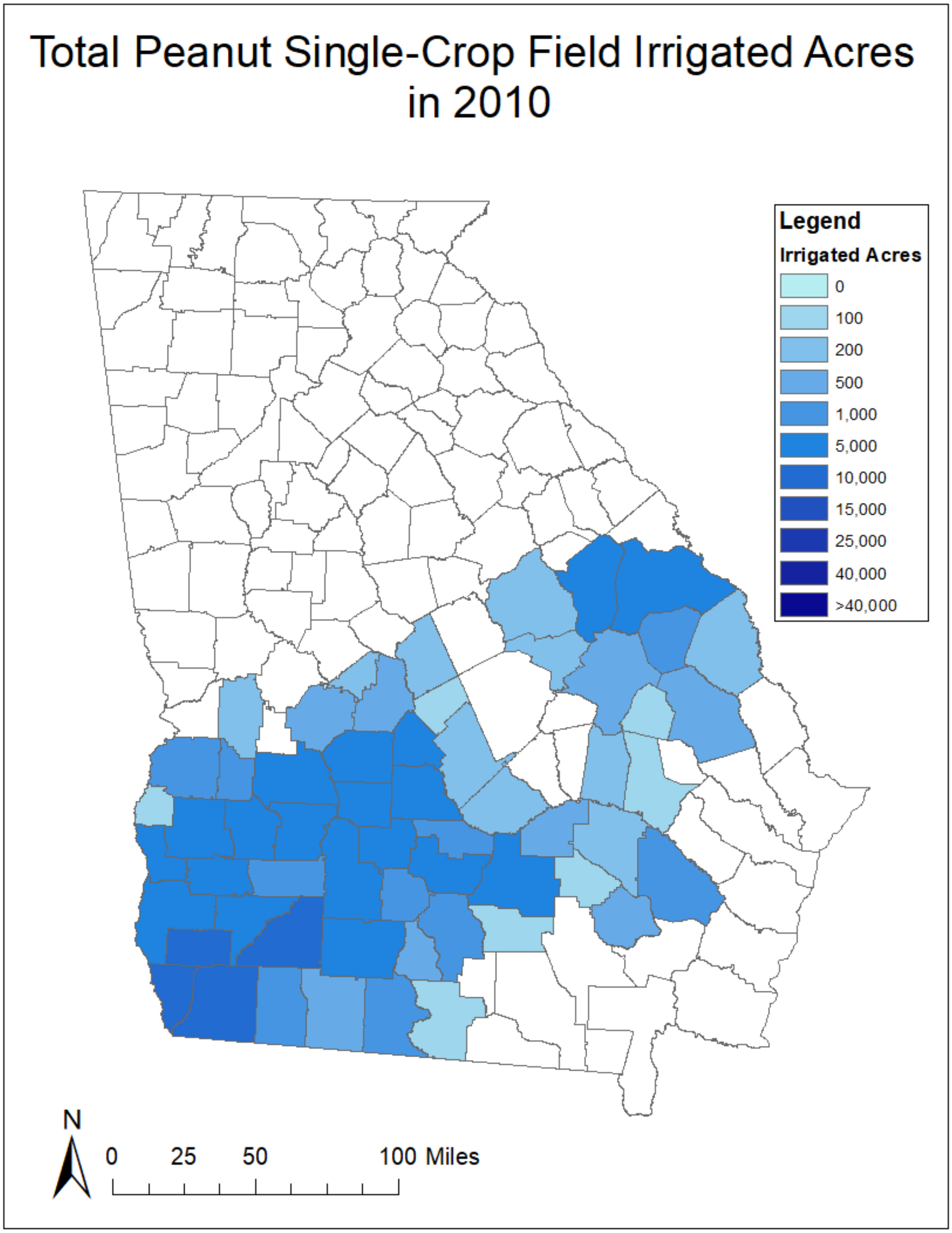
Map A.117 Total Cotton Single-Crop Field Irrigated Acres in Georgia for 2020



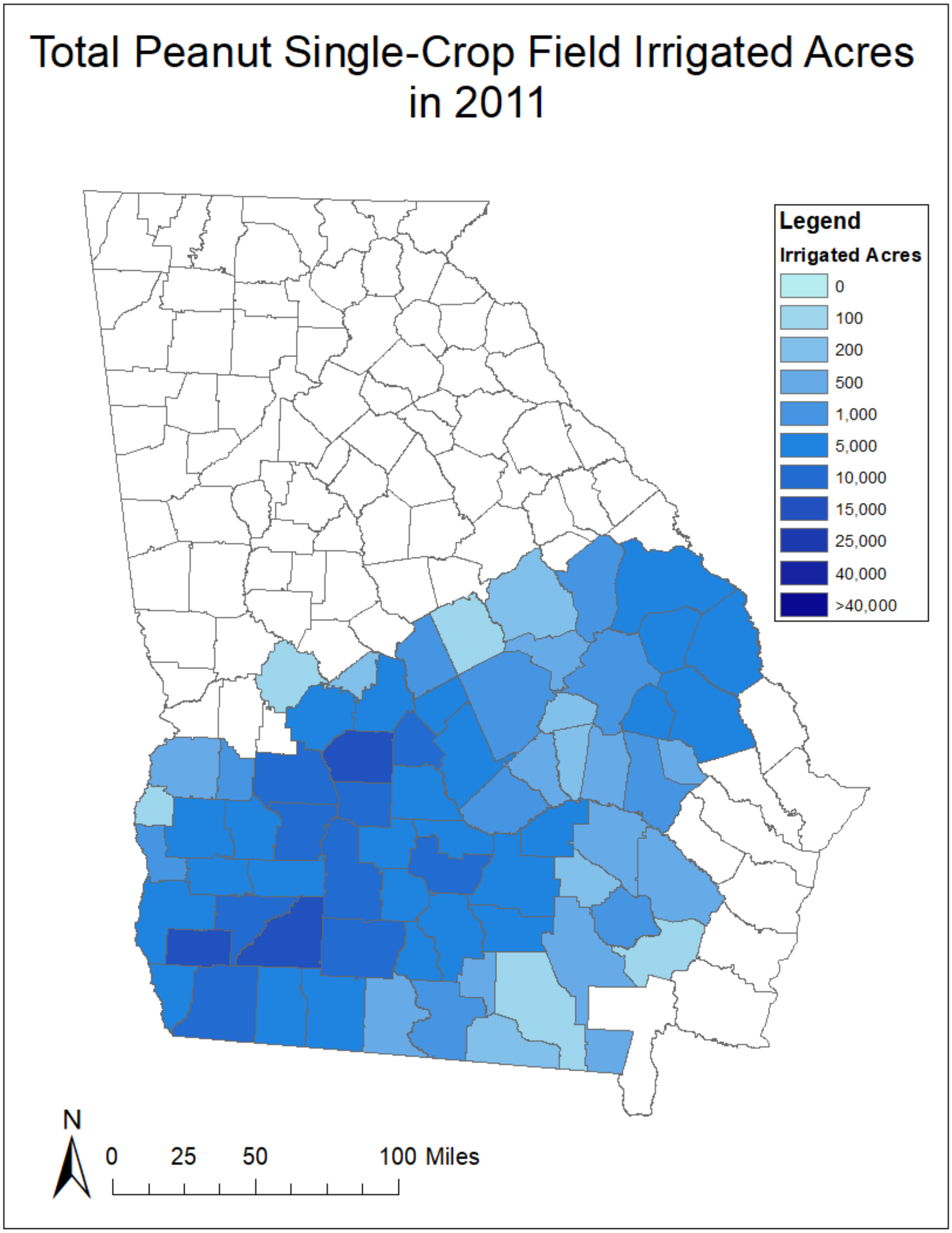
Map A.118 Total Peanut Single-Crop Field Irrigated Acres in Georgia for 2008



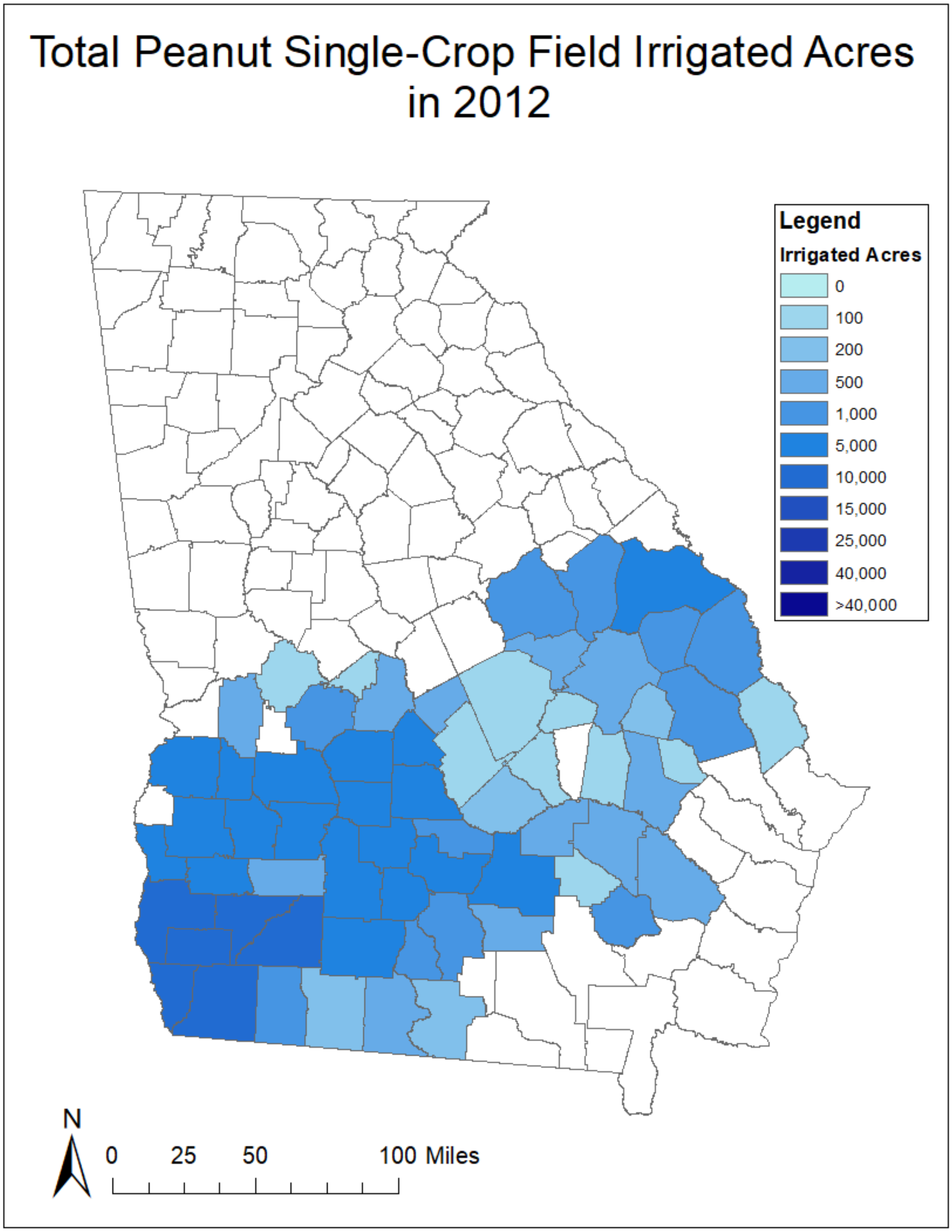
Map A.119 Total Peanut Single-Crop Field Irrigated Acres in Georgia for 2009



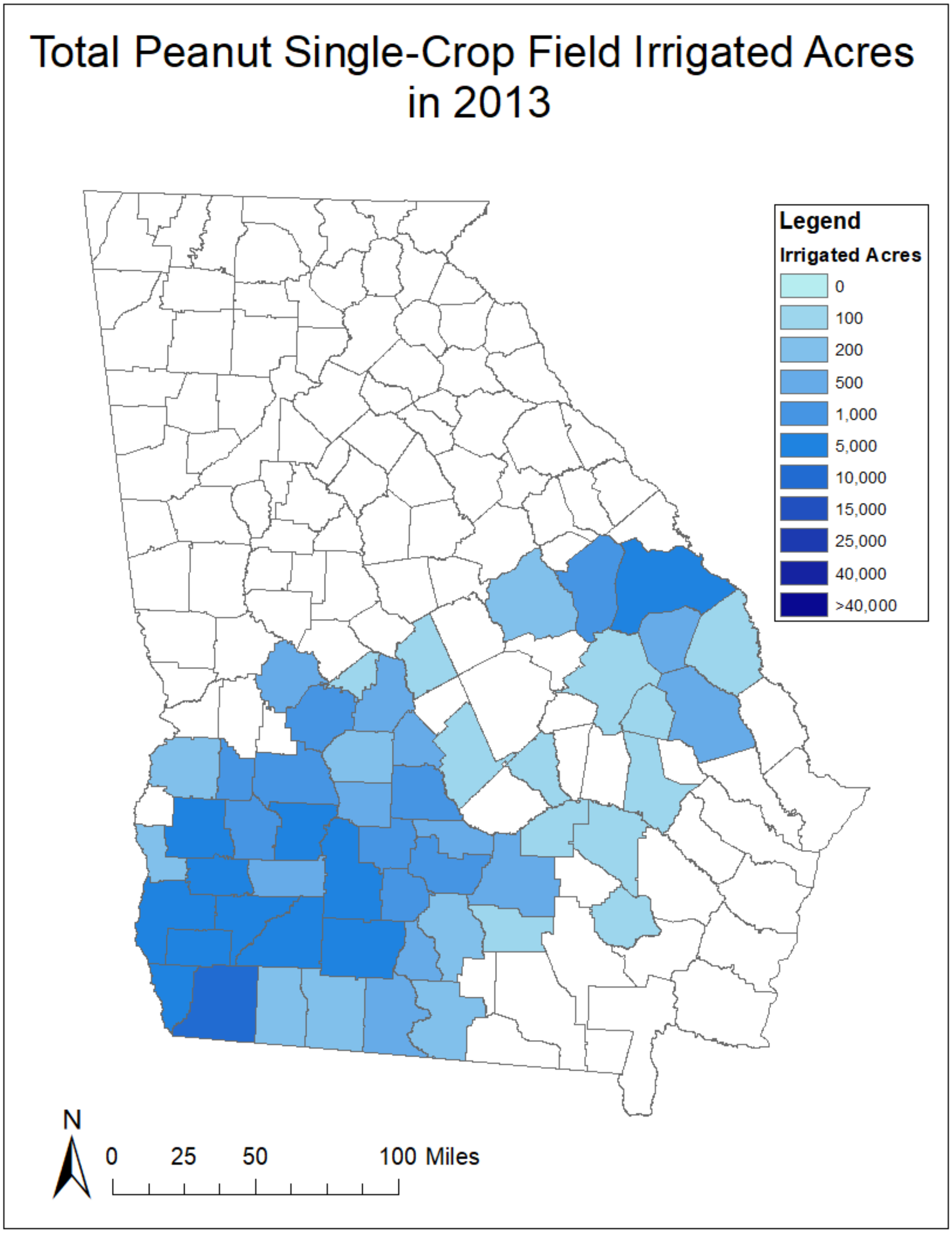
Map A.120 Total Peanut Single-Crop Field Irrigated Acres in Georgia for 2010



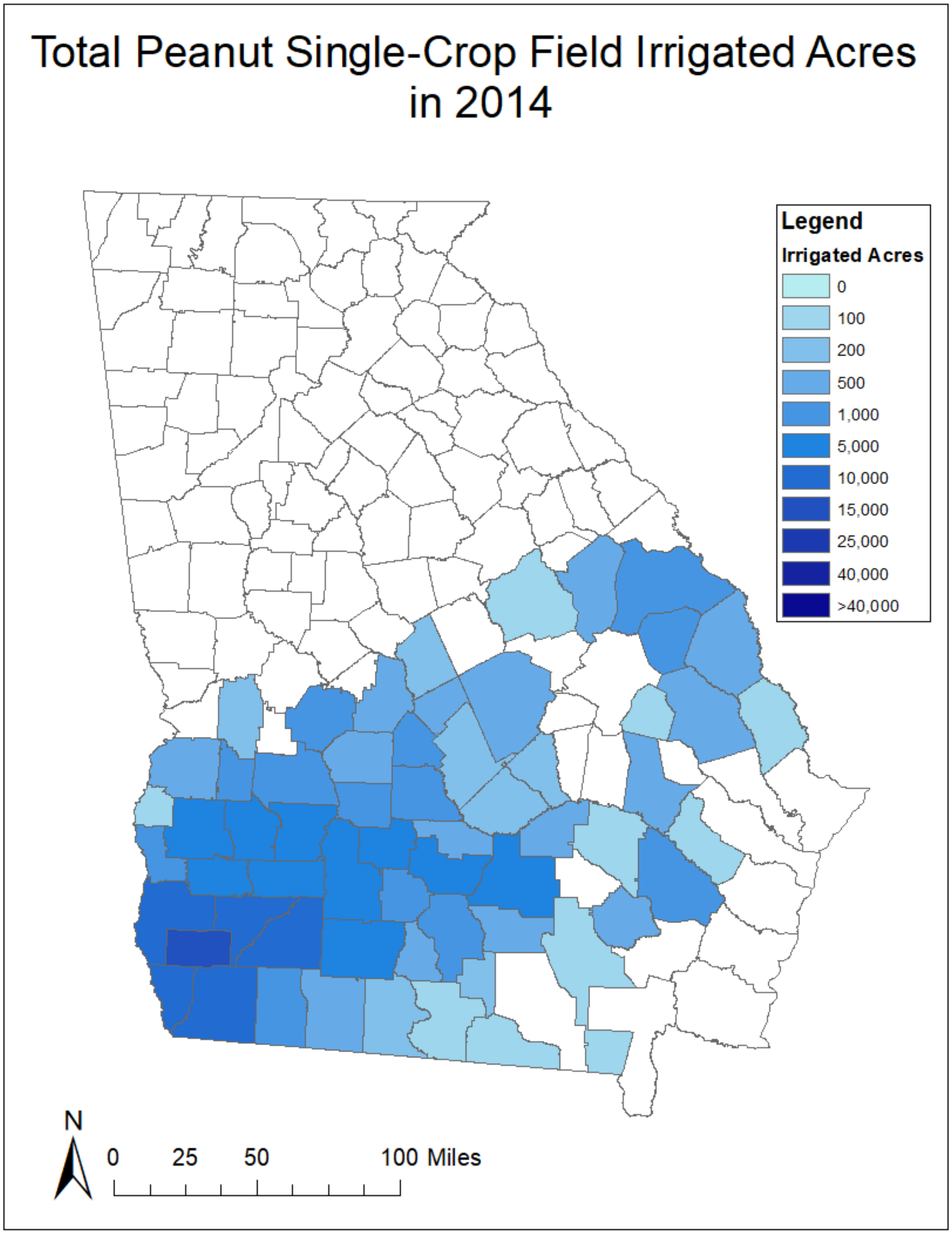
Map A.121 Total Peanut Single-Crop Field Irrigated Acres in Georgia for 2011



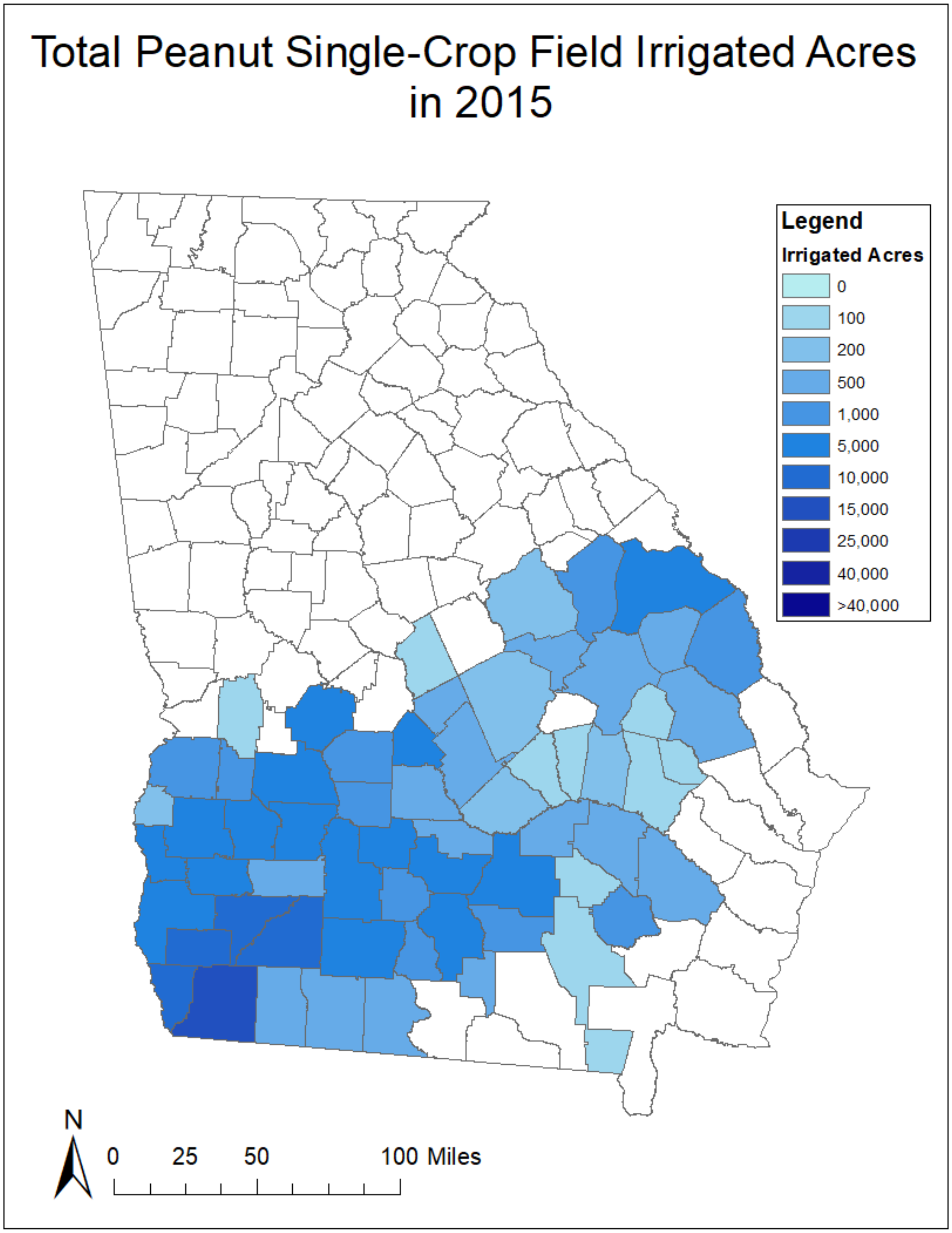
Map A.122 Total Peanut Single-Crop Field Irrigated Acres in Georgia for 2012



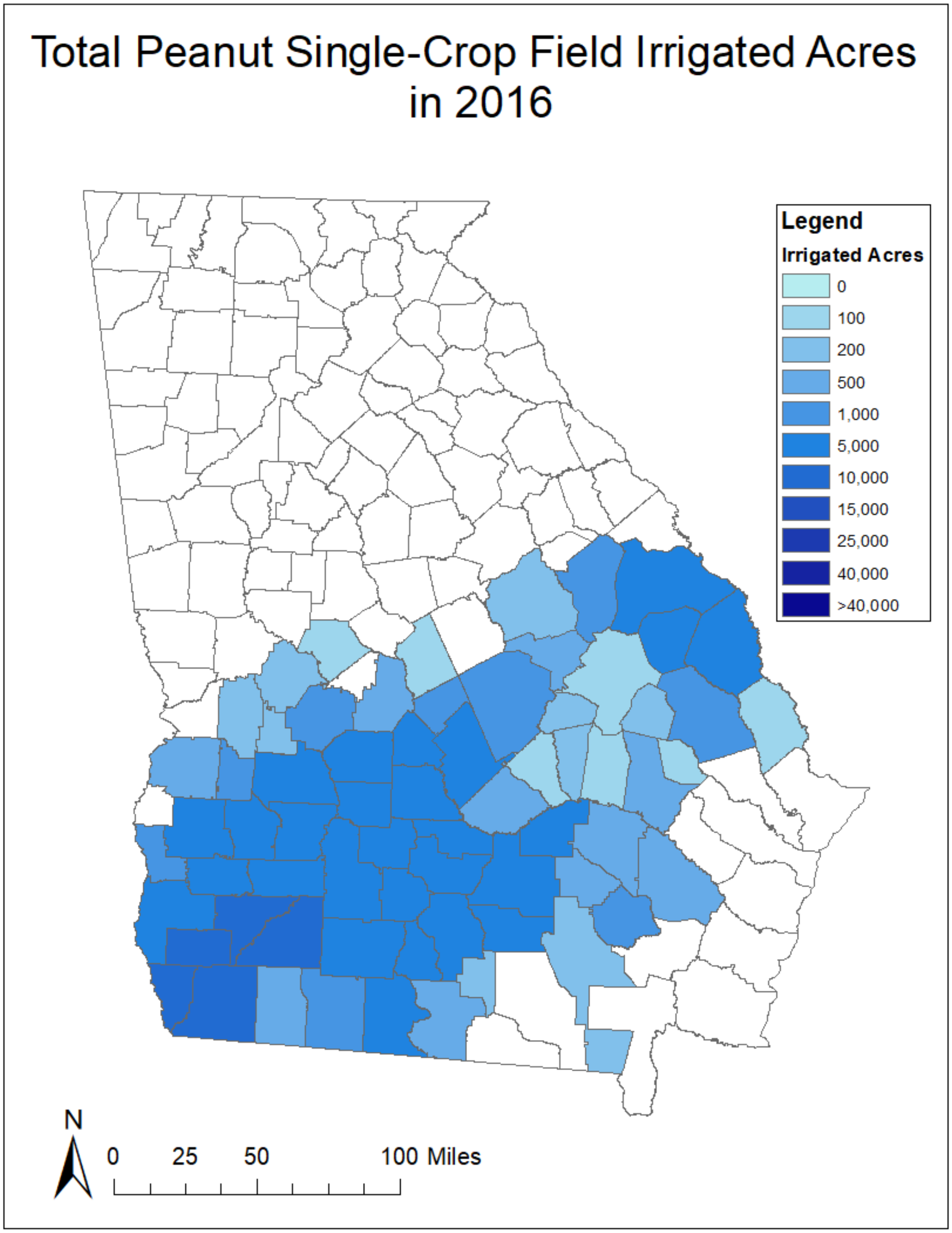
Map A.123 Total Peanut Single-Crop Field Irrigated Acres in Georgia for 2013



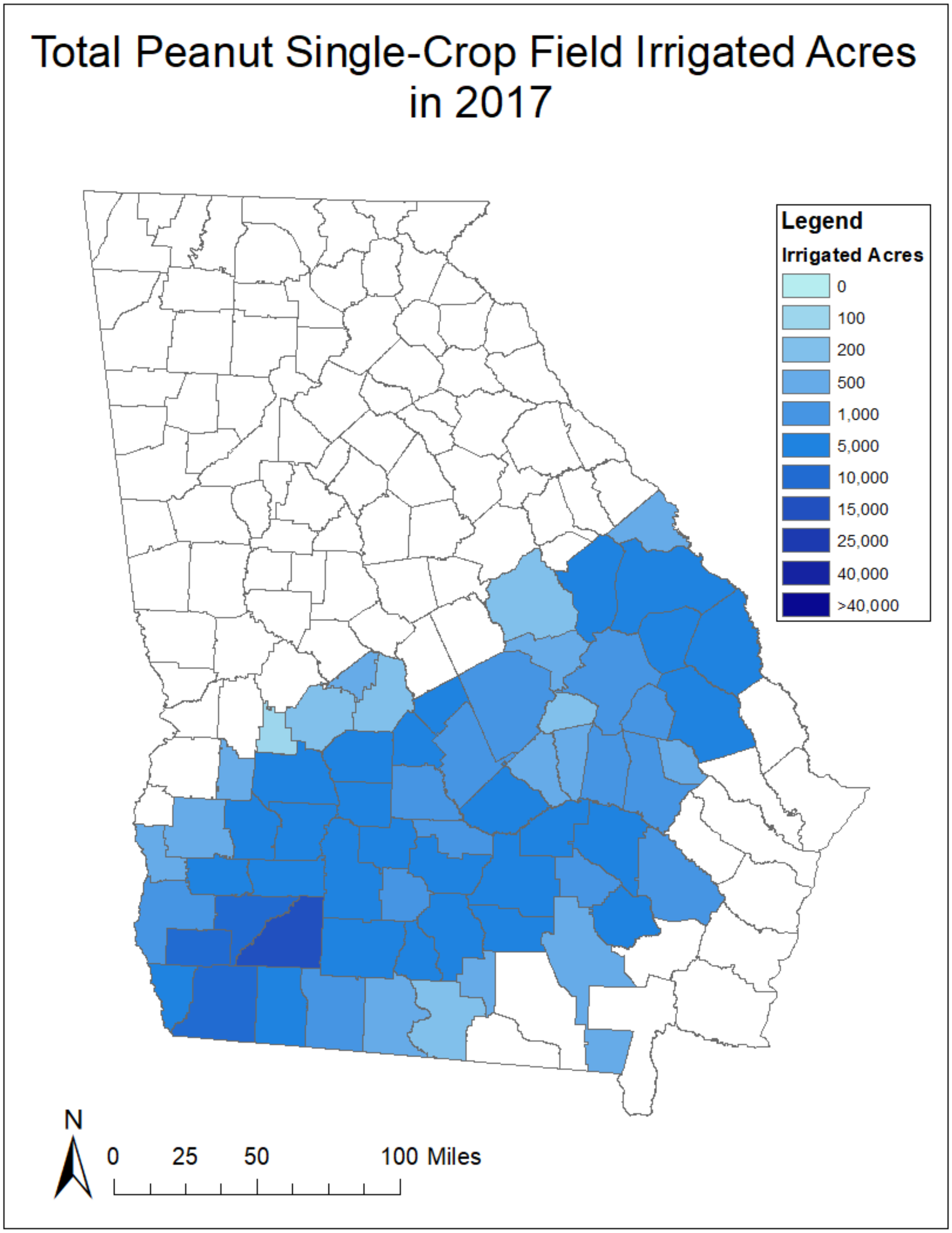
Map A.124 Total Peanut Single-Crop Field Irrigated Acres in Georgia for 2014



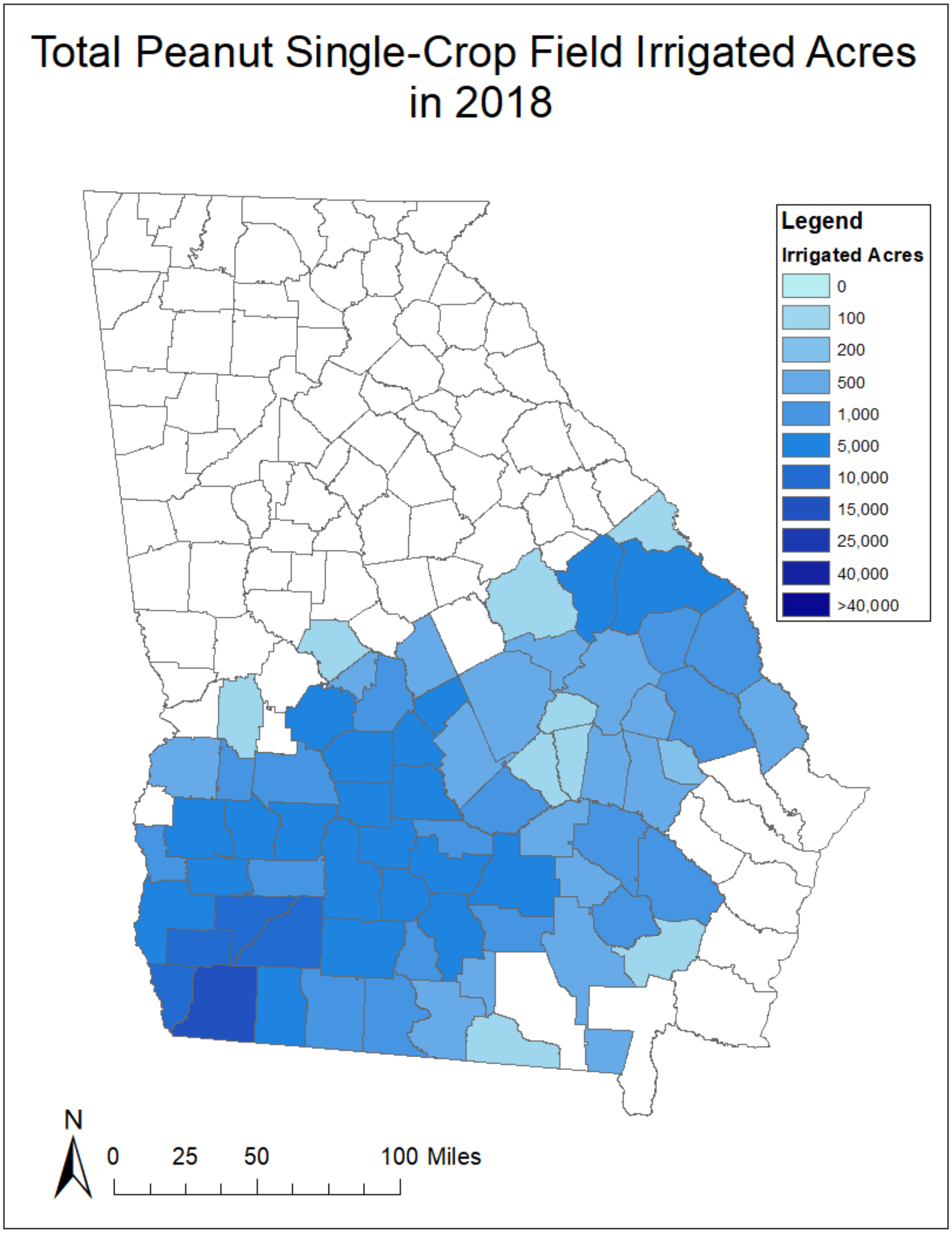
Map A.125 Total Peanut Single-Crop Field Irrigated Acres in Georgia for 2015



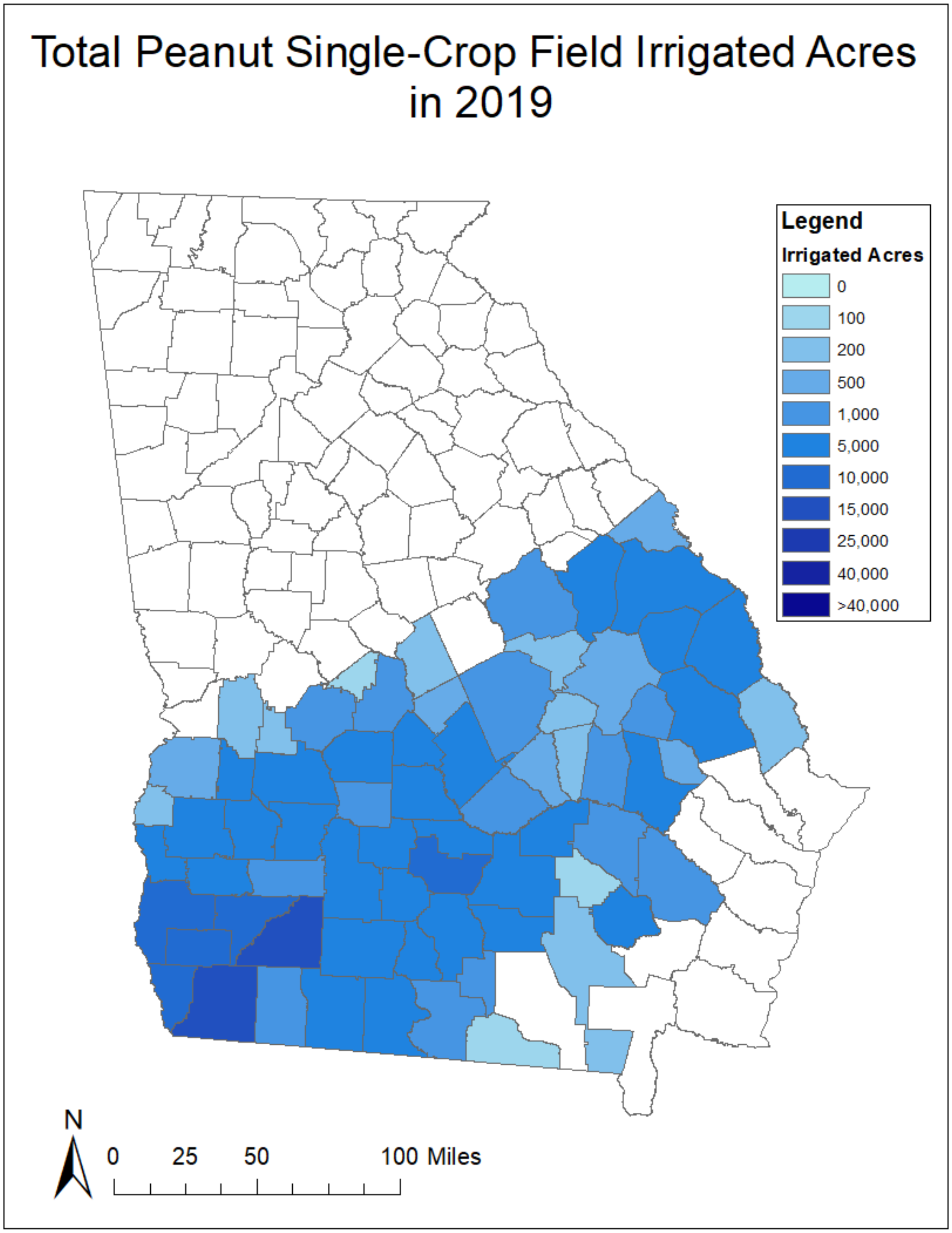
Map A.126 Total Peanut Single-Crop Field Irrigated Acres in Georgia for 2016



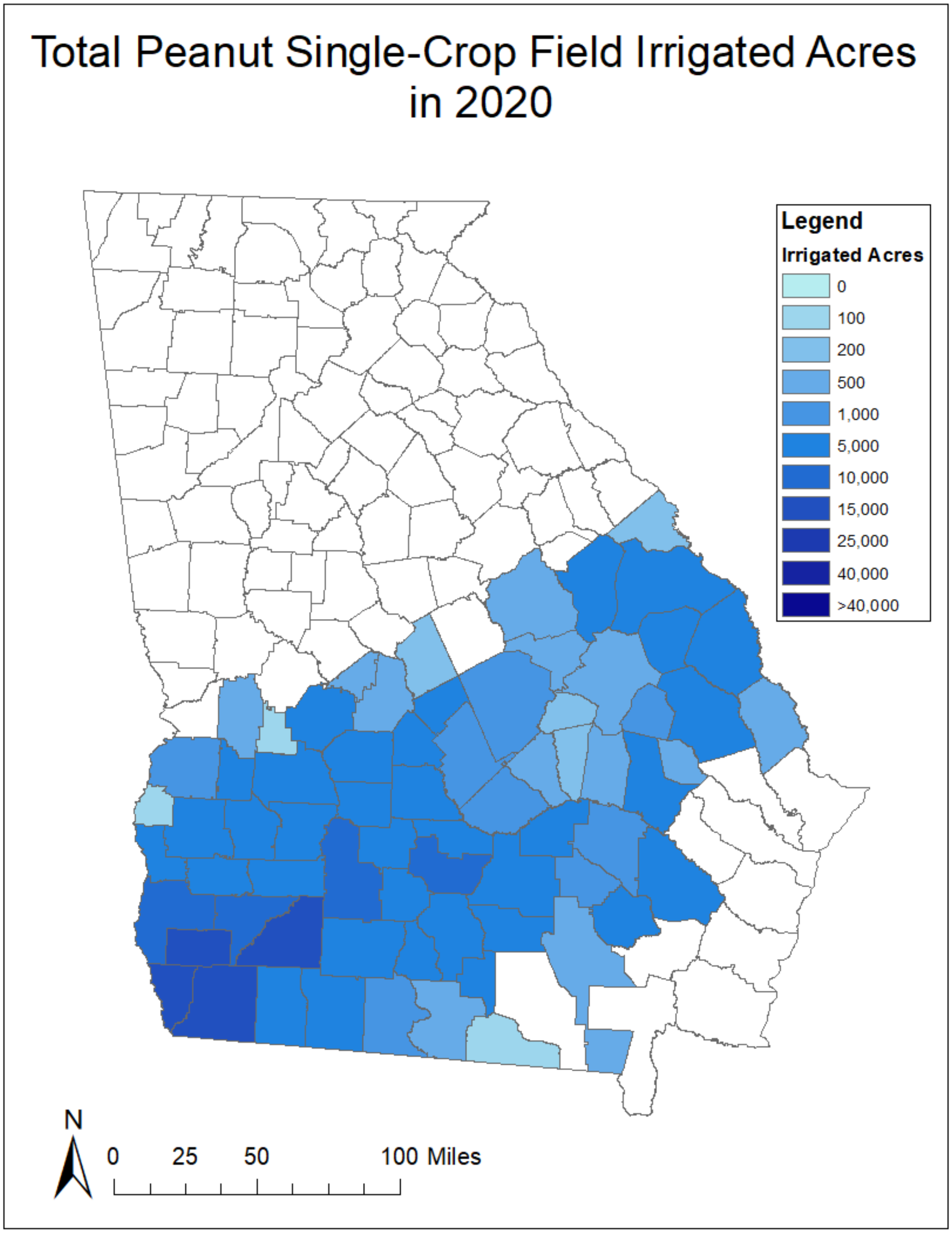
Map A.127 Total Peanut Single-Crop Field Irrigated Acres in Georgia for 2017



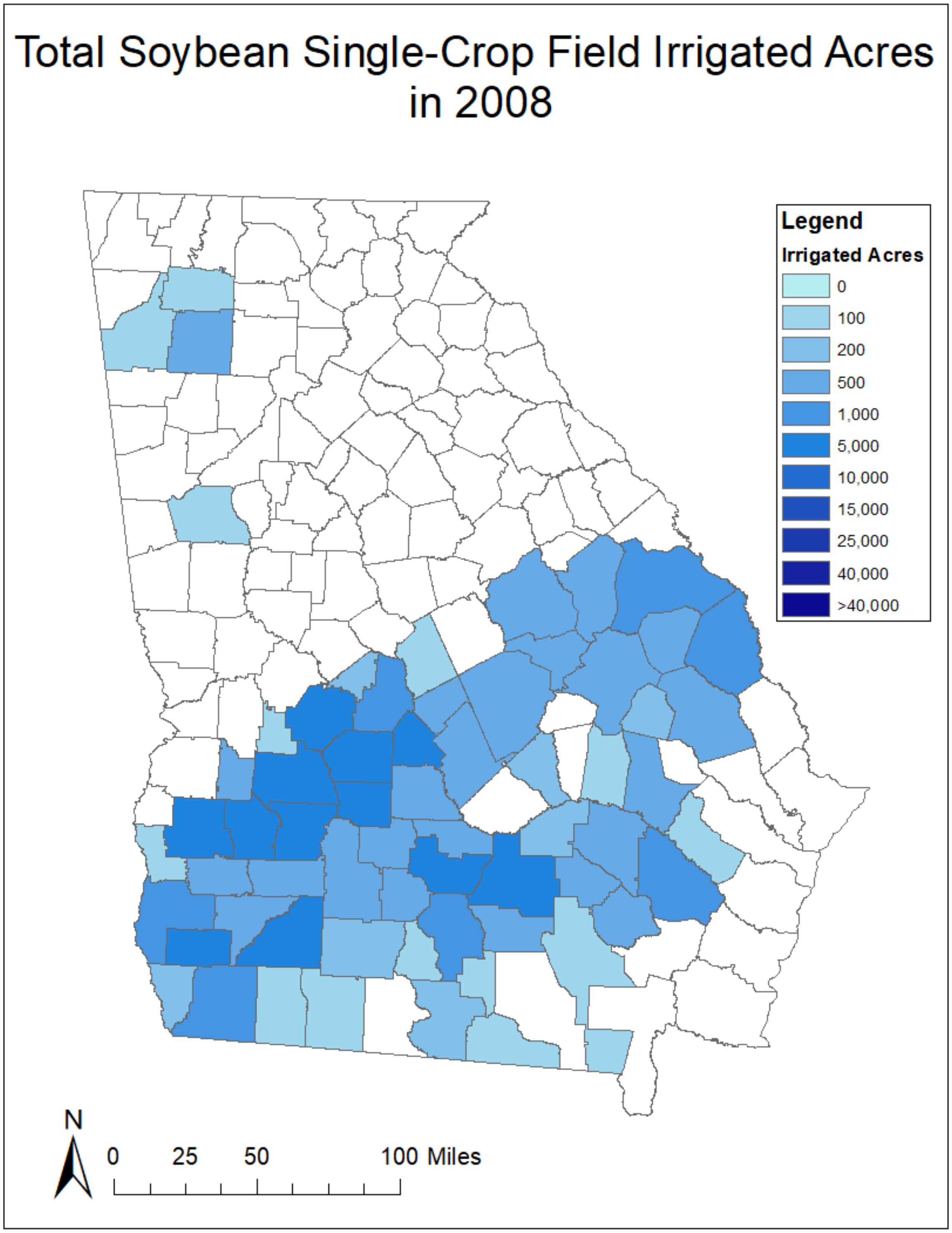
Map A.128 Total Peanut Single-Crop Field Irrigated Acres in Georgia for 2018



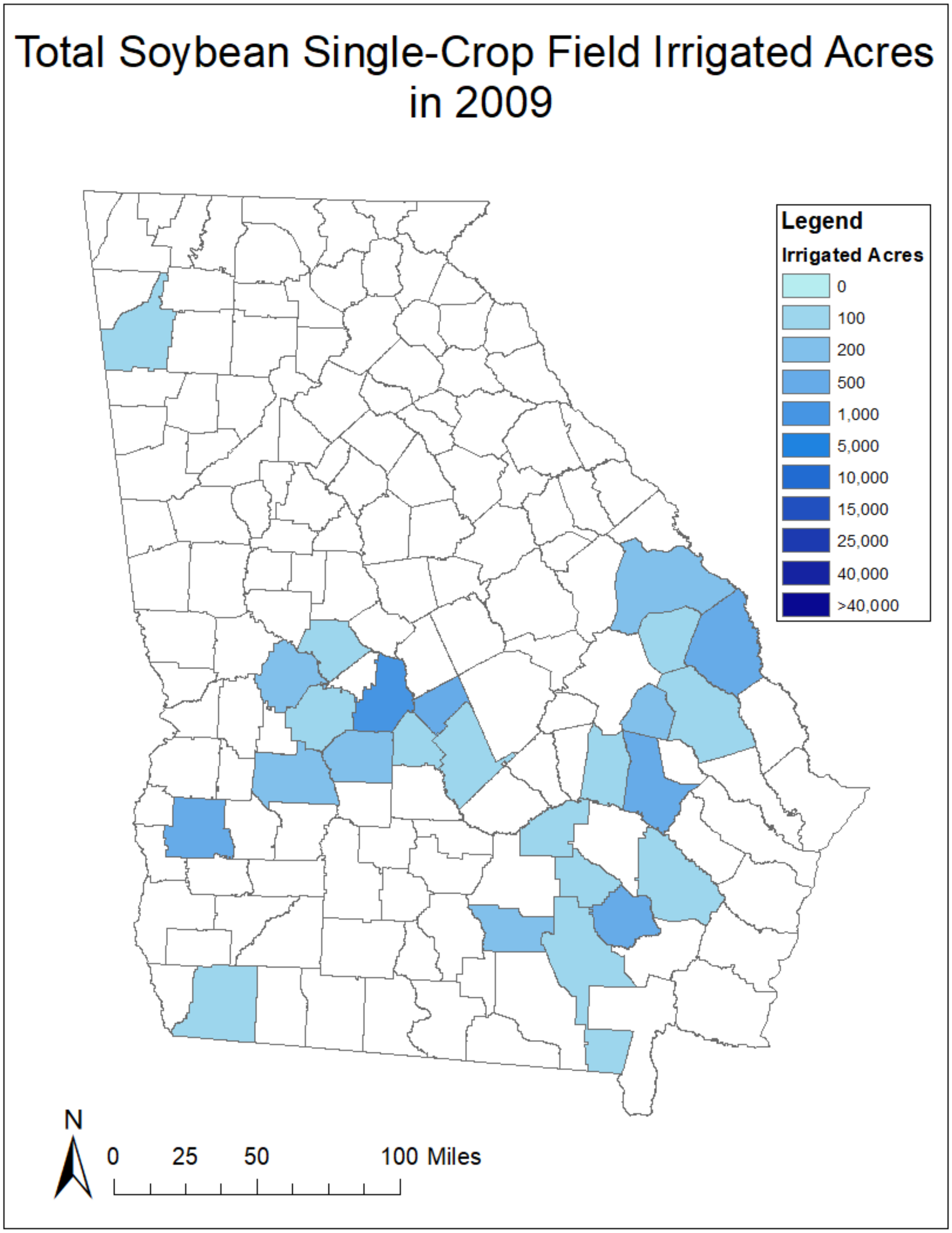
Map A.129 Total Peanut Single-Crop Field Irrigated Acres in Georgia for 2019



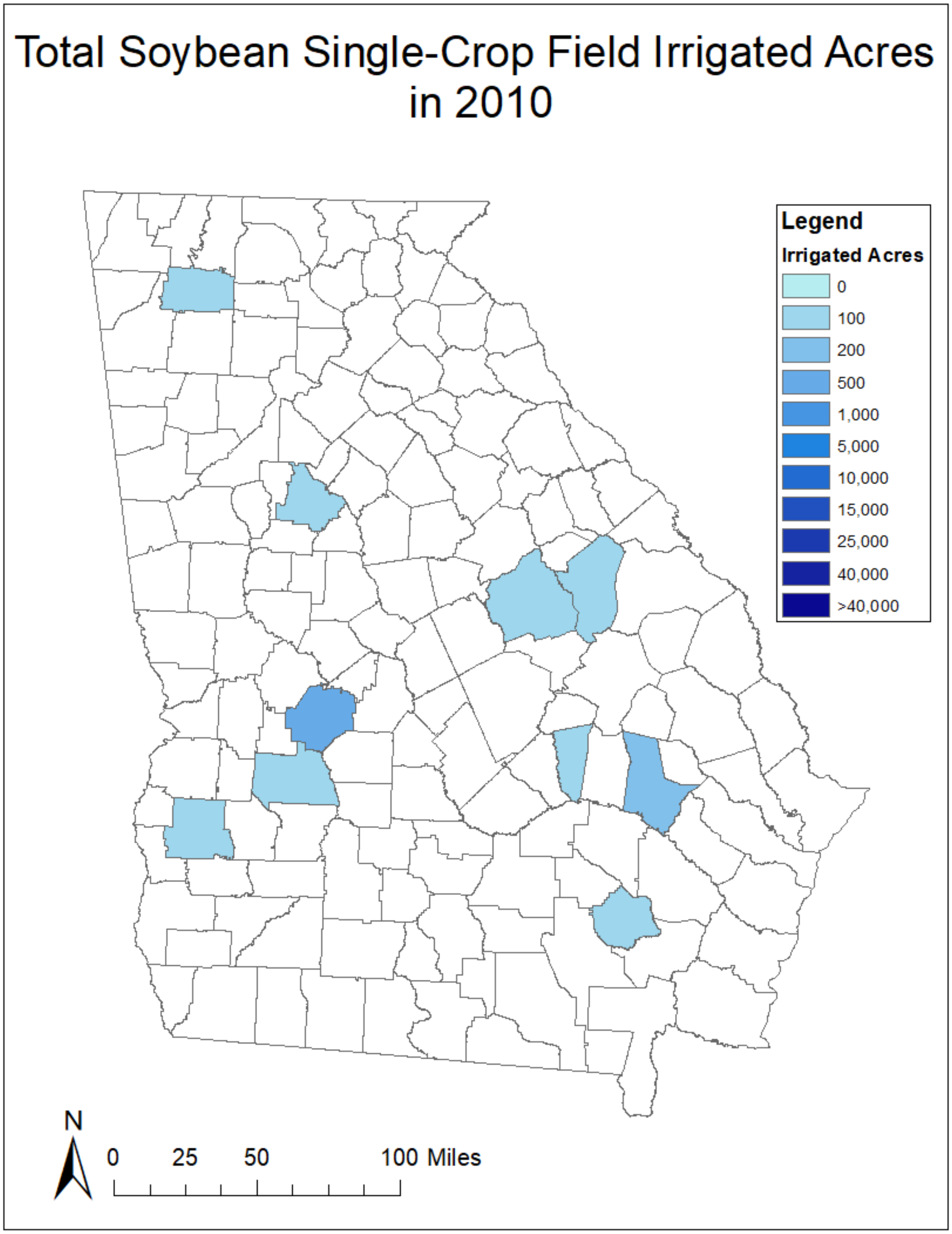
Map A.130 Total Peanut Single-Crop Field Irrigated Acres in Georgia for 2020



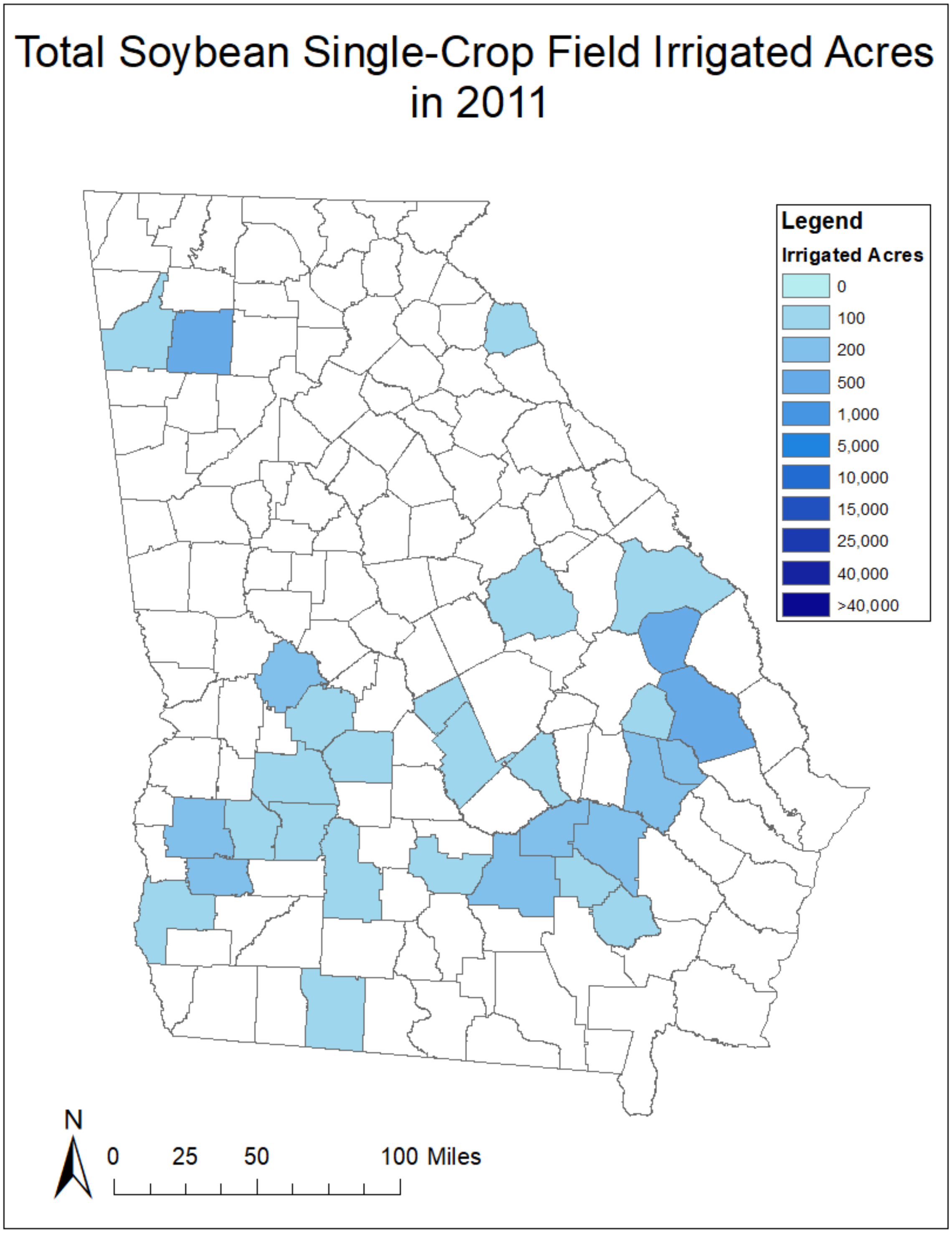
Map A.131 Total Soybean Single-Crop Field Irrigated Acres in Georgia for 2008



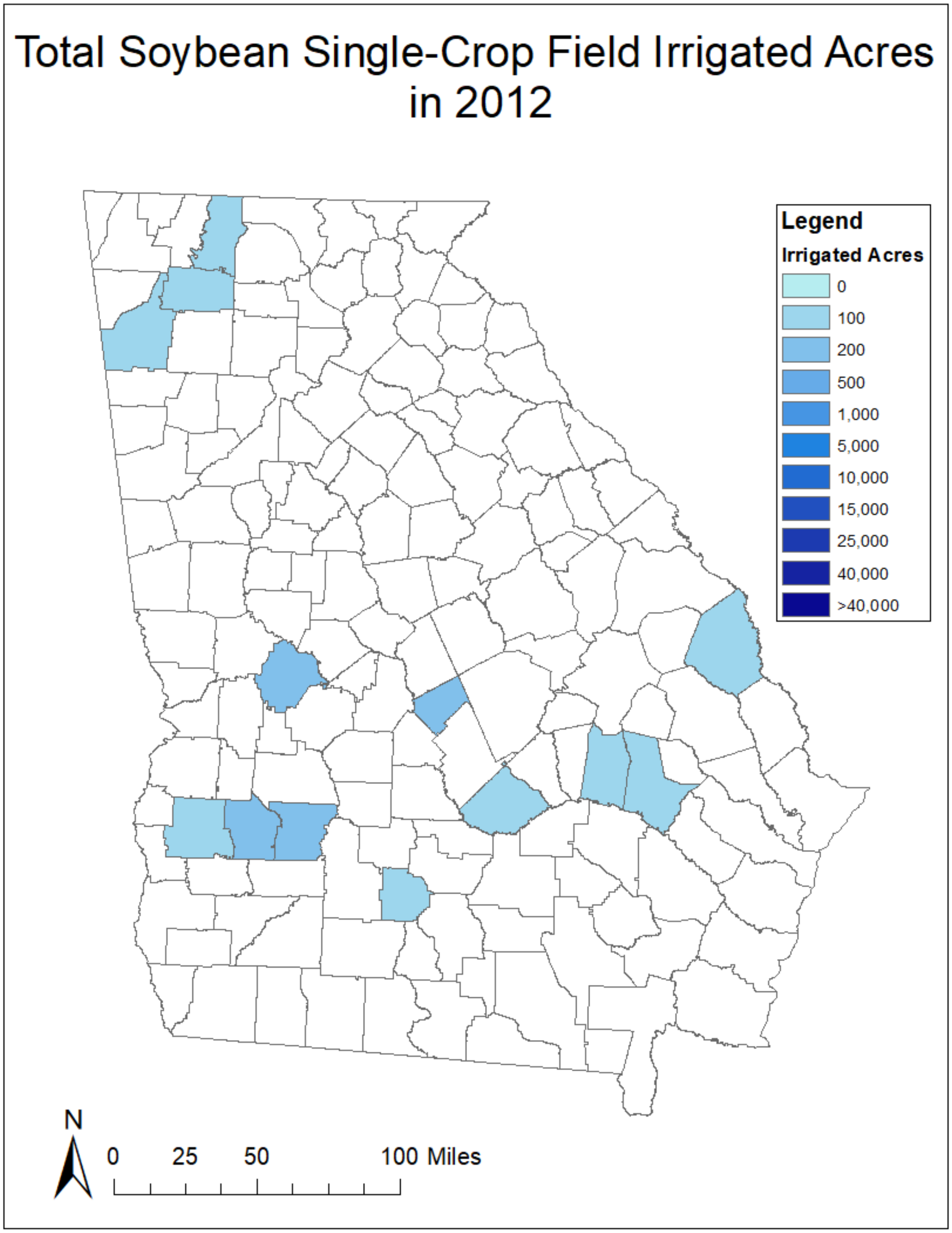
Map A.132 Total Soybean Single-Crop Field Irrigated Acres in Georgia for 2009



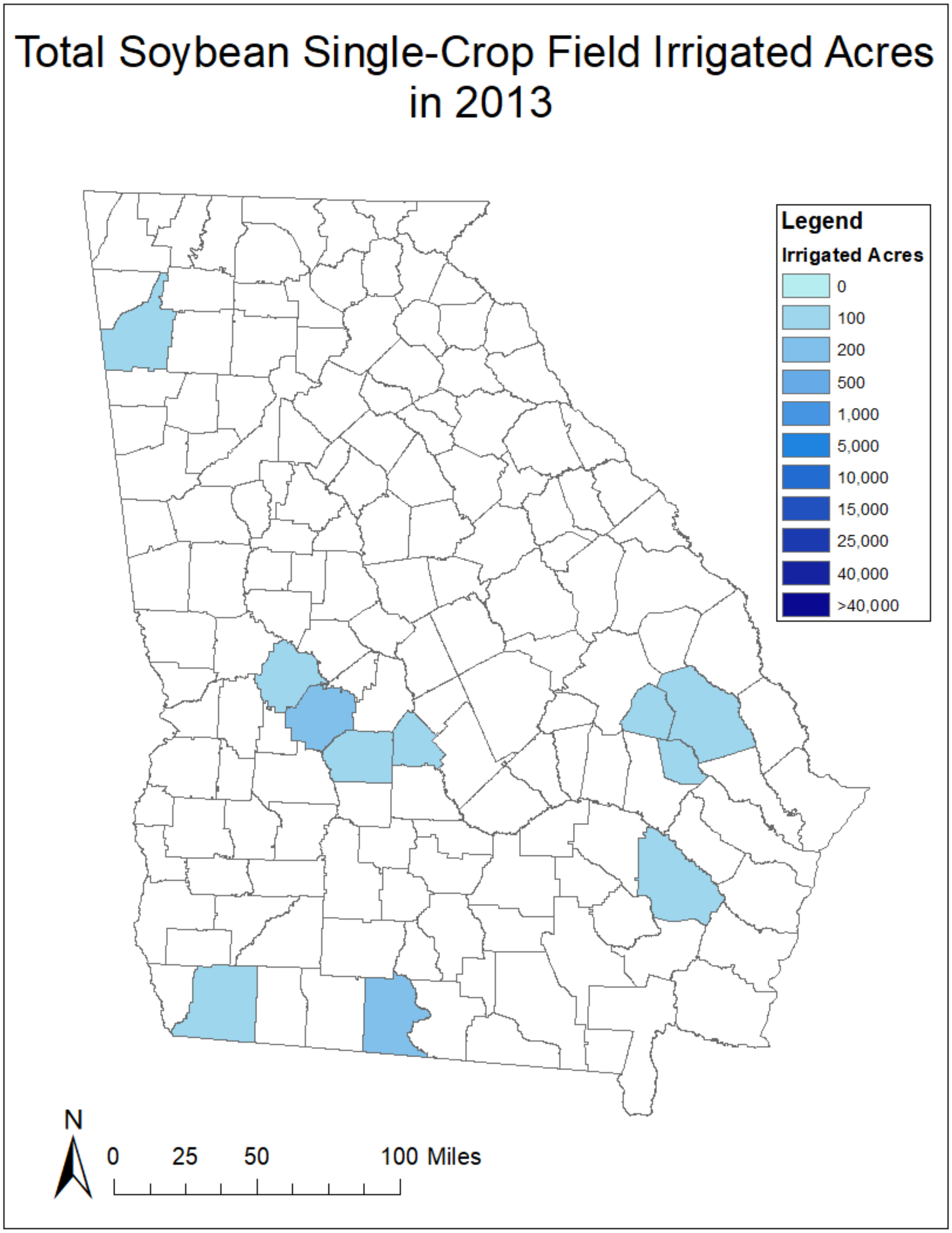
Map A.133 Total Soybean Single-Crop Field Irrigated Acres in Georgia for 2010



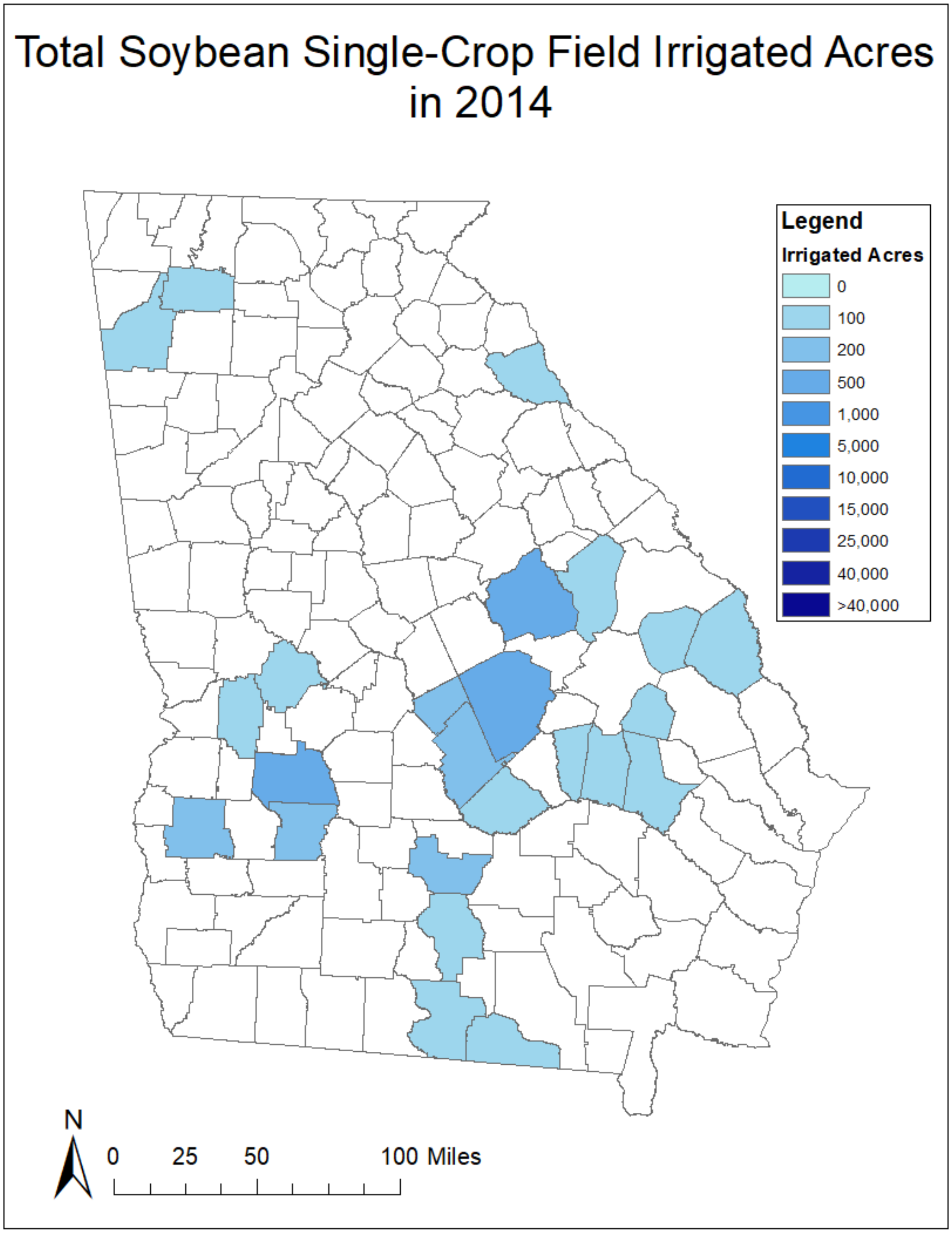
Map A.134 Total Soybean Single-Crop Field Irrigated Acres in Georgia for 2011



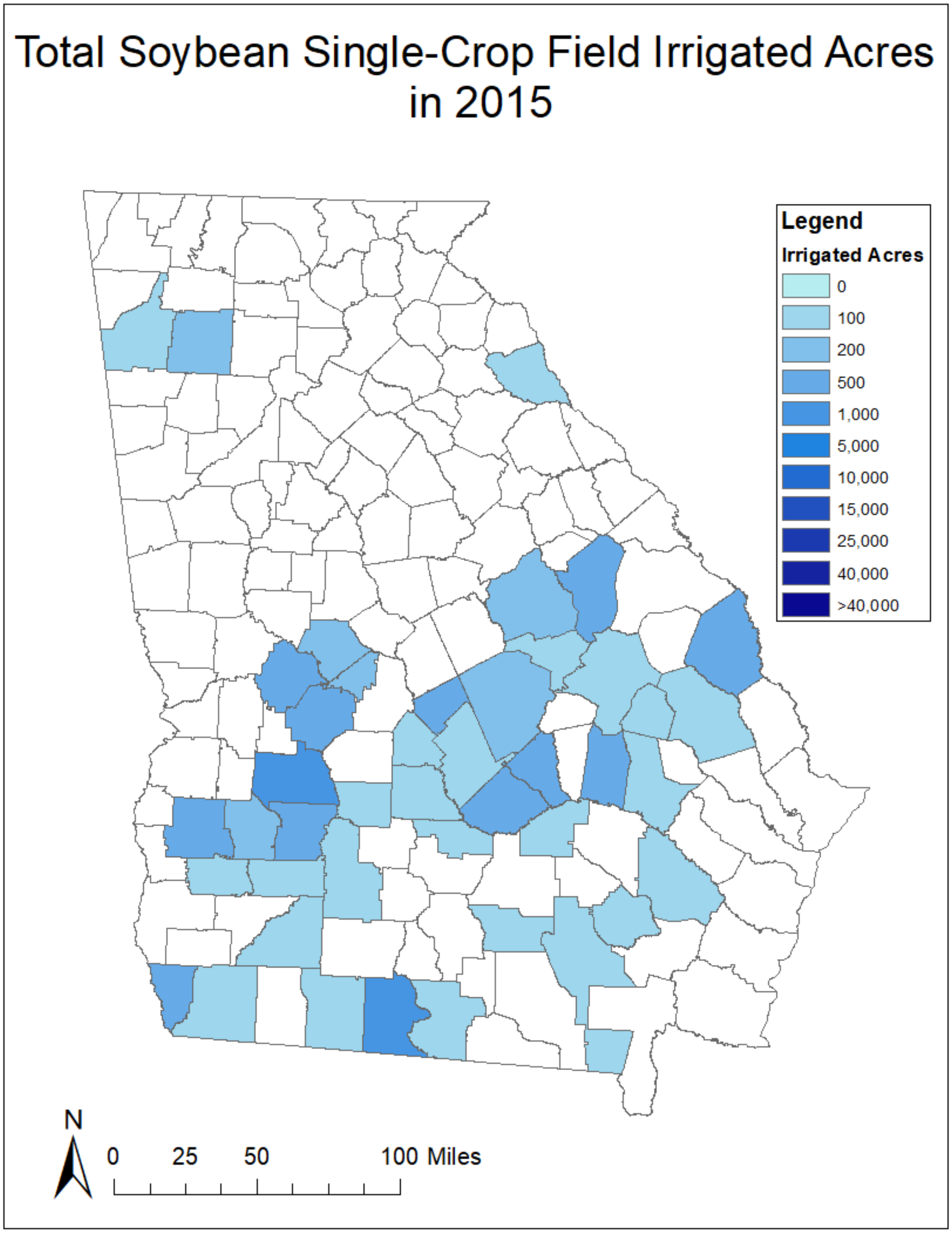
Map A.135 Total Soybean Single-Crop Field Irrigated Acres in Georgia for 2012



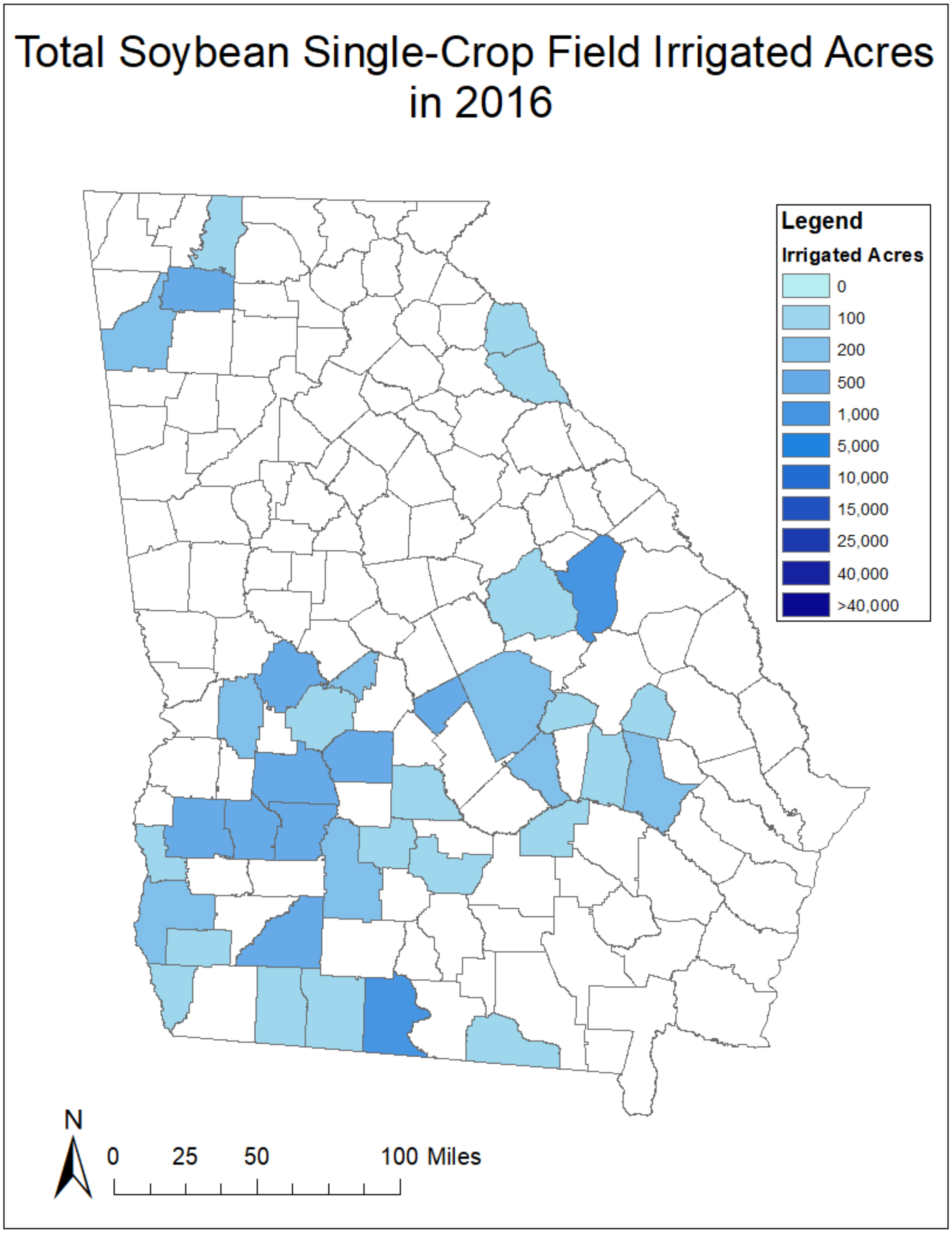
Map A.136 Total Soybean Single-Crop Field Irrigated Acres in Georgia for 2013



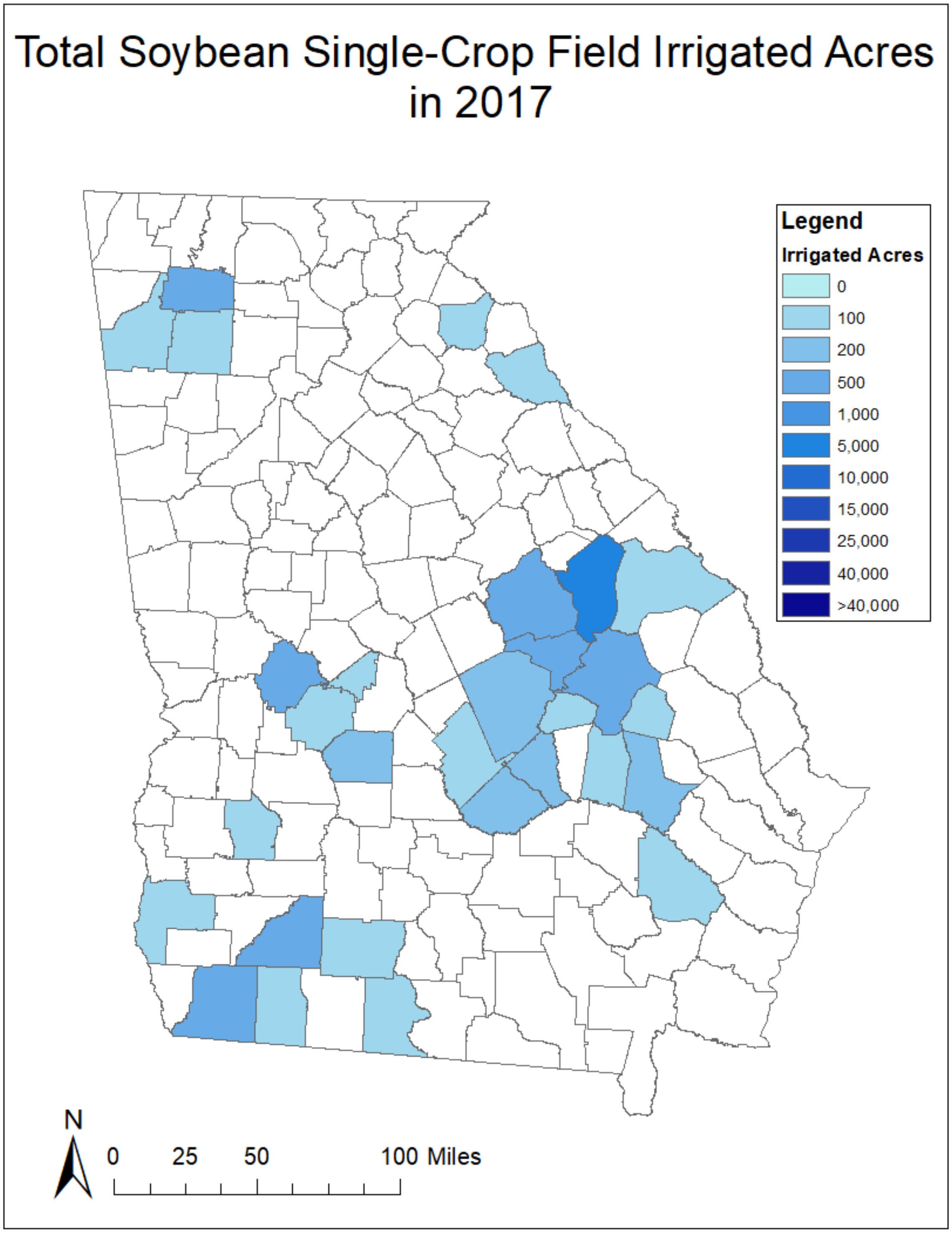
Map A.137 Total Soybean Single-Crop Field Irrigated Acres in Georgia for 2014



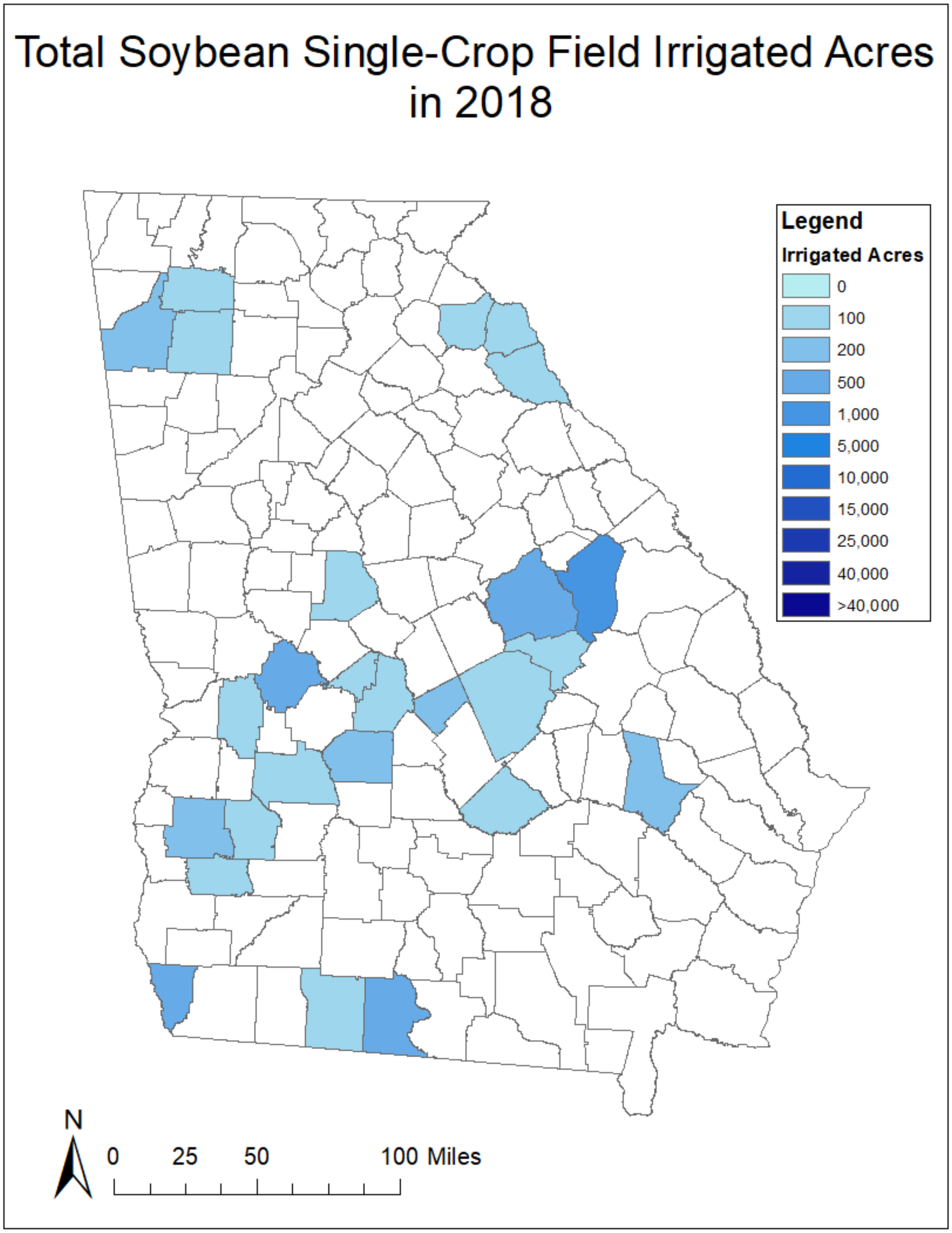
Map A.138 Total Soybean Single-Crop Field Irrigated Acres in Georgia for 2015



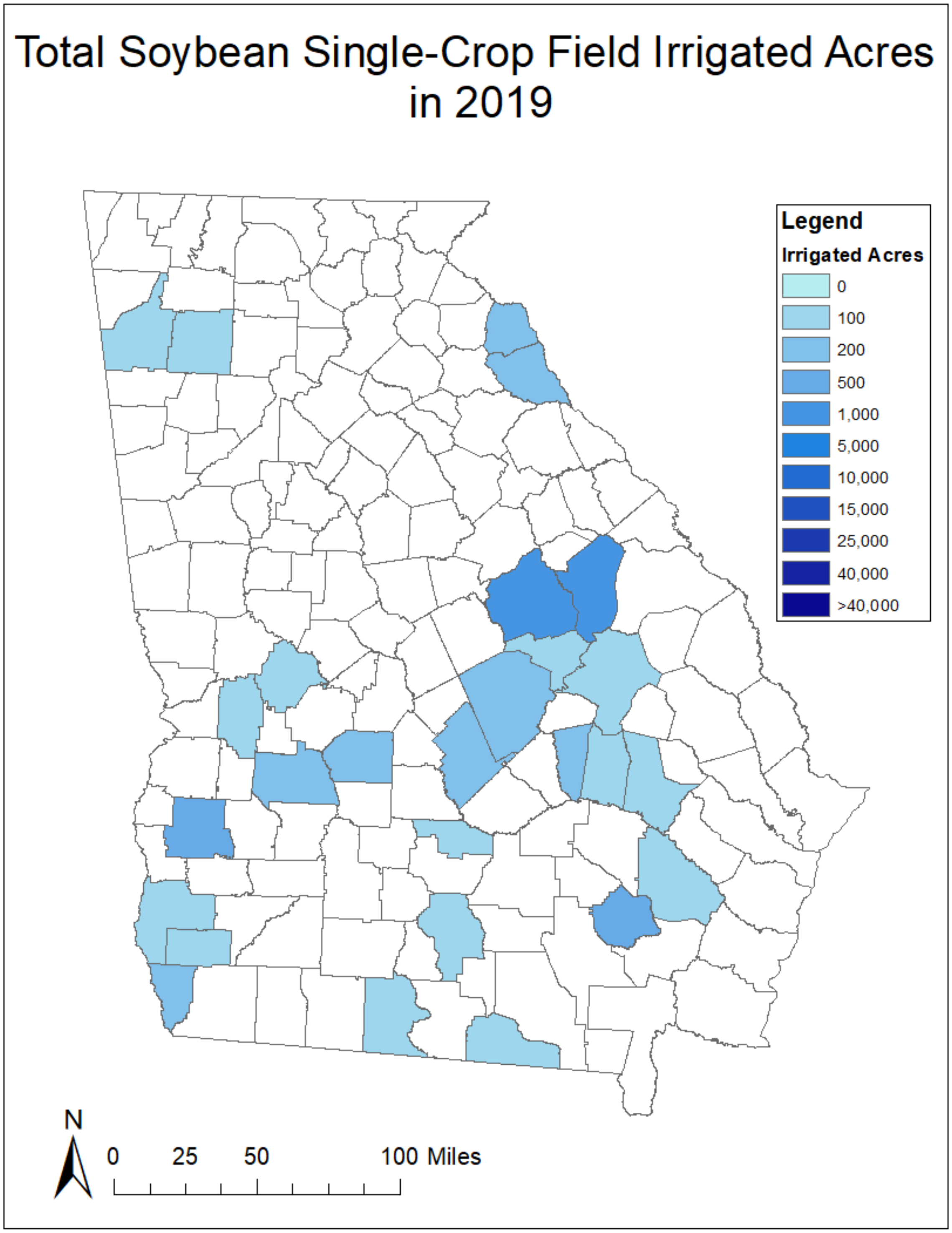
Map A.139 Total Soybean Single-Crop Field Irrigated Acres in Georgia for 2016



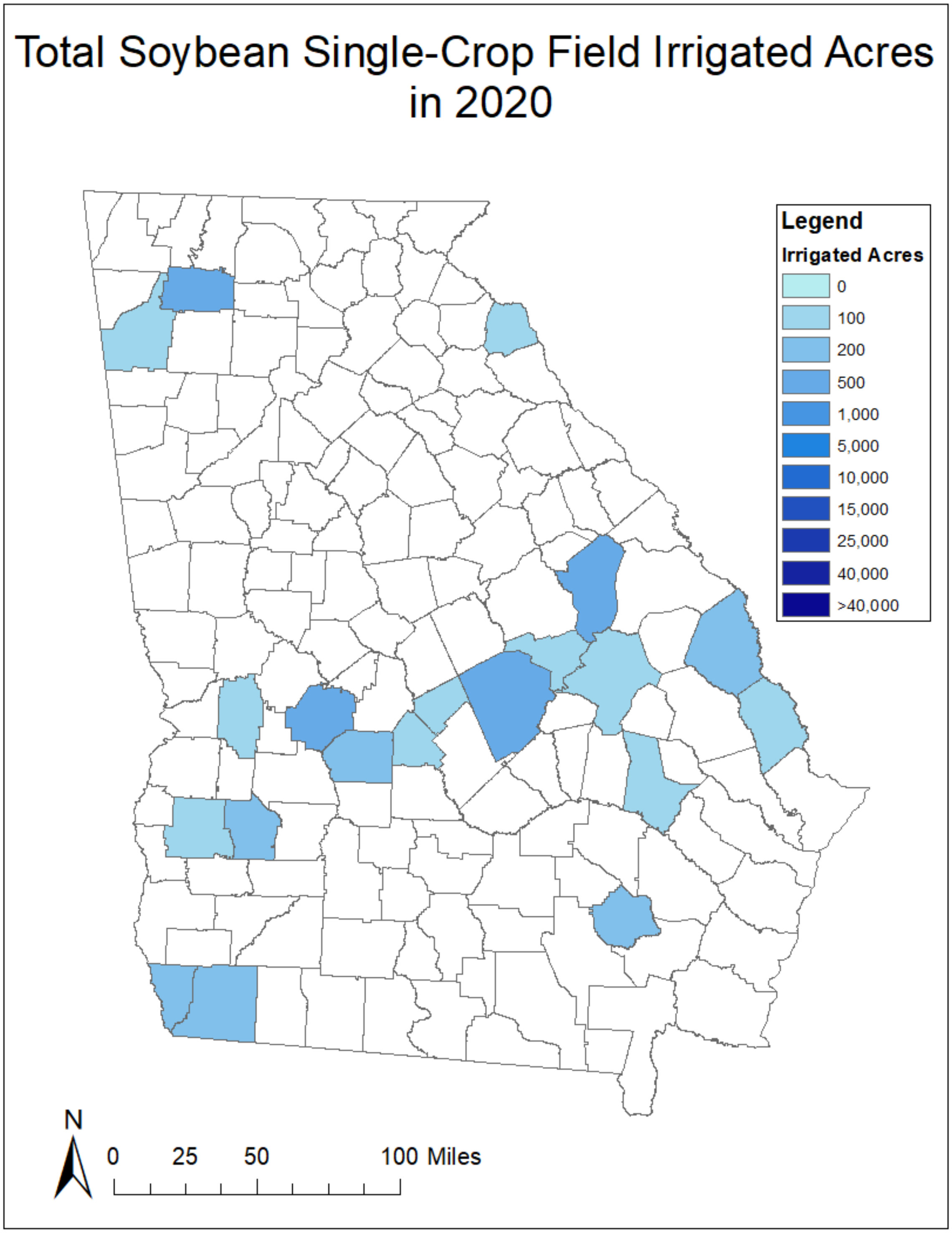
Map A.140 Total Soybean Single-Crop Field Irrigated Acres in Georgia for 2017



Map A.141 Total Soybean Single-Crop Field Irrigated Acres in Georgia for 2018

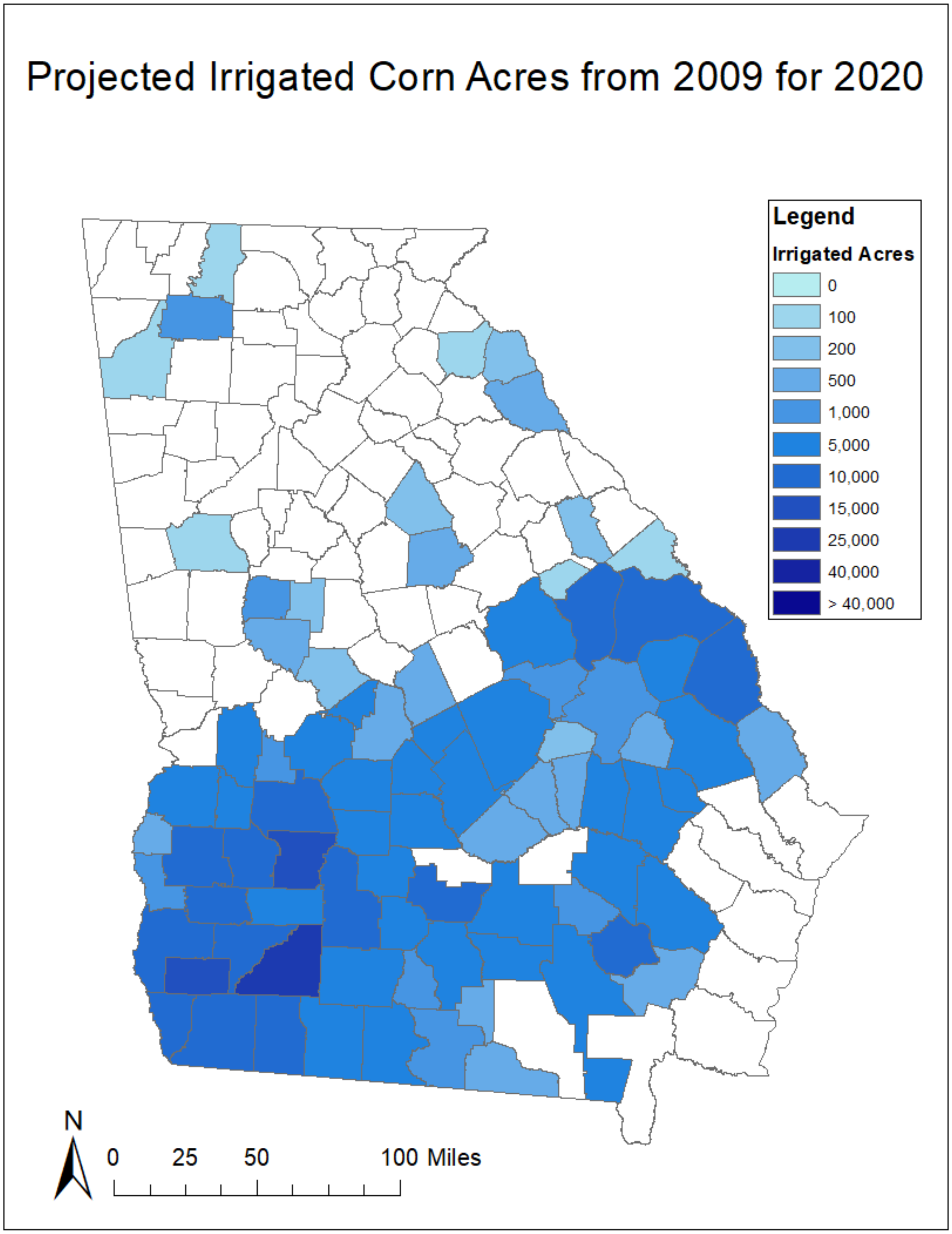


Map A.142 Total Soybean Single-Crop Field Irrigated Acres in Georgia for 2019

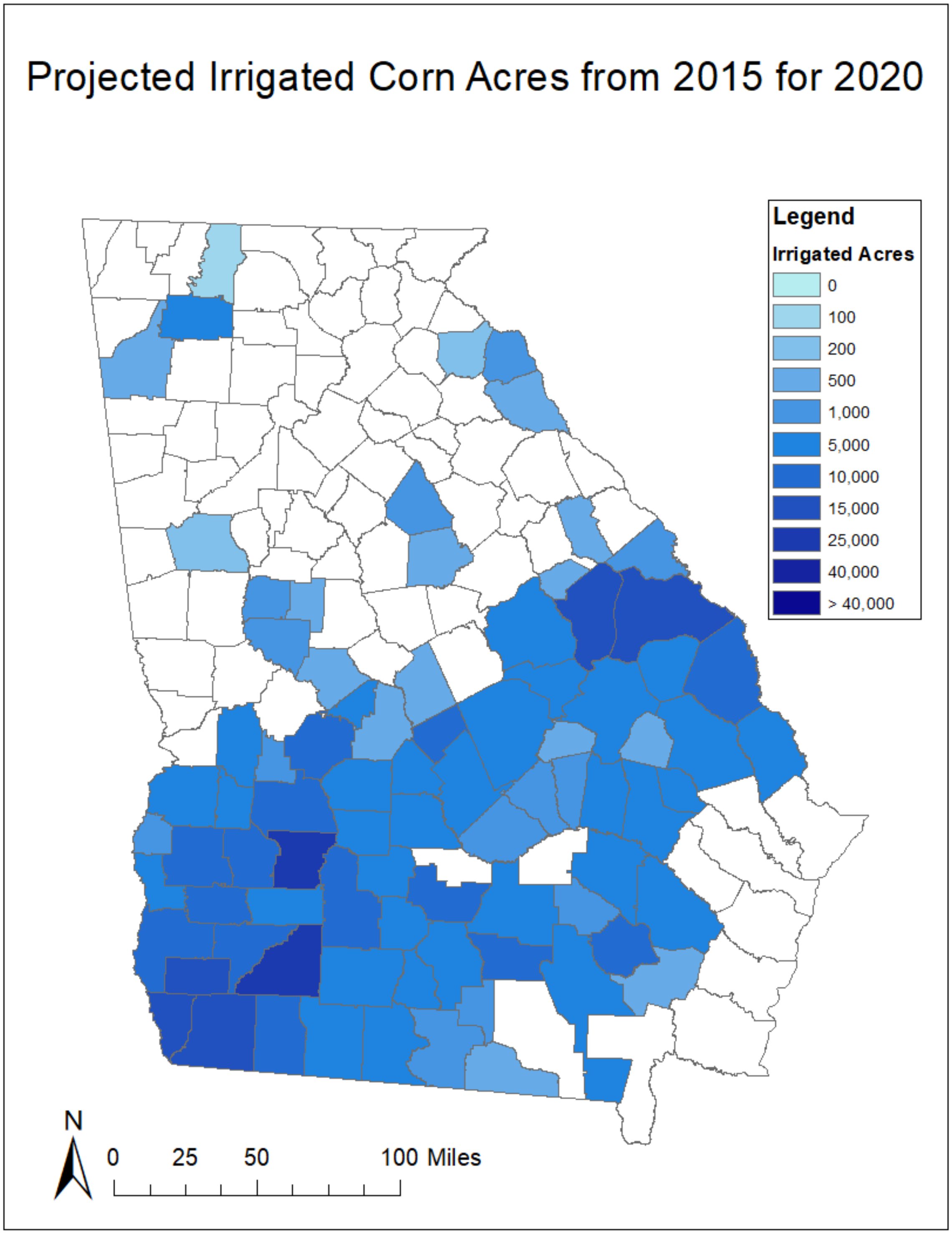


Map A.143 Total Soybean Single-Crop Field Irrigated Acres in Georgia for 2020

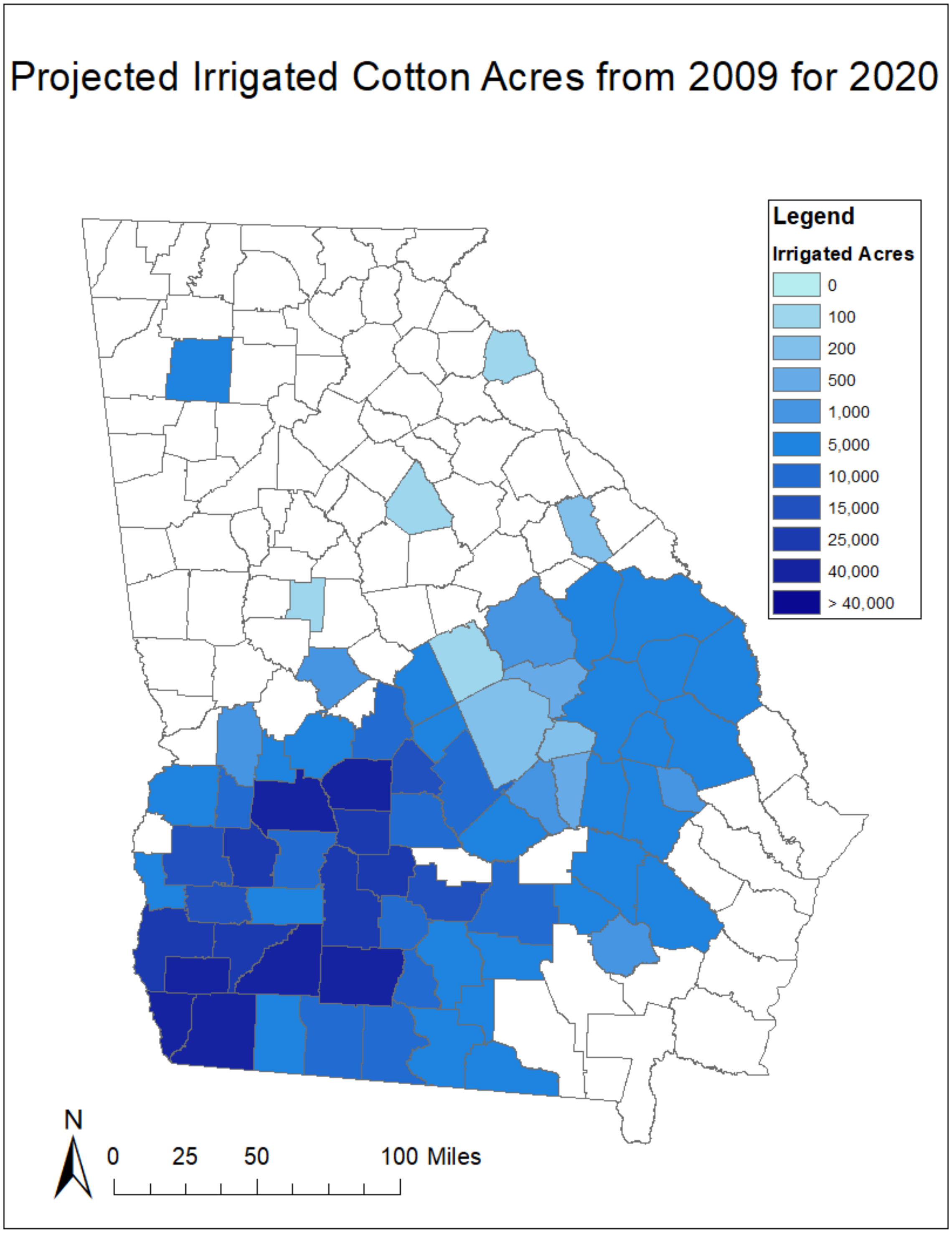
Appendix B: Projected Irrigated Acreage Maps



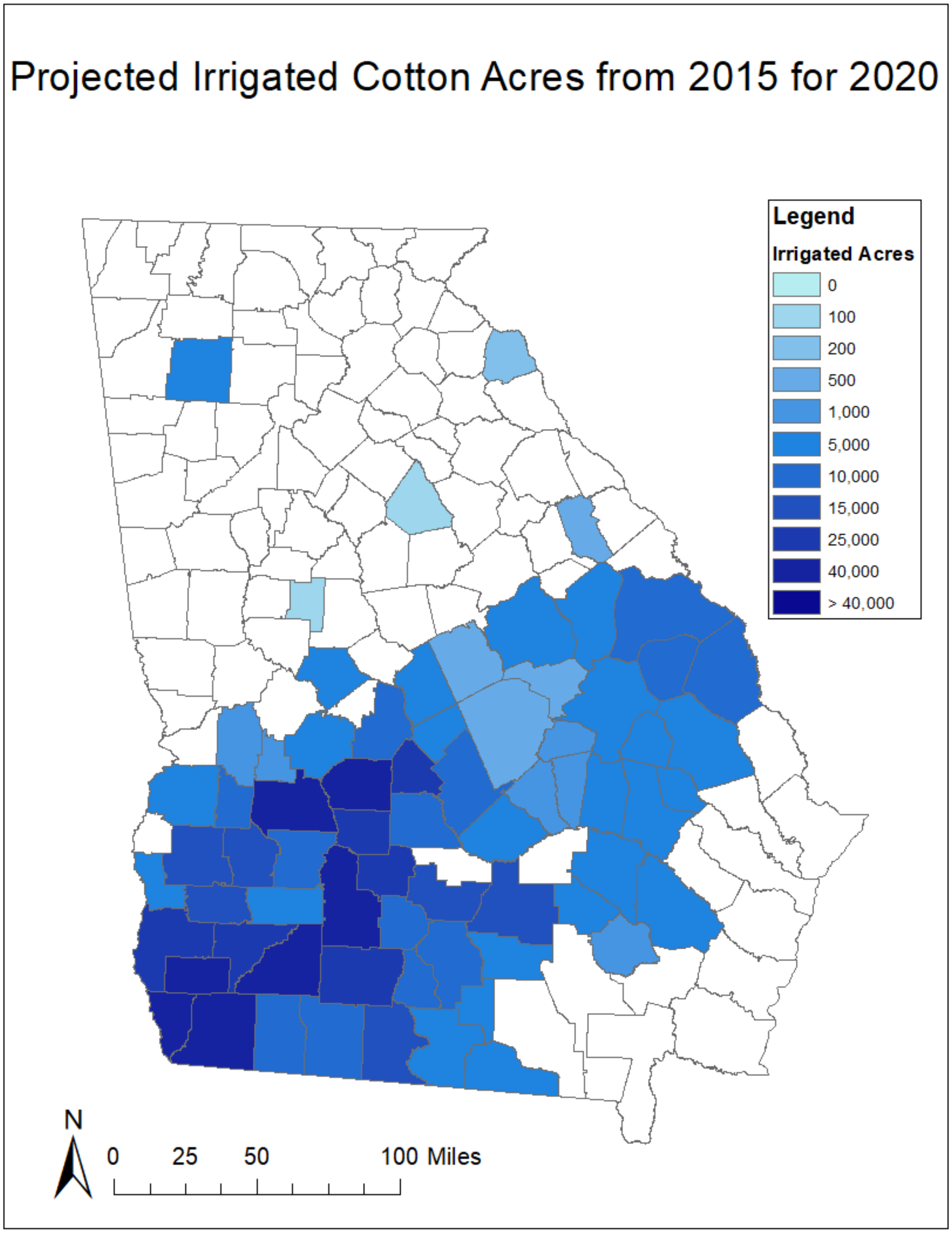
Map B.1 2009 Projected Irrigated Acres for Corn in 2020



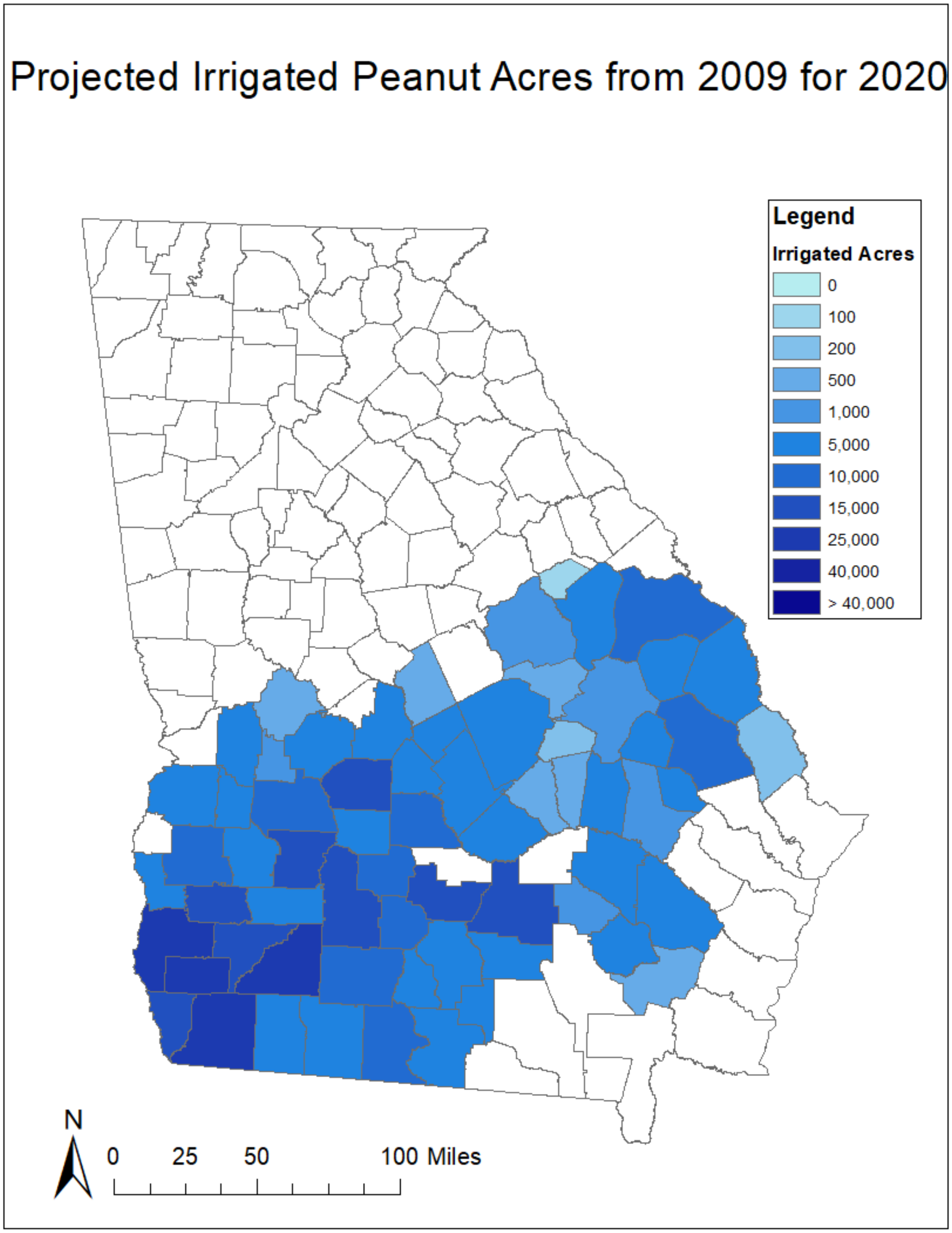
Map B.2 2015 Projected Irrigated Acres for Corn in 2020



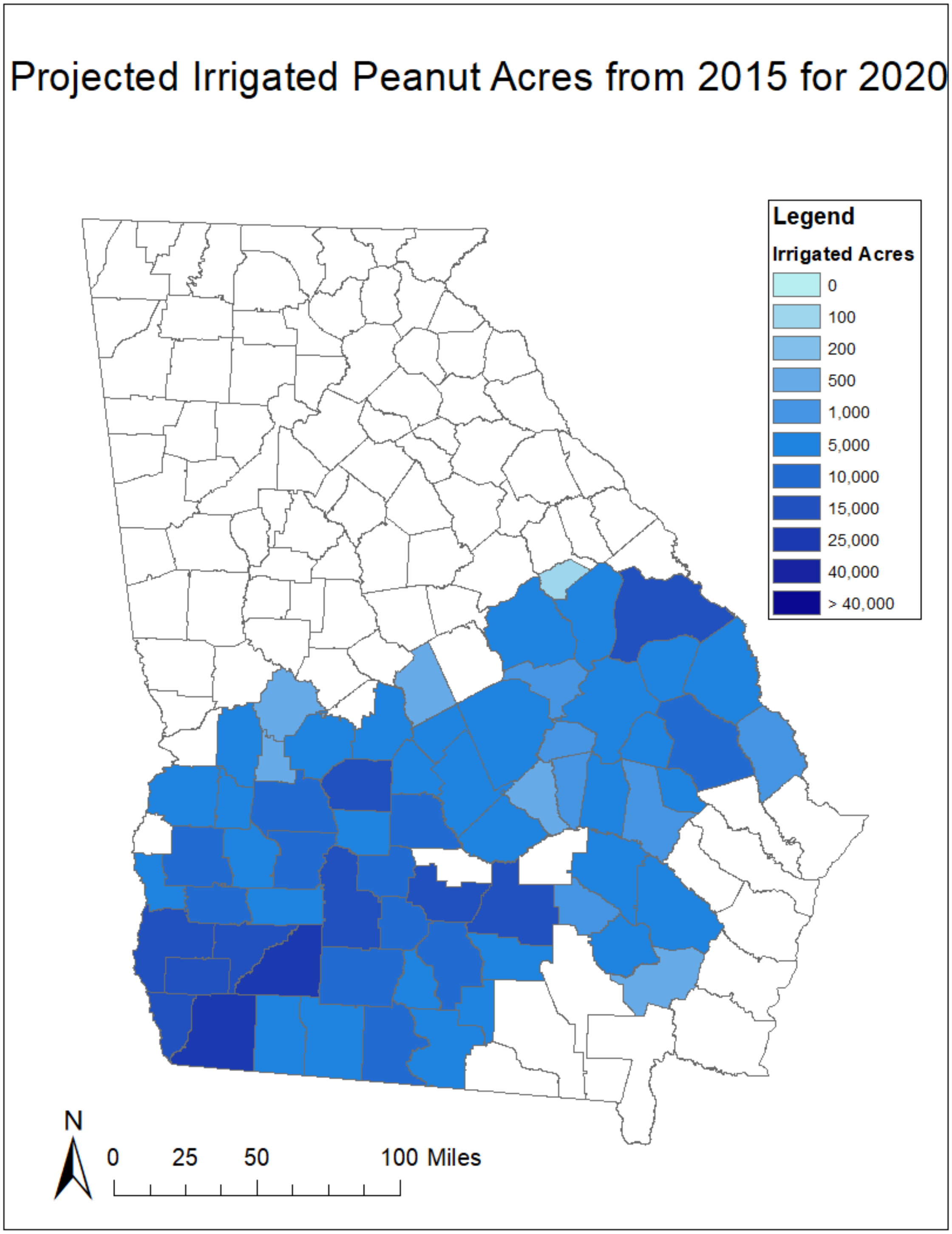
Map B.3 2009 Projected Irrigated Acres for Cotton in 2020



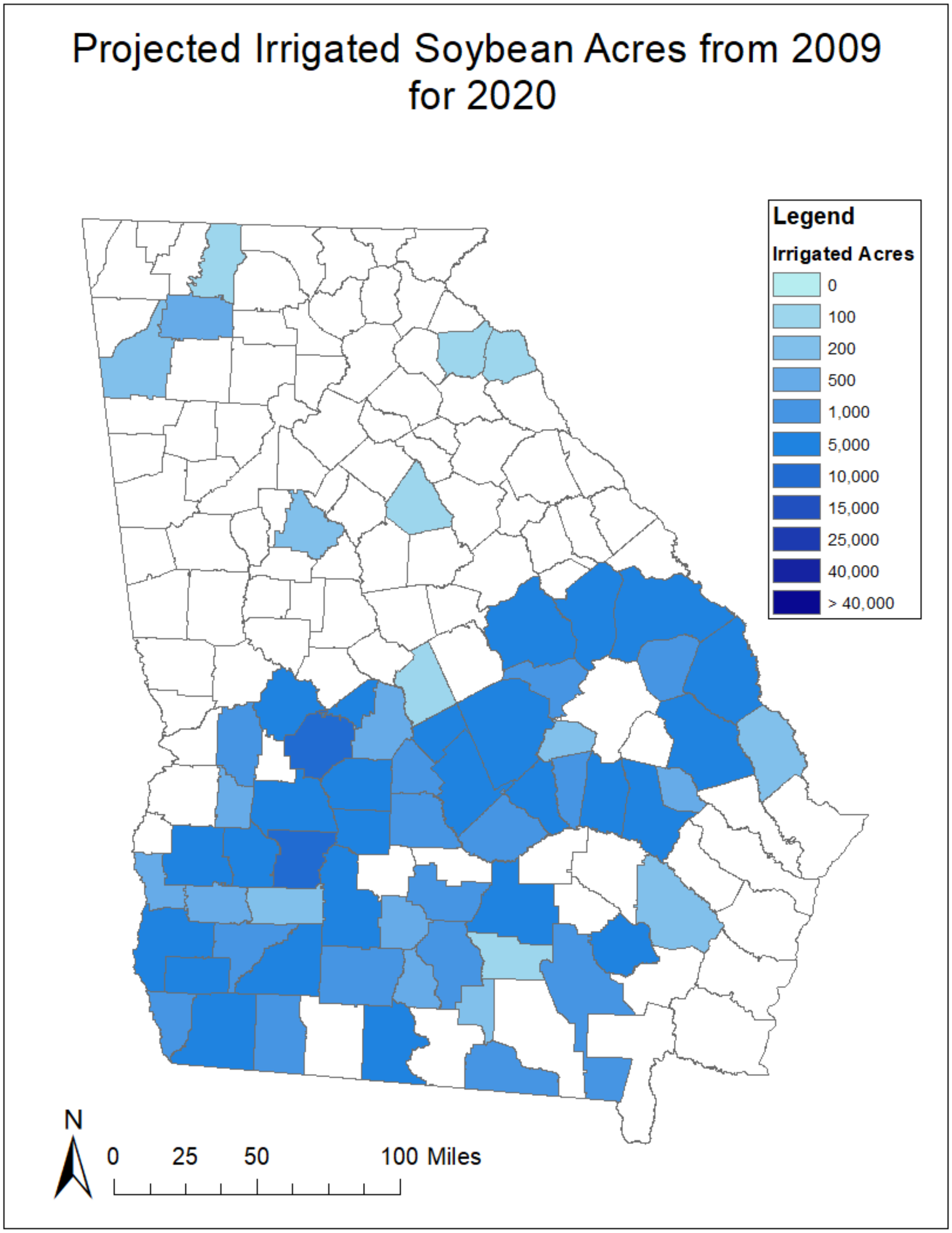
Map B.4 2015 Projected Irrigated Acres for Cotton in 2020



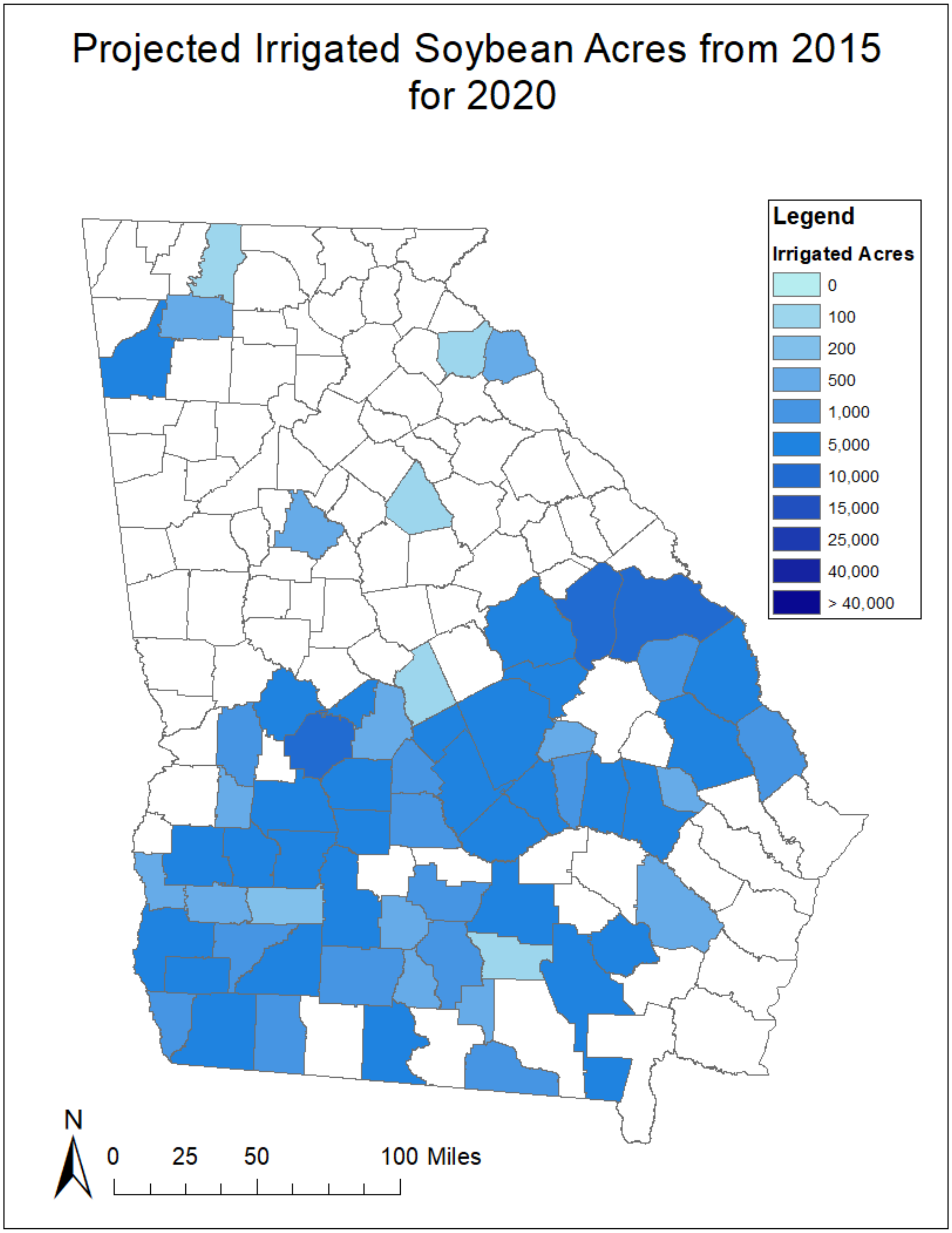
Map B.5 2009 Projected Irrigated Acres for Peanuts in 2020



Map B.6 2015 Projected Irrigated Acres for Peanuts in 2020

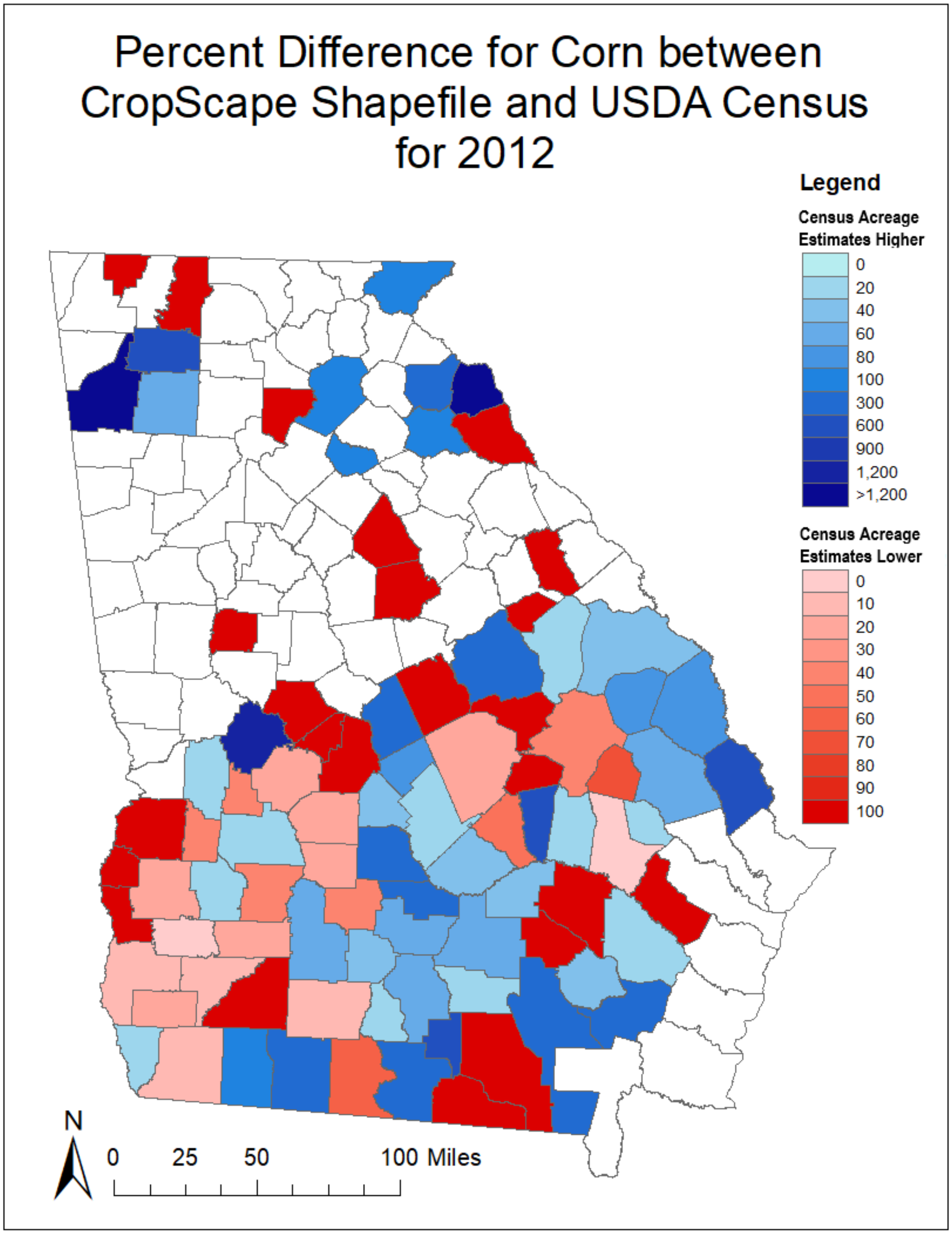


Map B.7 2009 Projected Irrigated Acres for Soybeans in 2020

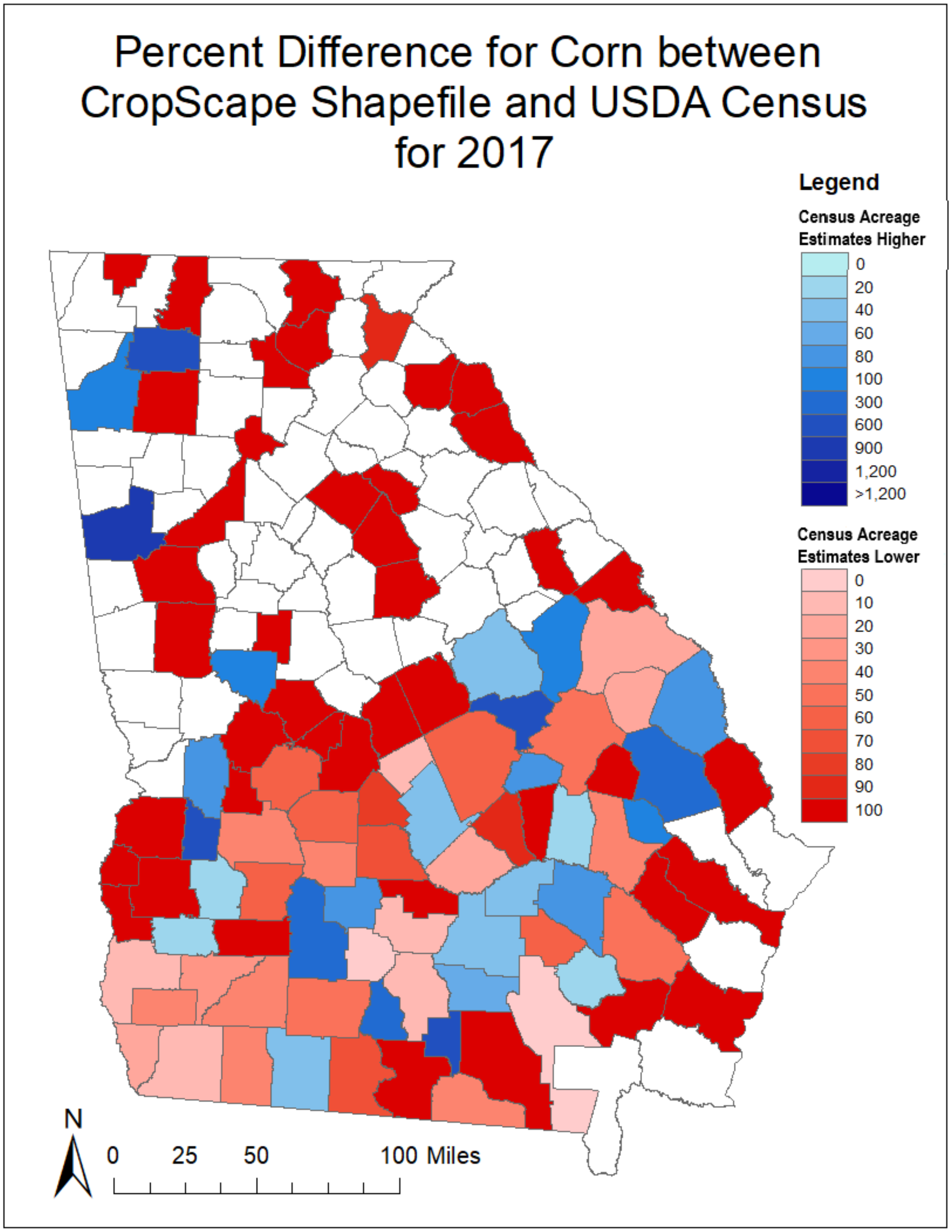


Map B.8 2015 Projected Irrigated Acres for Soybeans in 2020

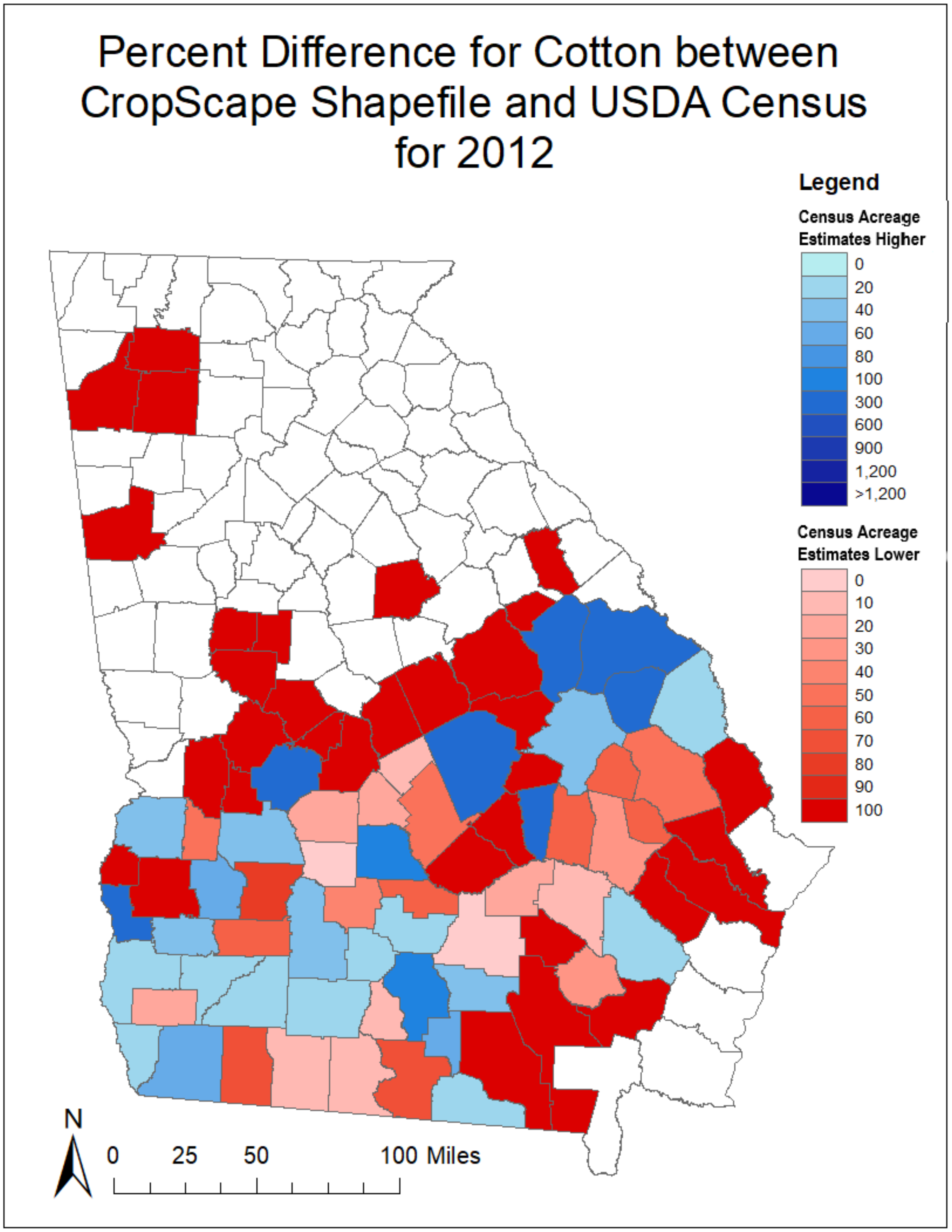
Appendix C: Percent Differences Between CropScape and USDA Census Maps



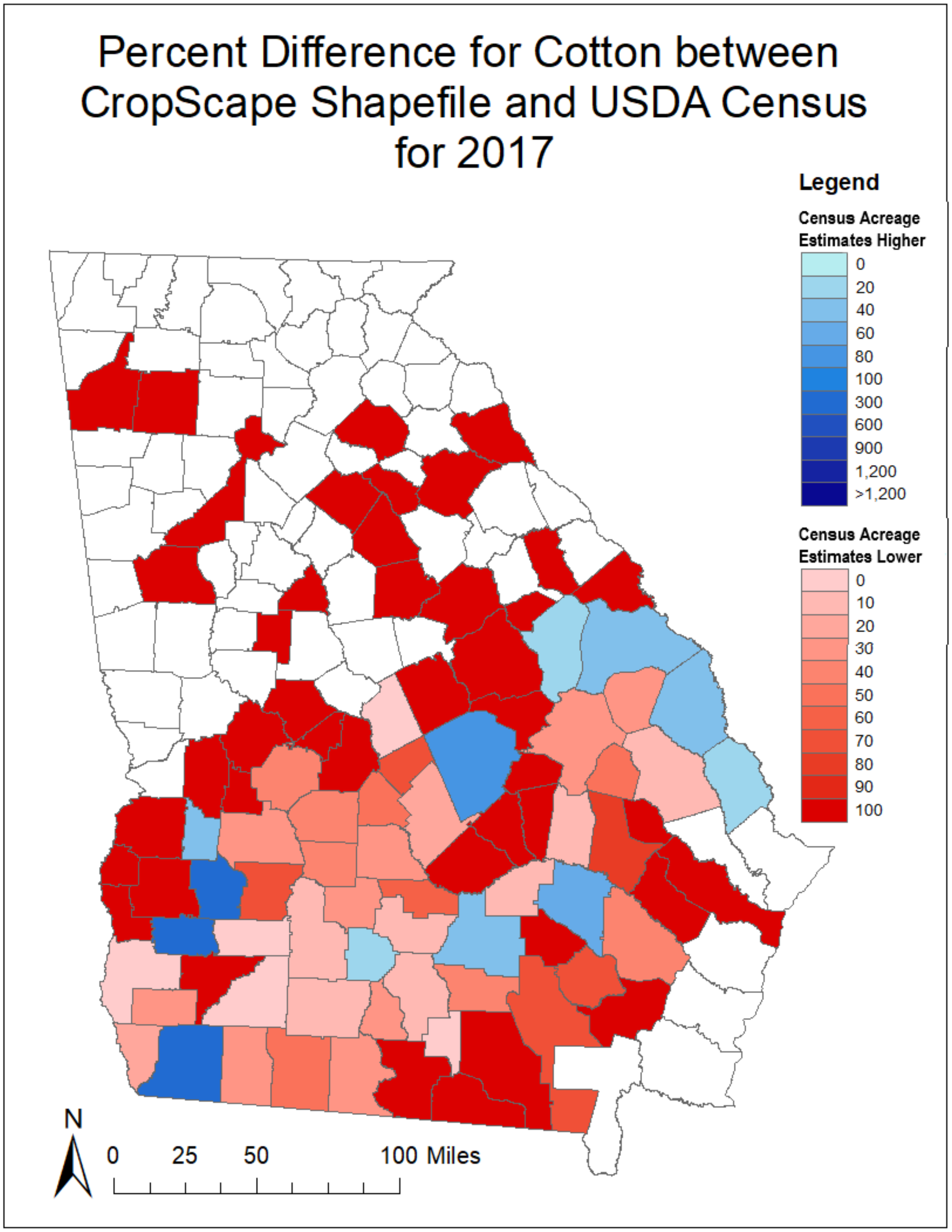
Map C.1 Percent Differences for Corn Irrigated Acres between CropScape Shapefiles and USDA for 2012



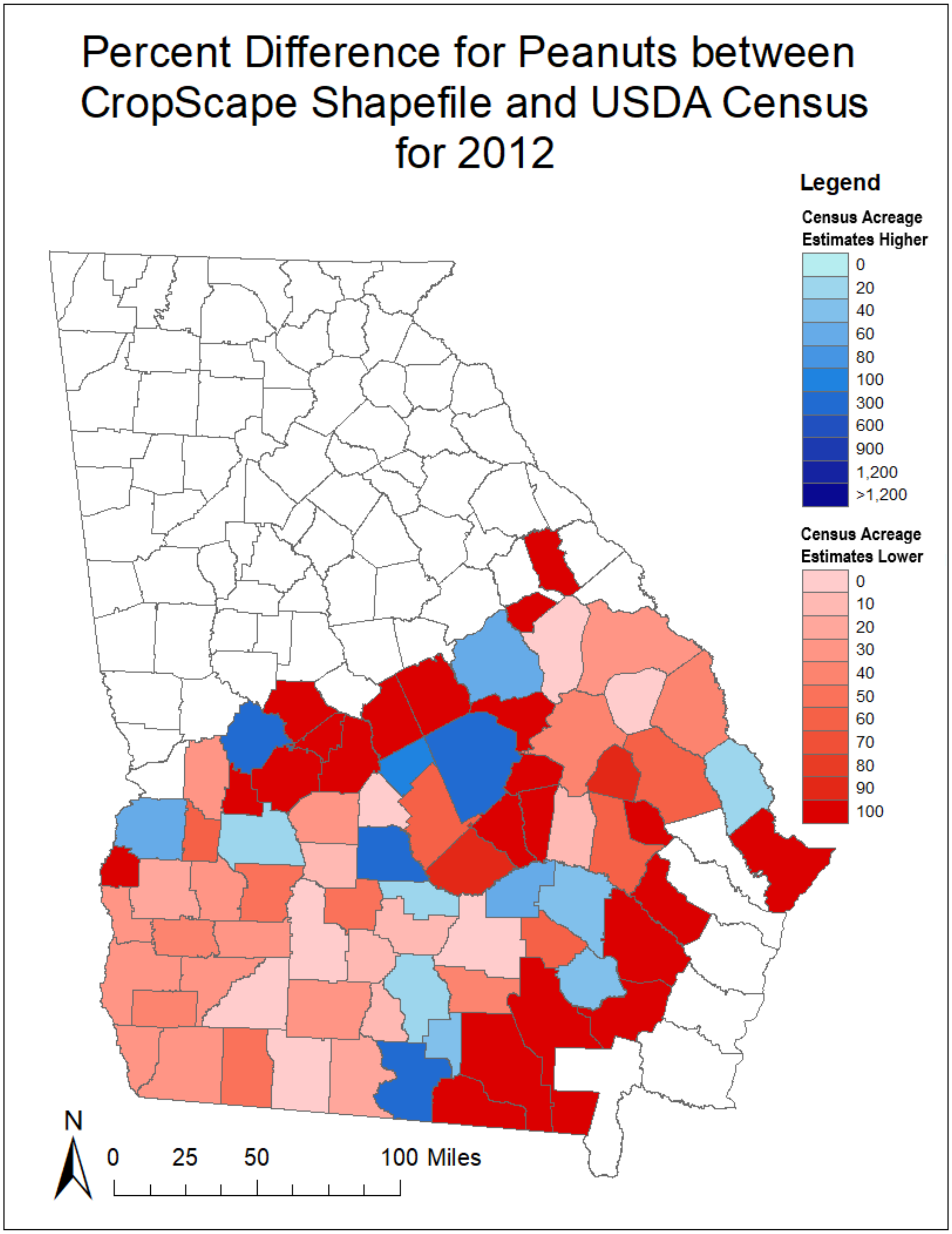
Map C.2 Percent Differences for Corn Irrigated Acres between CropScape Shapefiles and USDA for 2017



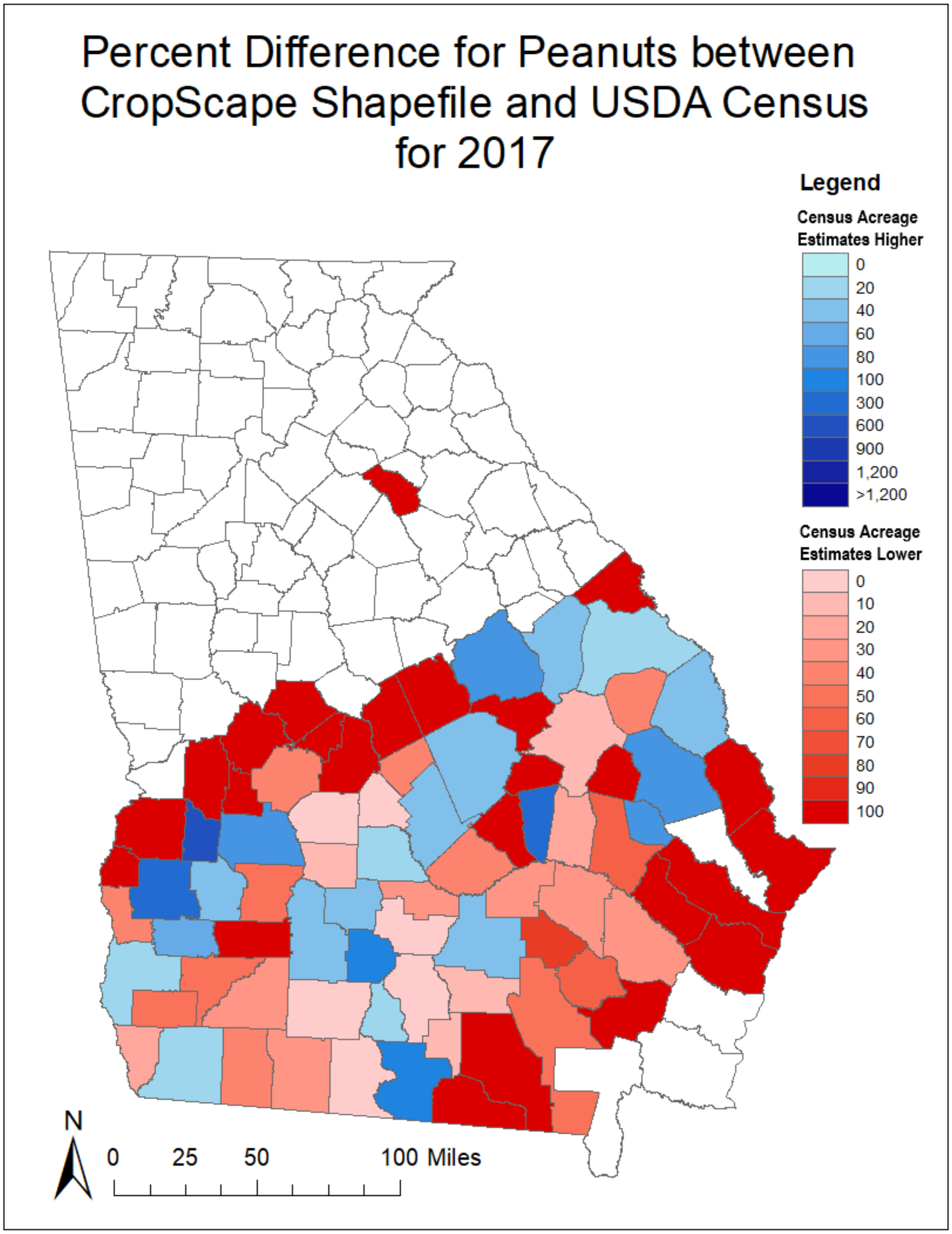
Map C.3 Percent Differences for Cotton Irrigated Acres between CropScape Shapefiles and USDA for 2012



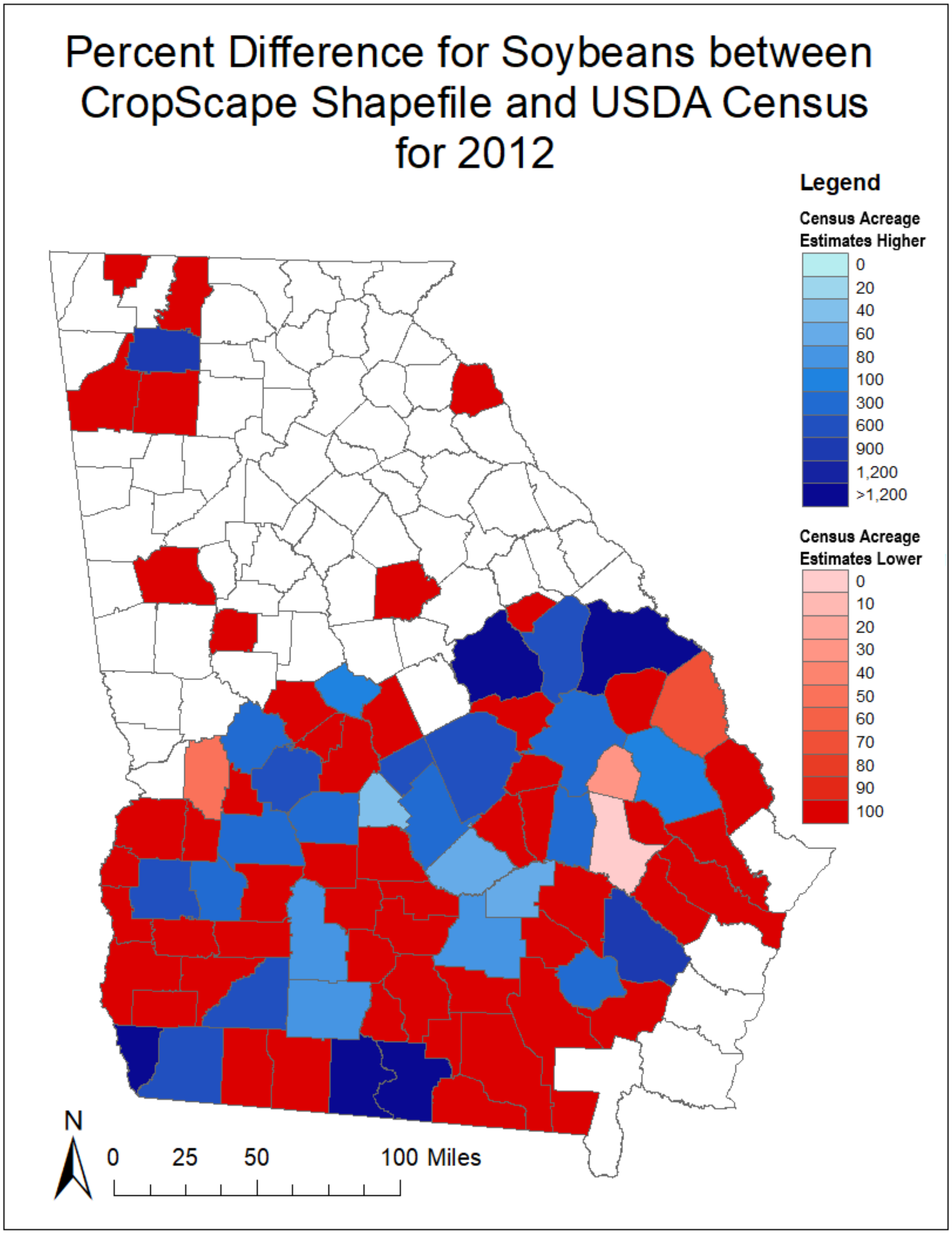
Map C.4 Percent Differences for Cotton Irrigated Acres between CropScape Shapefiles and USDA for 2017



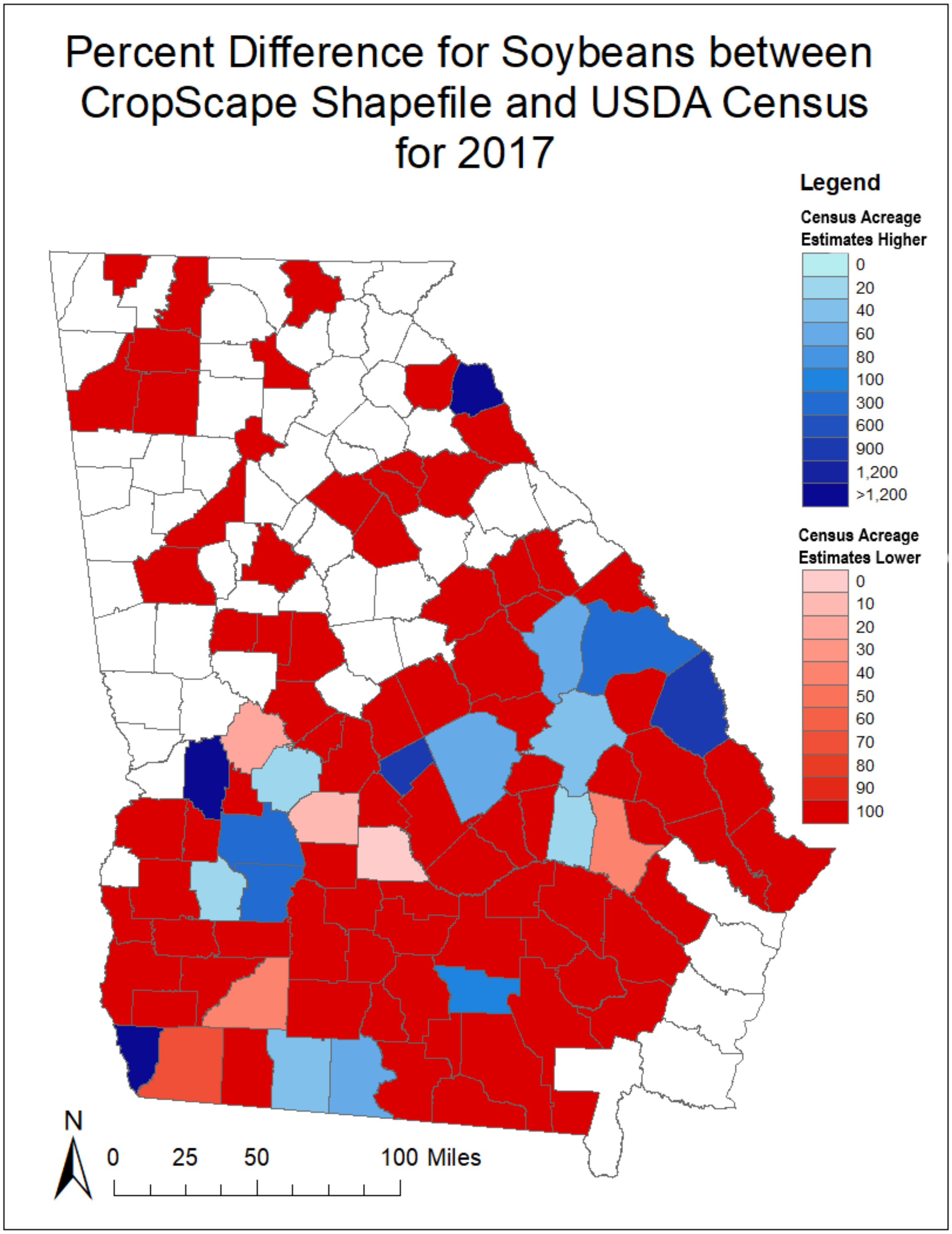
Map C.5 Percent Differences for Peanut Irrigated Acres between CropScape Shapefiles and USDA for 2012



Map C.6 Percent Differences for Peanut Irrigated Acres between CropScape Shapefiles and USDA for 2017



Map C.7 Percent Differences for Soybean Irrigated Acres between CropScape Shapefiles and USDA for 2012



Map C.8 Percent Differences for Soybean Irrigated Acres between CropScape Shapefiles and USDA for 2017

Appendix D: Relative Frequency Histograms of the Profit Margin of Total Revenue over Pumping Costs for the Irrigations Strategies

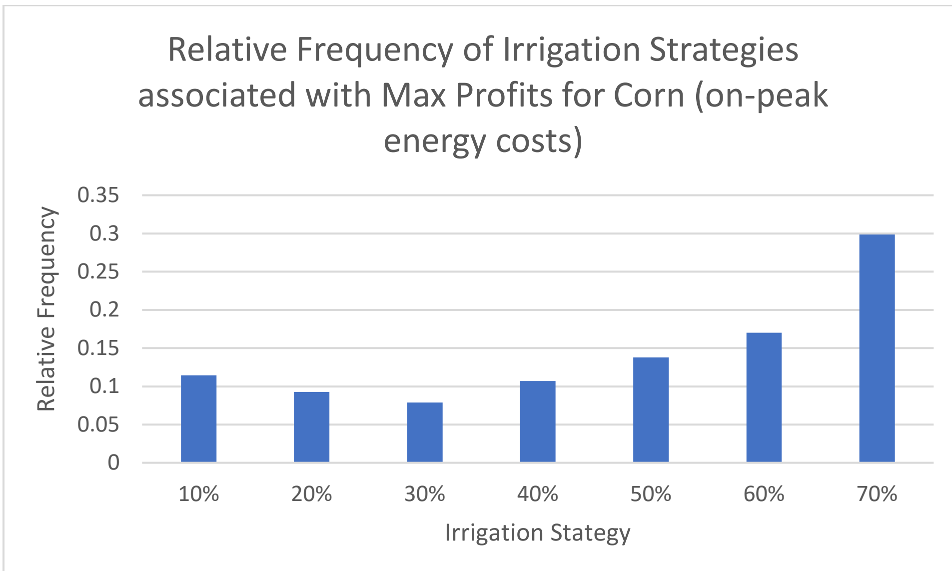


Figure D.1 Distribution of profits for on-peak energy costs with corn

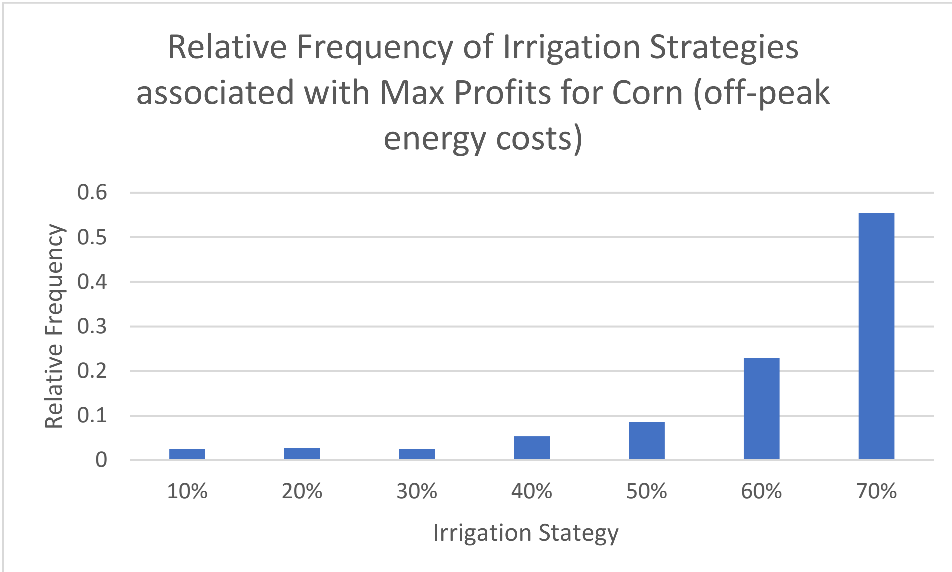


Figure D.2 Distribution of profits for off-peak energy costs with corn

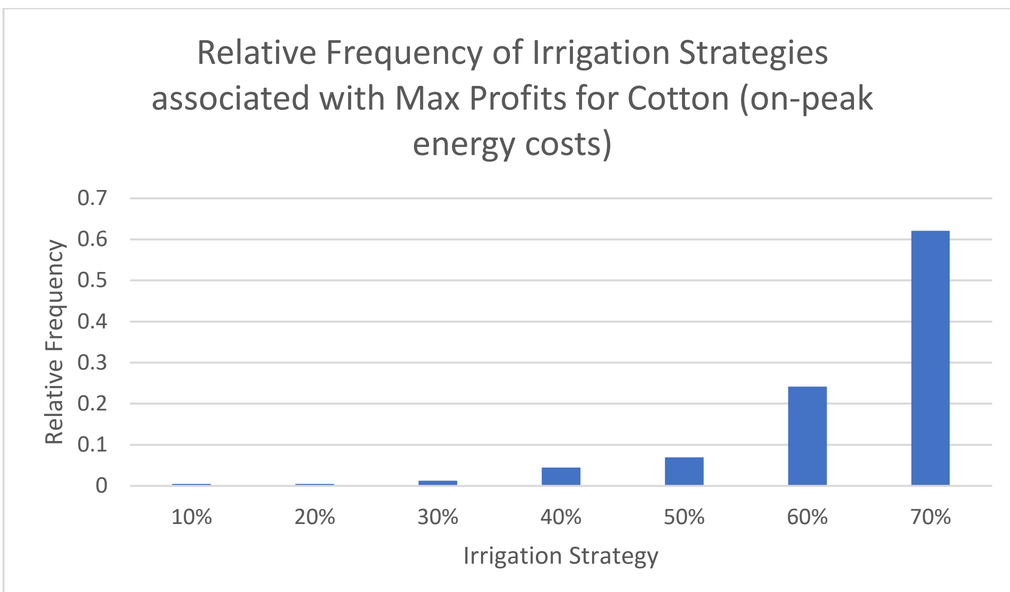


Figure D.3 Distribution of profits for on-peak energy costs with cotton

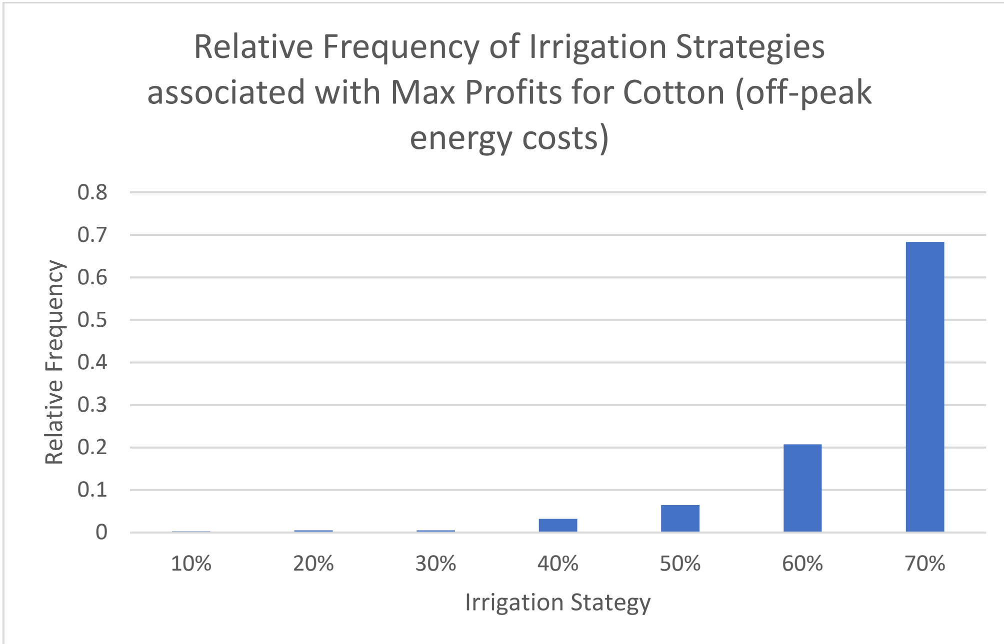


Figure D.4 Distribution of profits for off-peak energy costs with cotton

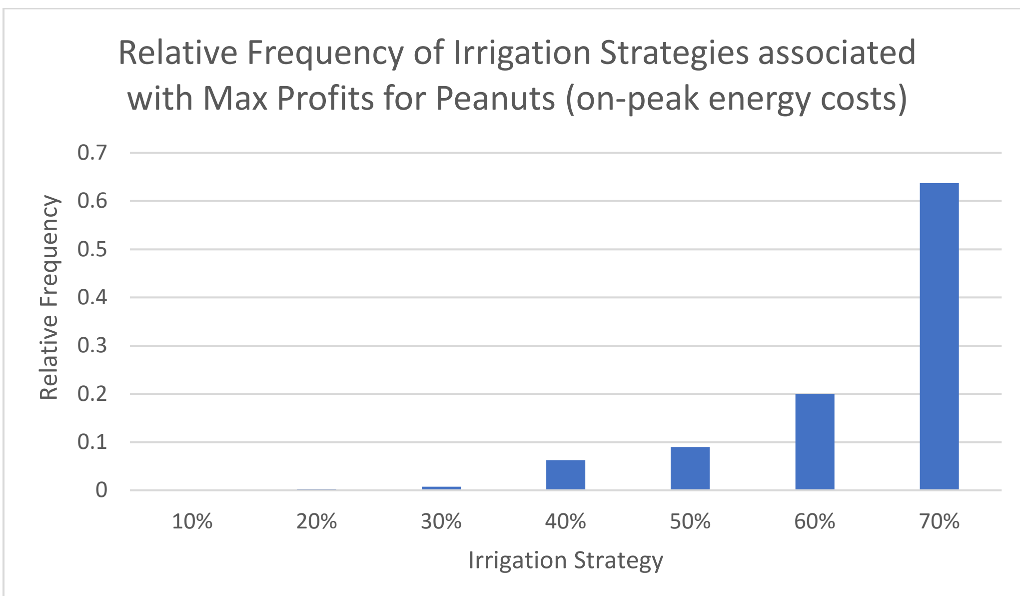


Figure D.5 Distribution of profits for on-peak energy costs with peanuts

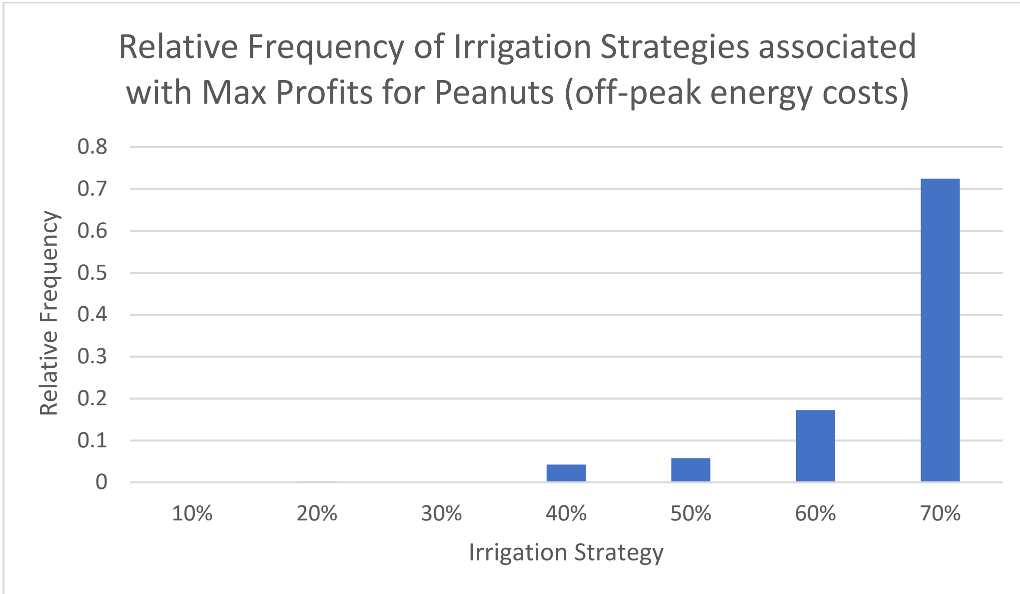


Figure D.6 Distribution of profits for off-peak energy costs with peanuts

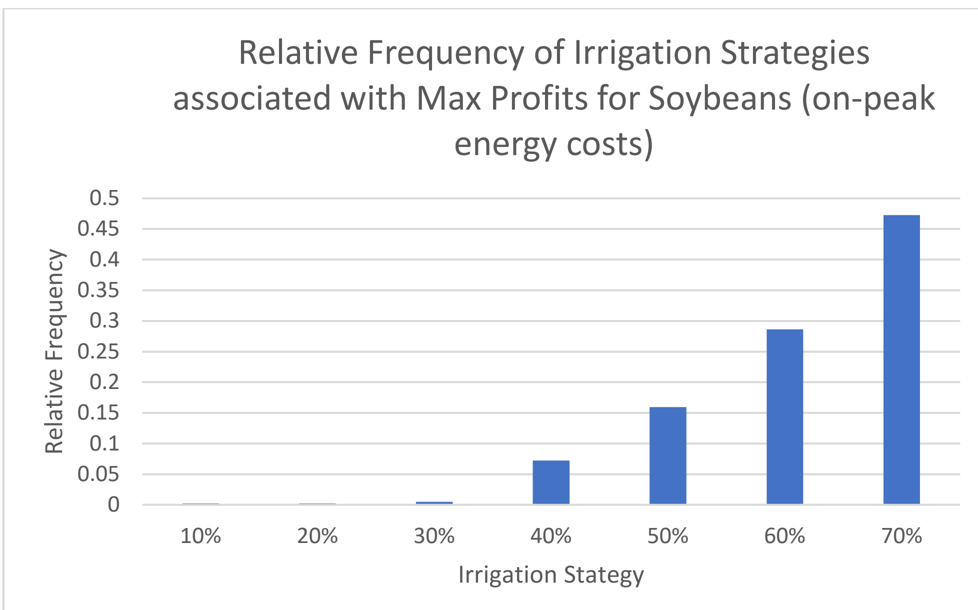


Figure D.7 Distribution of profits for on-peak energy costs with soybeans

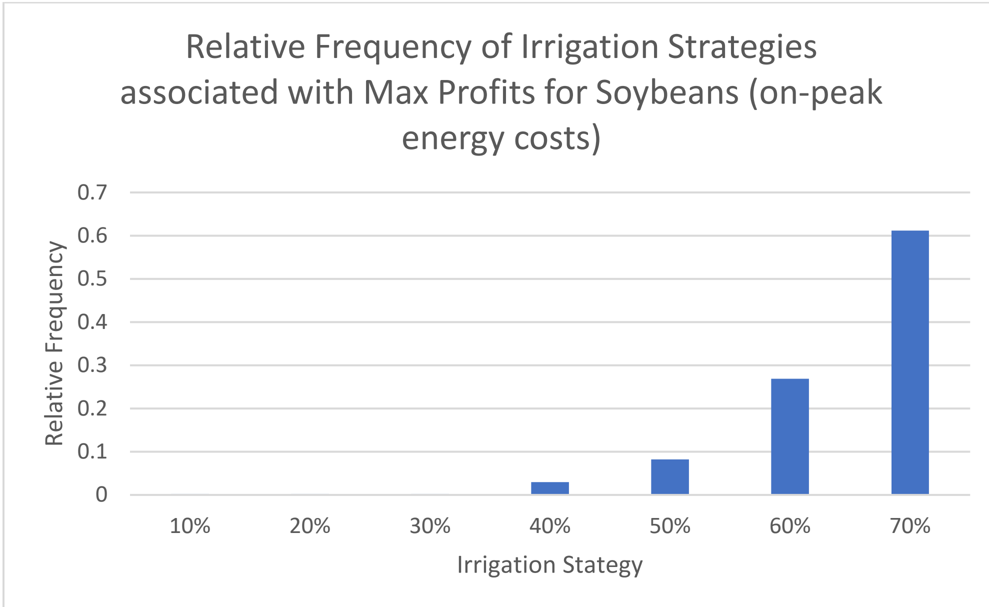


Figure D.8 Distribution of profits for off-peak energy costs with soybeans

Appendix E: Locational Analysis with DSSAT data using a One-Way Anova Test by Crop and Irrigation Strategy

Table E.1 Corn: One-way Anova test using 10% irrigation strategies

IRR STRATEGY: 10%
Anova: Single Factor

SUMMARY

Groups	*Count*	*Sum*	*Average*	*Variance*
Albany	35	11.8504	0.338583	0.342478
Arabi	35	16.73229	0.478066	0.363079
Arlington	35	13.77954	0.393701	0.296324
Attapulgus	35	13.77954	0.393701	0.35331
Byromville	35	11.81103	0.337458	0.281671
Camilla	35	11.81103	0.337458	0.338657
Dawson	35	15.78741	0.451069	0.421997
Donalsonville	35	6.889768	0.196851	0.159559
Ducker	35	12.79528	0.36558	0.232826
Newton	35	8.858273	0.253094	0.24748
Plains	35	16.81103	0.480315	0.600289
Sasser	35	14.76379	0.421823	0.358194
Shellman	35	10.86615	0.310461	0.332774
TyTy	35	8.858273	0.253094	0.190494

ANOVA

Source of Variation	*SS*	*df*	*MS*	*F*	*P-value*	*F crit*
Between Groups	3.366272	13	0.258944	0.802193	0.658069	1.740746
Within Groups	153.6506	476	0.322795			
Total	157.0168	489				

Table E.2 Corn: One-way Anova test using 20% irrigation strategies

IRR STRATEGY: 20%
Anova: Single Factor

SUMMARY

Groups	Count	Sum	Average	Variance
Albany	35	38.93703	1.112487	0.824087
Arabi	35	45.35436	1.295839	1.421297
Arlington	35	36.29923	1.037121	1.027648
Attapulgus	35	34.44884	0.984253	1.131321
Byromville	35	40.86616	1.167605	1.294613
Camilla	35	32.59844	0.931384	1.03631
Dawson	35	42.63782	1.218223	1.352693
Donalsonville	35	28.11025	0.80315	0.909871
Ducker	35	28.14962	0.804275	0.866114
Newton	35	42.59845	1.217099	1.305229
Plains	35	50.8268	1.452194	2.1471
Sasser	35	38.93703	1.112487	1.209947
Shellman	35	47.04727	1.344208	1.558224
TyTy	35	35.43309	1.012374	1.112408

ANOVA

Source of Variation	*SS*	*df*	*MS*	*F*	*P-value*	*F crit*
Between Groups	16.90579	13	1.300445	1.058695	0.393578	1.740746
Within Groups	584.6933	476	1.228347			
Total	601.5991	489				

Table E.3 Corn: One-way Anova test using 30% irrigation strategies

IRR STRATEGY: 30%
Anova: Single Factor

SUMMARY

Groups	Count	Sum	Average	Variance
Albany	35	77.63784	2.218224	2.294002
Arabi	35	97.63785	2.789653	2.721913
Arlington	35	72.83469	2.080991	2.619521
Attapulgus	35	74.5276	2.12936	3.127852
Byromville	35	94.44887	2.698539	3.837478
Camilla	35	71.22051	2.034872	2.198251
Dawson	35	86.10241	2.460069	2.783387
Donalsonville	35	75.82681	2.16648	2.649823
Ducker	35	70.23626	2.00675	3.035865
Newton	35	94.09454	2.688415	2.476504
Plains	35	98.66147	2.818899	5.234658
Sasser	35	91.73233	2.620924	2.97102
Shellman	35	92.1654	2.633297	3.660543
TyTy	35	84.44886	2.412825	2.453345

ANOVA

Source of Variation	*SS*	*df*	*MS*	*F*	*P-value*	*F crit*
Between Groups	40.43763	13	3.110587	1.035281	0.415583	1.740746
Within Groups	1430.182	476	3.004583			
Total	1470.619	489				

Table E.4 Corn: One-way Anova test using 40% irrigation strategies

IRR STRATEGY: 40%
Anova: Single Factor
SUMMARY

Groups	Count	Sum	Average	Variance
Albany	35	124.6851	3.562432	2.916869
Arabi	35	150.9056	4.311588	4.384906
Arlington	35	117.2442	3.349833	3.196144
Attapulgus	35	108.6615	3.104614	5.343974
Byromville	35	150.1576	4.290216	4.694279
Camilla	35	120.0788	3.430823	3.595751
Dawson	35	132.6772	3.790778	3.901141
Donalsonville	35	126.6142	3.61755	3.551861
Ducker	35	105.63	3.017999	3.617068
Newton	35	143.9371	4.112488	3.143167
Plains	35	144.0552	4.115863	7.143091
Sasser	35	136.9686	3.913388	3.458352
Shellman	35	146.2599	4.178855	4.658324
TyTy	35	136.2993	3.894265	3.731989

ANOVA

Source of Variation	SS	df	MS	F	P-value	F crit
Between Groups	82.95137	13	6.380875	1.558023	0.09365	1.740746
Within Groups	1949.455	476	4.095494			
Total	2032.407	489				

Table E.5 Corn: One-way Anova test using 50% irrigation strategies

IRR STRATEGY: 50%
Anova: Single Factor
SUMMARY

Groups	Count	Sum	Average	Variance
Albany	35	162.5985	4.645672	3.233948
Arabi	35	197.5592	5.644547	4.922276
Arlington	35	148.3072	4.237348	3.405551
Attapulgus	35	141.6142	4.046121	4.995308
Byromville	35	184.9607	5.284592	5.553675
Camilla	35	153.2678	4.37908	3.708257
Dawson	35	166.8899	4.768282	4.322669
Donalsonville	35	162.2836	4.636673	3.864261
Ducker	35	144.8032	4.137235	3.992481
Newton	35	181.3781	5.18223	3.776002
Plains	35	180.7481	5.164232	7.723992
Sasser	35	183.0316	5.229474	3.376593
Shellman	35	183.2284	5.235098	4.400508
TyTy	35	176.4962	5.042747	4.359833

ANOVA

Source of Variation	SS	df	MS	F	P-value	F crit
Between Groups	111.9639	13	8.612606	1.956288	0.022669	1.740746
Within Groups	2095.602	476	4.402525			
Total	2207.566	489				

Table E.6 Corn: One-way Anova test using 60% irrigation strategies

IRR STRATEGY: 60%
Anova: Single Factor

SUMMARY

Groups	*Count*	*Sum*	*Average*	*Variance*
Albany	35	195.7875	5.593929	3.684578
Arabi	35	221.5749	6.330712	5.86365
Arlington	35	176.8111	5.051746	3.449652
Attapulgus	35	173.6615	4.961757	6.344943
Byromville	35	215.0395	6.143985	5.879619
Camilla	35	179.4489	5.127112	4.803655
Dawson	35	190.63	5.446572	4.962289
Donalsonville	35	195.7088	5.591679	4.45649
Ducker	35	177.5592	5.073119	3.571498
Newton	35	211.1812	6.033749	4.406604
Plains	35	211.4962	6.042748	7.913173
Sasser	35	209.3308	5.980881	3.613369
Shellman	35	219.7245	6.277844	4.877623
TyTy	35	207.3623	5.924638	5.31655

ANOVA

Source of Variation	*SS*	*df*	*MS*	*F*	*P-value*	*F crit*
Between Groups	107.003	13	8.231	1.666587	0.064842	1.740746
Within Groups	2350.886	476	4.938835			
Total	2457.889	489				

Table E.7 Corn: One-way Anova test using 70% irrigation strategies

IRR STRATEGY: 70%
Anova: Single Factor

SUMMARY

Groups	*Count*	*Sum*	*Average*	*Variance*
Albany	35	230.8663	6.596179	4.04682
Arabi	35	260.0789	7.430825	5.774984
Arlington	35	213.4253	6.097866	4.083056
Attapulgus	35	208.1497	5.947135	6.353647
Byromville	35	255.8269	7.30934	6.15634
Camilla	35	217.9922	6.22835	5.32206
Dawson	35	231.1419	6.604053	5.204218
Donalsonville	35	234.3308	6.695167	5.251776
Ducker	35	219.4883	6.271095	4.228739
Newton	35	249.9214	7.140611	4.55994
Plains	35	248.3072	7.094492	8.463373
Sasser	35	246.1812	7.03375	3.907648
Shellman	35	252.756	7.221601	4.782429
TyTy	35	243.2678	6.95051	6.419057

ANOVA

Source of Variation	*SS*	*df*	*MS*	*F*	*P-value*	*F crit*
Between Groups	105.3159	13	8.101222	1.521273	0.105662	1.740746
Within Groups	2534.839	476	5.325292			
Total	2640.155	489				

Table E.8 Cotton: One-way Anova test using 10% irrigation strategies

IRR STRATEGY: 10%

Anova: Single Factor

SUMMARY

Groups	*Count*	*Sum*	*Average*	*Variance*
Albany	25	38.66144	1.546458	0.756211
Arabi	25	47.55908	1.902363	1.968987
Arlington	25	25.82679	1.033071	1.278273
Attapulgus	25	19.76379	0.790552	0.740892
Byromville	25	48.50396	1.940159	0.698732
Camilla	25	21.77167	0.870867	0.769877
Dawson	25	31.69293	1.267717	0.538239
Donalsonville	25	23.62206	0.944882	0.603856
Ducker	25	29.64569	1.185827	0.818444
Newton	25	32.5197	1.300788	0.874136
Plains	25	36.57482	1.462993	0.588185
Sasser	25	34.72443	1.388977	1.409022
Shellman	25	32.63781	1.305513	0.800149
TyTy	25	46.53546	1.861418	1.010541

ANOVA

Source of Variation	*SS*	*df*	*MS*	*F*	*P-value*	*F crit*
Between Groups	45.30927	13	3.485328	3.795607	1.05E-05	1.74936
Within Groups	308.533	336	0.918253			
Total	353.8423	349				

Table E.9 Cotton: One-way Anova test using 20% irrigation strategies

IRR STRATEGY: 20%

Anova: Single Factor

SUMMARY

Groups	*Count*	*Sum*	*Average*	*Variance*
Albany	25	74.9213	2.996852	1.492567
Arabi	25	115.8662	4.634648	4.003988
Arlington	25	72.04728	2.881891	3.237572
Attapulgus	25	44.64569	1.785828	1.760015
Byromville	25	108.5827	4.343309	1.597244
Camilla	25	58.42523	2.337009	2.092362
Dawson	25	85.82682	3.433073	1.203191
Donalsonville	25	59.33074	2.37323	1.749893
Ducker	25	71.92917	2.877167	2.350572
Newton	25	67.55909	2.702364	3.14869
Plains	25	93.81895	3.752758	1.761286
Sasser	25	86.65359	3.466144	3.480339
Shellman	25	98.70084	3.948034	3.385148
TyTy	25	101.5355	4.06142	3.269823

ANOVA

Source of Variation	*SS*	*df*	*MS*	*F*	*P-value*	*F crit*
Between Groups	224.3794	13	17.25996	6.99741	5.07E-12	1.74936
Within Groups	828.7846	336	2.466621			
Total	1053.164	349				

Table E.10 Cotton: One-way Anova test using 30% irrigation strategies

IRR STRATEGY: 30%

Anova: Single Factor

SUMMARY

Groups	*Count*	*Sum*	*Average*	*Variance*
Albany	25	119.0158	4.760632	2.649077
Arabi	25	167.3229	6.692917	8.300405
Arlington	25	109.8819	4.395278	5.1739
Attapulgus	25	72.87406	2.914962	2.969613
Byromville	25	165.5906	6.623626	3.154813
Camilla	25	96.53549	3.861419	3.786135
Dawson	25	130.0394	5.201578	2.554449
Donalsonville	25	105.0394	4.201577	2.674084
Ducker	25	103.3465	4.133861	3.414273
Newton	25	120.7087	4.828349	5.890132
Plains	25	144.8032	5.792129	2.479791
Sasser	25	134.6851	5.387404	6.431058
Shellman	25	161.2206	6.448822	9.959556
TyTy	25	151.8505	6.074019	6.239611

ANOVA

Source of Variation	*SS*	*df*	*MS*	*F*	*P-value*	*F crit*
Between Groups	423.3245	13	32.56342	6.941374	6.54E-12	1.74936
Within Groups	1576.245	336	4.691207			
Total	1999.57	349				

Table E.11 Cotton: One-way Anova test using 40% irrigation strategies

IRR STRATEGY:
40%
Anova: Single Factor

SUMMARY **IR+S88:V94**

Groups	*Count*	*Sum*	*Average*	*Variance*
Albany	25	144.252	5.770082	3.843506
Arabi	25	200.4725	8.018902	12.32056
Arlington	25	132.4804	5.299215	5.972298
Attapulgus	25	97.99218	3.919687	3.681272
Byromville	25	198.8584	7.954335	5.004769
Camilla	25	126.9292	5.077168	4.944319
Dawson	25	160.7481	6.429925	3.267245
Donalsonville	25	123.9371	4.957483	3.65658
Ducker	25	137.1261	5.485042	3.389824
Newton	25	144.567	5.78268	6.135735
Plains	25	179.5277	7.181106	3.993458
Sasser	25	160.2363	6.409452	7.418452
Shellman	25	194.5277	7.781107	11.99379
TyTy	25	176.693	7.06772	7.777423

ANOVA

Source of Variation	*SS*	*df*	*MS*	*F*	*P-value*	*F crit*
Between Groups	509.4066	13	39.18512	6.577898	3.39E-11	1.74936
Within Groups	2001.582	336	5.957088			
Total	2510.988	349				

Table E.12 Cotton: One-way Anova test using 50% irrigation strategies

IRR STRATEGY: 50%

Anova: Single Factor

SUMMARY

Groups	Count	Sum	Average	Variance
Albany	25	176.0631	7.042523	4.116337
Arabi	25	225.9844	9.039375	13.49925
Arlington	25	159.6458	6.38583	6.084673
Attapulgus	25	128.2678	5.130711	4.506344
Byromville	25	230.0395	9.20158	5.710156
Camilla	25	156.4568	6.258271	4.671647
Dawson	25	175.5906	7.023626	3.94657
Donalsonville	25	155.0001	6.200003	4.967781
Ducker	25	165.2363	6.609452	3.260606
Newton	25	172.8741	6.914964	6.979398
Plains	25	208.504	8.340162	5.524951
Sasser	25	190.3544	7.614177	8.970007
Shellman	25	222.7954	8.911816	13.06459
TyTy	25	203.7009	8.148036	7.105671

ANOVA

Source of Variation	SS	df	MS	F	P-value	F crit
Between Groups	492.9046	13	37.91574	5.744313	1.51E-09	1.74936
Within Groups	2217.791	336	6.60057			
Total	2710.696	349				

Table E.13 Cotton: One-way Anova test using 60% irrigation strategies

IRR STRATEGY: 60%

Anova: Single Factor

SUMMARY

Groups	Count	Sum	Average	Variance
Albany	25	200.5513	8.022052	4.219666
Arabi	25	249.6064	9.984257	14.16562
Arlington	25	175.2757	7.011027	5.486361
Attapulgus	25	154.1339	6.165358	3.296214
Byromville	25	255.5119	10.22048	6.281265
Camilla	25	182.5985	7.303941	3.523176
Dawson	25	204.0946	8.163784	3.330557
Donalsonville	25	174.0946	6.963783	5.231437
Ducker	25	192.9922	7.719689	3.090699
Newton	25	194.9607	7.798429	6.45253
Plains	25	221.0631	8.842524	5.654159
Sasser	25	210.7088	8.428351	8.58172
Shellman	25	240.5907	9.623627	13.86132
TyTy	25	227.4017	9.096068	7.585398

ANOVA

Source of Variation	SS	df	MS	F	P-value	F crit
Between Groups	471.2241	13	36.24801	5.591355	3.02E-09	1.74936
Within Groups	2178.243	336	6.482866			
Total	2649.467	349				

Table E.14 Cotton: One-way Anova test using 70% irrigation strategies

IRR STRATEGY: 70%

Anova: Single Factor

SUMMARY

Groups	*Count*	*Sum*	*Average*	*Variance*
Albany	26	230.397	8.861422	4.319915
Arabi	26	287.5151	11.05827	16.56885
Arlington	26	207.0584	7.963784	5.08532
Attapulgus	26	178.0694	6.848823	3.318062
Byromville	26	288.334	11.08977	6.840198
Camilla	26	206.2395	7.932288	3.939259
Dawson	26	240.5923	9.253548	3.800795
Donalsonville	26	214.6741	8.256697	4.986244
Ducker	26	224.0915	8.618902	3.002411
Newton	26	229.2096	8.815753	7.466053
Plains	26	259.7135	9.988982	5.961755
Sasser	26	241.6568	9.294493	8.577096
Shellman	26	275.3135	10.58898	14.3319
TyTy	26	261.4332	10.05512	8.760875

ANOVA

Source of Variation	*SS*	*df*	*MS*	*F*	*P-value*	*F crit*
Between Groups	532.2252	13	40.9404	5.911439	6.37E-10	1.748187
Within Groups	2423.968	350	6.925624			
Total	2956.193	363				

Table E.15 Peanuts: One-way Anova test using 10% irrigation strategies

IRR STRATEGY: 10%
Anova: Single Factor

SUMMARY

Groups	*Count*	*Sum*	*Average*	*Variance*
Albany	25	10.82678	0.433071	0.329376
Arabi	25	32.55907	1.302363	1.202535
Arlington	25	7.87402	0.314961	0.219584
Attapulgus	25	12.79528	0.511811	0.332605
Byromville	25	26.61419	1.064568	0.56168
Camilla	25	1.968505	0.07874	0.074271
Dawson	25	14.76379	0.590552	0.322918
Donalsonville	25	7.87402	0.314961	0.219584
Ducker	25	7.87402	0.314961	0.219584
Newton	25	7.87402	0.314961	0.219584
Plains	25	20.6693	0.826772	0.377814
Sasser	25	15.74804	0.629922	0.31323
Shellman	25	19.68505	0.787402	0.484376

ANOVA

Source of Variation	*SS*	*df*	*MS*	*F*	*P-value*	*F crit*
Between Groups	35.53448	12	2.961207	7.893084	7.06E-13	1.783282
Within Groups	117.0514	312	0.375165			
Total	152.5859	324				

Table E.16 Peanuts: One-way Anova test using 20% irrigation strategies

IRR STRATEGY: 20%
Anova: Single Factor

SUMMARY

Groups	*Count*	*Sum*	*Average*	*Variance*
Albany	25	54.33074	2.17323	1.434917
Arabi	25	91.81107	3.672443	4.173455
Arlington	25	40.74805	1.629922	2.18654
Attapulgus	25	34.40947	1.376379	1.374787
Byromville	25	82.67721	3.307088	1.033466
Camilla	25	47.08664	1.883466	1.49778
Dawson	25	58.97641	2.359056	1.441623
Donalsonville	25	44.40947	1.776379	1.06089
Ducker	25	42.55908	1.702363	0.500171
Newton	25	56.2205	2.24882	1.461308
Plains	25	72.51972	2.900789	0.961483
Sasser	25	61.65358	2.466143	1.748519
Shellman	25	70.7087	2.828348	3.033706
TyTy	25	76.22051	3.048821	2.343747

ANOVA

Source of Variation	*SS*	*df*	*MS*	*F*	*P-value*	*F crit*
Between Groups	153.9262	13	11.84048	6.835065	1.06E-11	1.74936
Within Groups	582.0574	336	1.732314			
Total	735.9836	349				

Table E.17 Peanuts: One-way Anova test using 30% irrigation strategies

IRR STRATEGY: 30%
Anova: Single Factor
SUMMARY

Groups	Count	Sum	Average	Variance
Albany	25	107.6772	4.307089	2.401732
Arabi	25	160.0395	6.401578	9.835426
Arlington	25	98.50399	3.94016	3.561126
Attapulgus	25	69.44886	2.777954	2.952899
Byromville	25	155.2363	6.209452	4.365268
Camilla	25	92.75596	3.710238	3.26538
Dawson	25	112.0867	4.483467	2.592295
Donalsonville	25	95.11816	3.804726	2.755118
Ducker	25	97.0473	3.881892	2.132936
Newton	25	111.4568	4.45827	4.158311
Plains	25	134.0552	5.362208	3.144831
Sasser	25	119.3701	4.774806	5.088991
Shellman	25	150.7875	6.031499	6.812142
TyTy	25	135.2363	5.409452	5.79986

ANOVA

Source of Variation	*SS*	*df*	*MS*	*F*	*P-value*	*F crit*
Between Groups	371.7884	13	28.59911	6.801641	1.23E-11	1.74936
Within Groups	1412.792	336	4.204737			
Total	1784.58	349				

Table E.18 Peanuts: One-way Anova test using 40% irrigation strategies

IRR STRATEGY: 40%
Anova: Single Factor

SUMMARY

Groups	*Count*	*Sum*	*Average*	*Variance*
Albany	25	153.3859	6.135436	2.985268
Arabi	25	197.3623	7.894492	12.20488
Arlington	25	144.8426	5.793704	6.051048
Attapulgus	25	107.441	4.29764	3.176306
Byromville	25	202.7954	8.111815	5.073228
Camilla	25	137.1654	5.486617	5.528464
Dawson	25	168.8584	6.754334	4.156606
Donalsonville	25	139.2914	5.571657	4.02357
Ducker	25	147.7166	5.908665	2.441118
Newton	25	158.8584	6.354334	5.499159
Plains	25	180.1576	7.206303	5.908422
Sasser	25	173.5828	6.943311	7.047985
Shellman	25	203.7796	8.151186	11.95499
TyTy	25	185.1576	7.406303	8.613805

ANOVA

Source of Variation	*SS*	*df*	*MS*	*F*	*P-value*	*F crit*
Between Groups	412.9635	13	31.76642	5.252828	1.42E-08	1.74936
Within Groups	2031.956	336	6.047489			
Total	2444.92	349				

Table E.19 Peanuts: One-way Anova test using 50% irrigation strategies

IRR STRATEGY: 50%
Anova: Single Factor

SUMMARY

Groups	*Count*	*Sum*	*Average*	*Variance*
Albany	25	194.1733	7.766933	4.488752
Arabi	25	238.5828	9.543312	15.68062
Arlington	25	172.9135	6.916539	5.442806
Attapulgus	25	151.378	6.055121	2.943459
Byromville	25	252.2442	10.08977	7.093793
Camilla	25	179.8032	7.19213	4.109414
Dawson	25	195.9844	7.839374	5.541438
Donalsonville	25	173.6221	6.944886	6.117094
Ducker	25	186.3781	7.455122	2.969535
Newton	25	194.134	7.765359	7.922369
Plains	25	219.3308	8.773233	8.076904
Sasser	25	211.1812	8.447249	9.010705
Shellman	25	241.3387	9.653549	15.3931
TyTy	25	212.0867	8.483469	7.110275

ANOVA

Source of Variation	*SS*	*df*	*MS*	*F*	*P-value*	*F crit*
Between Groups	440.2002	13	33.86156	4.652214	2.19E-07	1.74936
Within Groups	2445.606	336	7.27859			
Total	2885.807	349				

Table E.20 Peanuts: One-way Anova test using 60% irrigation strategies

IRR STRATEGY: 60%
Anova: Single Factor

SUMMARY

Groups	*Count*	*Sum*	*Average*	*Variance*
Albany	25	227.0474	9.081895	4.620011
Arabi	25	267.9529	10.71812	16.74861
Arlington	25	201.7324	8.069296	6.03281
Attapulgus	25	176.8899	7.075594	5.128516
Byromville	25	281.6537	11.26615	9.700276
Camilla	25	203.1103	8.124414	5.642906
Dawson	25	229.1734	9.166934	5.679693
Donalsonville	25	200.63	8.025201	5.97626
Ducker	25	222.7954	8.911816	3.867117
Newton	25	221.5356	8.861422	8.33359
Plains	25	246.3387	9.853549	7.421748
Sasser	25	234.3702	9.374808	9.581138
Shellman	25	267.7561	10.71024	16.35739
TyTy	25	246.0238	9.84095	8.527672

ANOVA

Source of Variation	*SS*	*df*	*MS*	*F*	*P-value*	*F crit*
Between Groups	456.4679	13	35.11292	4.32662	9.62E-07	1.74936
Within Groups	2726.826	336	8.115553			
Total	3183.294	349				

Table E.21 Peanuts: One-way Anova test using 70% irrigation strategies

IRR STRATEGY: 70%
Anova: Single Factor

SUMMARY

Groups	Count	Sum	Average	Variance
Albany	25	240.945	9.6378	4.666289
Arabi	25	303.7797	12.15119	19.56647
Arlington	25	226.693	9.067721	7.063594
Attapulgus	25	202.3623	8.094493	4.128309
Byromville	25	308.8978	12.35591	11.32468
Camilla	25	228.386	9.135438	4.950261
Dawson	25	261.5356	10.46142	6.465137
Donalsonville	25	233.071	9.32284	7.609878
Ducker	25	246.2993	9.851974	3.398938
Newton	25	249.7245	9.988982	9.57703
Plains	25	272.9923	10.91969	9.361109
Sasser	25	263.9372	10.55749	11.44584
Shellman	25	300.1576	12.00631	19.75616
TyTy	25	273.1104	10.92442	10.63976

ANOVA

Source of Variation	*SS*	*df*	*MS*	*F*	*P-value*	*F crit*
Between Groups	521.3944	13	40.10727	4.320791	9.88E-07	1.74936
Within Groups	3118.883	336	9.28239			
Total	3640.278	349				

Table E.22 Soybeans: One-way Anova test using 10% irrigation strategies

IRR STRATEGY: 10%
Anova: Single Factor

SUMMARY

Groups	*Count*	*Sum*	*Average*	*Variance*
Albany	25	28.62206	1.144883	0.870963
Arabi	25	41.45672	1.658269	0.875148
Arlington	25	28.66143	1.146457	0.951228
Attapulgus	25	24.64568	0.985827	0.894544
Byromville	25	40.39372	1.615749	0.798831
Camilla	25	22.67718	0.907087	0.804385
Dawson	25	32.59844	1.303938	0.46853
Donalsonville	25	23.66143	0.946457	0.768735
Ducker	25	36.45671	1.458269	0.418305
Newton	25	31.57482	1.262993	1.102689
Plains	25	36.53545	1.461418	0.580001
Sasser	25	32.71655	1.308662	1.372953
Shellman	25	36.45671	1.458269	0.741223
TyTy	25	32.59844	1.303938	0.959365

ANOVA

Source of Variation	*SS*	*df*	*MS*	*F*	*P-value*	*F crit*
Between Groups	18.18397	13	1.398767	1.687163	0.062021	1.74936
Within Groups	278.5656	336	0.829064			
Total	296.7496	349				

Table E.23 Soybeans: One-way Anova test using 20% irrigation strategies

IRR STRATEGY: 20%
Anova: Single Factor

SUMMARY

Groups	*Count*	*Sum*	*Average*	*Variance*
Albany	25	76.18114	3.047246	1.028557
Arabi	25	90.86619	3.634648	3.10514
Arlington	25	72.83469	2.913387	3.735124
Attapulgus	25	47.12601	1.88504	1.230228
Byromville	25	98.93706	3.957482	1.768183
Camilla	25	62.6772	2.507088	1.475698
Dawson	25	74.44886	2.977954	0.857525
Donalsonville	25	52.67719	2.107088	1.432995
Ducker	25	74.44886	2.977954	1.356626
Newton	25	71.81106	2.872442	2.758812
Plains	25	83.58272	3.343309	1.636666
Sasser	25	86.33863	3.453545	4.081101
Shellman	25	89.0158	3.560632	2.860544
TyTy	25	87.12603	3.485041	2.87437

ANOVA

Source of Variation	*SS*	*df*	*MS*	*F*	*P-value*	*F crit*
Between Groups	111.6433	13	8.587944	3.980959	4.58E-06	1.74936
Within Groups	724.8377	336	2.157255			
Total	836.4809	349				

Table E.24 Soybeans: One-way Anova test using 30% irrigation strategies

IRR STRATEGY: 30%
Anova: Single Factor

SUMMARY

Groups	*Count*	*Sum*	*Average*	*Variance*
Albany	25	123.3465	4.933861	2.374829
Arabi	25	151.693	6.06772	7.472614
Arlington	25	120.1182	4.804727	5.833892
Attapulgus	25	82.67721	3.307088	3.047051
Byromville	25	158.5434	6.341736	4.314945
Camilla	25	106.8505	4.274018	3.141353
Dawson	25	128.6615	5.146459	2.811905
Donalsonville	25	96.73234	3.869293	3.207415
Ducker	25	119.4095	4.776381	1.79474
Newton	25	115.2757	4.611026	6.7135
Plains	25	130.2757	5.211026	4.028447
Sasser	25	135.4331	5.417326	6.983805
Shellman	25	155.315	6.212602	8.936553
TyTy	25	141.378	5.655121	5.679977

ANOVA

Source of Variation	*SS*	*df*	*MS*	*F*	*P-value*	*F crit*
Between Groups	249.1779	13	19.16753	4.044939	3.44E-06	1.74936
Within Groups	1592.185	336	4.738645			
Total	1841.362	349				

Table E.25 Soybeans: One-way Anova test using 40% irrigation strategies

IRR STRATEGY: 40%
Anova: Single Factor

SUMMARY

Groups	*Count*	*Sum*	*Average*	*Variance*
Albany	25	164.3308	6.573232	3.466131
Arabi	25	196.4568	7.858272	12.1058
Arlington	25	151.6536	6.066145	8.240978
Attapulgus	25	111.9686	4.478743	4.421296
Byromville	25	207.8348	8.31339	5.402888
Camilla	25	146.2206	5.848822	4.261361
Dawson	25	166.378	6.655122	2.873642
Donalsonville	25	135.5513	5.42205	3.909954
Ducker	25	165.2363	6.609452	2.106239
Newton	25	160.3938	6.415751	7.641327
Plains	25	174.2914	6.971657	6.497997
Sasser	25	171.693	6.86772	9.894207
Shellman	25	199.9607	7.99843	14.25974
TyTy	25	189.1733	7.566933	7.661286

ANOVA

Source of Variation	*SS*	*df*	*MS*	*F*	*P-value*	*F crit*
Between Groups	357.071	13	27.467	4.146282	2.18E-06	1.74936
Within Groups	2225.828	336	6.624489			
Total	2582.899	349				

Table E.26 Soybeans: One-way Anova test using 50% irrigation strategies

IRR STRATEGY: 50%
Anova: Single Factor

SUMMARY

Groups	*Count*	*Sum*	*Average*	*Variance*
Albany	25	196.8899	7.875595	4.468597
Arabi	25	235.5513	9.422052	18.12637
Arlington	25	181.4174	7.256697	8.036351
Attapulgus	25	146.9292	5.877169	4.618952
Byromville	25	240.945	9.6378	7.038443
Camilla	25	177.9135	7.116539	3.818602
Dawson	25	195.0788	7.803154	3.594978
Donalsonville	25	167.1654	6.686618	3.848104
Ducker	25	193.504	7.740162	2.416845
Newton	25	189.3702	7.574807	8.630168
Plains	25	211.0237	8.440949	8.674343
Sasser	25	207.6379	8.305516	11.82066
Shellman	25	232.5592	9.302367	15.57025
TyTy	25	220.8269	8.833076	8.948291

ANOVA

Source of Variation	*SS*	*df*	*MS*	*F*	*P-value*	*F crit*
Between Groups	381.2083	13	29.32372	3.745356	1.32E-05	1.74936
Within Groups	2630.663	336	7.829353			
Total	3011.871	349				

Table E.27 Soybeans: One-way Anova test using 60% irrigation strategies

IRR STRATEGY: 60%
Anova: Single Factor

SUMMARY

Groups	*Count*	*Sum*	*Average*	*Variance*
Albany	25	230.0395	9.20158	4.927016
Arabi	25	261.4962	10.45985	20.02913
Arlington	25	199.9214	7.996855	8.983611
Attapulgus	25	172.7954	6.911815	6.332555
Byromville	25	266.6931	10.66772	9.253332
Camilla	25	206.3387	8.253548	4.074818
Dawson	25	222.9922	8.91969	4.244311
Donalsonville	25	185.0788	7.403154	5.228486
Ducker	25	220.4332	8.817328	3.096842
Newton	25	218.7009	8.748036	10.09363
Plains	25	228.819	9.152761	10.09313
Sasser	25	226.9686	9.078745	11.74452
Shellman	25	256.0631	10.24253	21.10082
TyTy	25	248.1497	9.92599	10.70166

ANOVA

Source of Variation	*SS*	*df*	*MS*	*F*	*P-value*	*F crit*
Between Groups	398.9428	13	30.68791	3.307298	9.14E-05	1.74936
Within Groups	3117.692	336	9.278847			
Total	3516.635	349				

Table E.28 Soybeans: One-way Anova test using 70% irrigation strategies

IRR STRATEGY: 70%
Anova: Single Factor

SUMMARY

Groups	*Count*	*Sum*	*Average*	*Variance*
Albany	25	247.4804	9.899218	5.752078
Arabi	25	289.0946	11.56379	24.12576
Arlington	25	220.1182	8.804729	8.822095
Attapulgus	25	193.2678	7.730713	7.008977
Byromville	25	292.4411	11.69764	9.572742
Camilla	25	220.7088	8.828351	3.876598
Dawson	25	245.2364	9.809454	4.902624
Donalsonville	25	218.5041	8.740162	5.399312
Ducker	25	244.5671	9.782682	3.054946
Newton	25	240.0789	9.603155	10.28427
Plains	25	250.5513	10.02205	10.96281
Sasser	25	251.0238	10.04095	13.93951
Shellman	25	285.9057	11.43623	22.68666
TyTy	25	271.2206	10.84882	11.88932

ANOVA

Source of Variation	*SS*	*df*	*MS*	*F*	*P-value*	*F crit*
Between Groups	445.0201	13	34.23231	3.368429	6.99E-05	1.74936
Within Groups	3414.665	336	10.16269			
Total	3859.685	349				

Appendix F: Descriptive Statistics for DSSAT Data for each Year and Crop Type

Table F.1 Descriptive Statistics for Corn

Descriptive Statistics for Corn

Year	*Irrigation Strategy*	*Nbr. of observations*	*Minimum*	*Maximum*	*Median*	*Mean*	*Variance (n-1)*	*Standard deviation (n-1)*	*Lower bound on mean (95%)*	*Upper bound on mean (95%)*
2016	10%	98	0.000	2.992	0.000	0.432	0.423	0.650	0.302	0.563
	20%	98	0.000	5.472	1.811	1.823	1.812	1.346	1.553	2.093
	30%	98	0.827	7.480	4.134	4.013	3.083	1.756	3.661	4.365
	40%	98	1.457	9.291	6.063	5.815	3.373	1.836	5.447	6.183
	50%	98	2.795	10.551	7.402	6.988	3.344	1.829	6.622	7.355
	60%	98	3.110	11.654	8.268	8.055	3.202	1.789	7.696	8.414
	70%	98	4.685	12.362	9.626	9.186	3.572	1.890	8.807	9.565
2017	10%	98	0.000	0.984	0.000	0.050	0.047	0.218	0.007	0.094
	20%	98	0.000	1.811	0.000	0.490	0.459	0.678	0.354	0.626
	30%	98	0.000	4.173	0.827	1.323	1.458	1.207	1.080	1.565
	40%	98	0.000	5.984	2.205	2.456	2.669	1.634	2.128	2.783
	50%	98	0.630	6.811	2.717	3.378	2.824	1.680	3.041	3.715
	60%	98	0.591	8.465	3.839	4.078	3.195	1.787	3.720	4.436
	70%	98	1.929	9.409	5.039	5.253	3.445	1.856	4.881	5.625
2018	10%	98	0.000	1.969	0.000	0.261	0.211	0.459	0.169	0.353
	20%	98	0.000	2.756	0.000	0.527	0.475	0.689	0.389	0.666

	30%	98	0.000	4.134	0.827	1.182	1.344	1.159	0.949	1.414
	40%	98	0.000	5.276	2.205	2.190	1.469	1.212	1.947	2.433
	50%	98	0.630	6.024	3.268	3.106	1.478	1.216	2.863	3.350
	60%	98	1.142	6.339	3.622	3.750	1.714	1.309	3.488	4.013
	70%	98	1.457	7.677	4.626	4.663	1.792	1.339	4.394	4.931
2019	10%	98	0.000	2.008	0.984	0.613	0.372	0.610	0.491	0.736
	20%	98	0.000	3.661	1.358	1.443	0.999	0.999	1.243	1.643
	30%	98	0.000	6.654	2.894	2.988	2.503	1.582	2.671	3.305
	40%	98	0.748	7.874	4.528	4.532	3.031	1.741	4.183	4.881
	50%	98	1.339	9.685	6.161	5.805	3.163	1.778	5.448	6.161
	60%	98	2.283	10.276	6.752	6.630	2.747	1.657	6.298	6.963
	70%	98	3.701	11.496	7.854	7.821	3.140	1.772	7.466	8.177
2020	10%	98	0.000	2.008	0.000	0.433	0.383	0.619	0.309	0.557
	20%	98	0.000	4.528	0.906	1.250	1.081	1.040	1.042	1.459
	30%	98	0.827	5.039	2.480	2.552	1.100	1.049	2.342	2.762
	40%	98	0.748	7.008	3.839	3.825	1.332	1.154	3.594	4.056
	50%	98	2.638	7.677	4.862	4.877	1.151	1.073	4.662	5.093
	60%	98	3.504	8.701	5.886	5.908	1.462	1.209	5.666	6.150
	70%	98	4.606	9.567	6.890	6.871	1.434	1.197	6.631	7.111

Table F.2 Descriptive Statistics for Cotton

Descriptive Statistics for Cotton

Year	*Irrigation Strategy*	*Nbr. of observations*	*Minimum*	*Maximum*	*Median*	*Mean*	*Variance (n-1)*	*Standard deviation (n-1)*	*Lower bound on mean (95%)*	*Upper bound on mean (95%)*
2016	10%	70	0.000	4.961	1.969	1.881	1.009	1.004	1.642	2.121
	20%	70	0.906	9.134	5.020	4.809	2.904	1.704	4.402	5.215
	30%	70	1.654	12.835	7.618	7.414	6.576	2.564	6.803	8.025
	40%	70	3.740	15.079	8.622	9.015	8.149	2.855	8.335	9.696
	50%	70	5.354	16.299	10.295	10.466	8.162	2.857	9.784	11.147
	60%	70	5.945	18.268	11.024	11.287	8.759	2.960	10.582	11.993
	70%	70	6.693	19.606	12.067	12.474	9.918	3.149	11.723	13.225
2017	10%	70	0.000	2.992	0.984	1.400	0.734	0.857	1.196	1.605
	20%	70	0.906	6.417	2.756	3.115	2.401	1.550	2.745	3.484
	30%	70	0.866	9.173	4.606	4.574	3.753	1.937	4.112	5.036
	40%	70	2.205	10.039	5.413	5.352	3.657	1.912	4.896	5.808
	50%	70	1.969	10.906	6.161	6.268	3.831	1.957	5.801	6.734
	60%	70	3.543	11.732	7.402	7.215	3.261	1.806	6.785	7.646
	70%	70	4.488	11.535	8.602	8.176	3.218	1.794	7.748	8.604
2018	10%	70	0.000	2.992	0.984	0.805	0.750	0.866	0.599	1.012
	20%	70	0.000	4.567	1.811	1.682	1.497	1.223	1.390	1.973
	30%	70	0.000	6.693	2.520	2.963	2.413	1.553	2.592	3.333
	40%	70	0.709	7.598	3.465	3.717	2.901	1.703	3.310	4.123
	50%	70	2.008	8.976	4.370	4.767	2.982	1.727	4.355	5.179
	60%	70	2.953	9.449	5.394	5.697	2.433	1.560	5.325	6.069
	70%	70	3.976	9.961	6.280	6.429	2.181	1.477	6.077	6.781

	10%	70	0.000	4.016	0.984	1.541	1.306	1.143	1.269	1.814
	20%	70	0.906	6.417	3.622	3.455	2.158	1.469	3.105	3.805
	30%	70	1.614	10.000	5.827	5.726	3.512	1.874	5.279	6.172
2019	40%	70	2.992	10.669	6.949	7.052	3.807	1.951	6.587	7.518
	50%	70	3.976	12.283	8.150	8.139	3.948	1.987	7.665	8.613
	60%	70	5.748	12.953	9.154	9.299	3.355	1.832	8.862	9.736
	70%	70	6.535	13.858	10.039	10.268	3.749	1.936	9.807	10.730
	10%	70	0.000	2.992	0.984	1.087	0.633	0.795	0.897	1.276
	20%	70	0.906	5.551	2.756	3.223	1.280	1.131	2.954	3.493
	30%	70	1.693	7.638	4.606	4.794	1.887	1.374	4.467	5.122
2020	40%	70	3.071	8.819	5.945	5.983	2.069	1.438	5.640	6.326
	50%	70	4.213	9.882	7.028	7.082	1.854	1.362	6.757	7.407
	60%	70	4.291	10.276	7.874	7.695	2.105	1.451	7.349	8.041
	70%	70	5.197	11.299	8.622	8.591	2.219	1.490	8.235	8.946

Table F.3 Descriptive Statistics for Peanuts

Descriptive Statistics for Peanuts

Year	*Irrigation Strategy*	*Nbr. of observations*	*Minimum*	*Maximum*	*Median*	*Mean*	*Variance (n-1)*	*Standard deviation (n-1)*	*Lower bound on mean (95%)*	*Upper bound on mean (95%)*
2016	10%	70	0.000	3.976	0.984	0.987	0.964	0.982	0.752	1.221
	20%	70	0.906	8.150	3.622	3.812	2.434	1.560	3.440	4.184
	30%	70	2.480	12.520	6.713	7.159	5.981	2.446	6.576	7.742
	40%	70	3.740	15.669	9.823	9.641	7.687	2.773	8.980	10.302
	50%	70	6.260	17.008	11.732	11.569	8.584	2.930	10.870	12.267
	60%	70	7.362	18.583	12.520	12.838	9.056	3.009	12.120	13.556
	70%	70	8.346	21.102	13.740	14.324	10.858	3.295	13.538	15.110
2017	10%	70	0.000	2.008	0.000	0.493	0.332	0.576	0.355	0.630
	20%	70	0.000	4.528	1.811	1.630	0.942	0.971	1.398	1.861
	30%	70	0.827	7.402	3.307	3.567	2.602	1.613	3.182	3.952
	40%	70	2.244	9.764	5.157	5.173	2.596	1.611	4.789	5.557
	50%	70	3.346	9.921	6.417	6.399	2.633	1.623	6.012	6.786
	60%	70	3.465	11.339	7.835	7.488	3.069	1.752	7.070	7.905
	70%	70	5.118	11.732	9.232	8.656	2.860	1.691	8.253	9.060
2018	10%	70	0.000	1.969	0.000	0.394	0.376	0.613	0.247	0.540
	20%	70	0.000	3.661	0.906	1.257	1.059	1.029	1.012	1.502
	30%	70	0.827	5.827	2.480	2.720	1.500	1.225	2.428	3.012
	40%	70	1.457	6.929	3.799	4.169	2.386	1.545	3.800	4.537
	50%	70	3.307	10.039	5.374	5.573	2.416	1.554	5.202	5.944
	60%	70	4.134	10.315	6.024	6.339	2.287	1.512	5.979	6.700
	70%	70	4.685	10.866	6.949	7.228	2.286	1.512	6.868	7.589

	10%	70	0.000	1.969	0.984	0.633	0.310	0.557	0.500	0.765
	20%	70	0.906	4.528	2.717	2.408	0.904	0.951	2.181	2.634
	30%	70	2.441	8.307	4.980	5.172	2.496	1.580	4.795	5.548
2019	40%	70	3.740	11.339	7.520	7.328	2.840	1.685	6.926	7.730
	50%	70	5.276	13.425	8.917	8.912	3.838	1.959	8.445	9.379
	60%	70	6.535	14.646	10.413	10.544	3.258	1.805	10.114	10.975
	70%	70	8.071	16.299	11.220	11.607	3.974	1.994	11.132	12.083
	10%	70	0.000	1.969	0.000	0.478	0.302	0.549	0.347	0.609
	20%	70	0.000	5.472	2.717	2.812	1.206	1.098	2.550	3.074
	30%	70	2.480	7.480	4.961	4.794	1.636	1.279	4.489	5.099
2020	40%	70	3.740	9.213	6.772	6.552	1.944	1.394	6.219	6.884
	50%	70	4.685	10.551	7.992	7.878	2.019	1.421	7.539	8.217
	60%	70	6.339	11.732	8.740	8.891	1.832	1.354	8.568	9.214
	70%	70	6.457	12.480	9.823	9.782	2.035	1.427	9.442	10.123

Table F.4 Descriptive Statistics for Soybeans

Descriptive Statistics for Soybeans

Year	*Irrigation Strategy*	*Nbr. of observations*	*Minimum*	*Maximum*	*Median*	*Mean*	*Variance (n-1)*	*Standard deviation (n-1)*	*Lower bound on mean (95%)*	*Upper bound on mean (95%)*
	10%	70	0.000	2.992	1.969	1.677	0.462	0.680	1.514	1.839
	20%	70	0.906	8.150	4.094	4.098	2.409	1.552	3.728	4.469
	30%	70	2.480	13.425	6.673	7.071	5.748	2.397	6.499	7.643
2016	40%	70	2.992	17.165	9.094	9.299	8.236	2.870	8.614	9.983
	50%	70	4.685	19.843	10.512	11.023	9.925	3.150	10.271	11.774
	60%	70	6.378	20.709	12.165	12.352	10.798	3.286	11.569	13.136
	70%	70	6.535	23.228	13.051	13.501	12.418	3.524	12.661	14.341
	10%	70	0.000	2.992	1.969	1.425	0.616	0.785	1.237	1.612
	20%	70	0.000	6.378	3.169	3.115	2.158	1.469	2.764	3.465
	30%	70	0.000	9.173	4.961	4.840	3.507	1.873	4.394	5.287
2017	40%	70	0.000	9.882	6.043	6.092	4.404	2.099	5.592	6.593
	50%	70	0.000	11.614	7.402	7.242	4.504	2.122	6.736	7.748
	60%	70	0.000	12.283	8.484	7.943	5.193	2.279	7.399	8.486
	70%	70	0.000	12.480	9.528	8.841	5.761	2.400	8.269	9.413
	10%	70	0.000	1.969	0.984	0.759	0.370	0.608	0.614	0.904
	20%	70	0.000	4.528	1.811	2.007	1.047	1.023	1.763	2.251
	30%	70	1.614	7.402	3.307	3.429	1.841	1.357	3.106	3.753
2018	40%	70	1.457	7.717	4.567	4.603	2.478	1.574	4.228	4.979
	50%	70	2.638	10.827	5.551	5.742	3.245	1.801	5.313	6.172
	60%	70	3.425	11.614	6.791	6.764	3.085	1.756	6.345	7.183
	70%	70	4.016	12.126	7.421	7.545	3.032	1.741	7.130	7.960

	10%	70	0.984	3.937	1.969	2.203	0.376	0.613	2.057	2.349
	20%	70	1.811	5.472	4.094	4.091	0.864	0.930	3.869	4.313
	30%	70	3.307	9.961	6.594	6.504	1.673	1.293	6.196	6.812
2019	40%	70	5.197	13.032	8.366	8.326	2.303	1.517	7.964	8.688
	50%	70	6.102	14.882	9.488	9.583	2.682	1.638	9.192	9.973
	60%	70	7.323	16.457	10.787	10.811	3.395	1.843	10.372	11.250
	70%	70	8.032	17.598	11.614	11.657	3.581	1.892	11.206	12.109
	10%	70	0.000	1.969	0.000	0.352	0.282	0.531	0.225	0.478
	20%	70	0.000	4.567	1.811	1.947	1.087	1.043	1.698	2.195
	30%	70	0.000	6.614	3.307	3.380	2.091	1.446	3.035	3.725
2020	40%	70	0.000	9.213	5.236	5.124	3.128	1.769	4.703	5.546
	50%	70	0.000	9.843	6.201	6.365	3.019	1.738	5.951	6.779
	60%	70	0.000	10.591	7.028	7.052	3.711	1.926	6.592	7.511
	70%	70	0.000	11.772	8.150	8.030	4.544	2.132	7.522	8.538

Appendix G: Two-Way Anova Test with Replication for DSSAT data between irrigation strategies and year

Table G.1 Two-way Anova results for Corn

Anova: Two-Factor With Replication

SUMMARY	10	20	30	40	50	60	70	Total
2016								
Count	98	98	98	98	98	98	98	686
Sum	42.36223	178.6221	393.3073	569.8428	684.8429	789.4099	900.1973	3558.585
Average	0.432268	1.822675	4.01334	5.814723	6.988193	8.055203	9.185687	5.187441
Variance	0.422847	1.811531	3.082938	3.372632	3.343544	3.202206	3.571582	11.69897
2017								
Count	98	98	98	98	98	98	98	686
Sum	4.921263	47.99215	129.6064	240.6694	331.0632	399.6459	514.7641	1668.662
Average	0.050217	0.489716	1.322514	2.45581	3.378196	4.078019	5.252694	2.432452
Variance	0.047388	0.459315	1.457606	2.668901	2.82381	3.194541	3.444811	5.177604
2018								
Count	98	98	98	98	98	98	98	686
Sum	25.59057	51.69294	115.7875	214.6458	304.4096	367.5199	456.9294	1536.576
Average	0.261128	0.527479	1.181505	2.190263	3.106221	3.750203	4.662545	2.239906
Variance	0.210749	0.474932	1.343566	1.468522	1.477761	1.714028	1.792381	3.614799

2019								
Count	98	98	98	98	98	98	98	686
Sum	60.11814	141.4174	292.7954	444.1735	568.8586	649.7641	766.4965	2923.624
Average	0.61345	1.443035	2.987709	4.532382	5.804679	6.630246	7.821393	4.261842
Variance	0.372063	0.998909	2.50295	3.030795	3.162843	2.746507	3.140084	8.498744

2020								
Count	98	98	98	98	98	98	98	686
Sum	42.4016	122.5198	250.0789	374.8427	477.9924	578.9767	673.3468	2520.159
Average	0.432669	1.250202	2.551825	3.824926	4.877473	5.907925	6.870886	3.673701
Variance	0.383362	1.080819	1.099684	1.331545	1.151059	1.462048	1.433969	6.034993

Total							
Count	490	490	490	490	490	490	490
Sum	175.3938	542.2444	1181.575	1844.174	2367.167	2785.316	3311.734
Average	0.357947	1.106621	2.411378	3.763621	4.830952	5.684319	6.758641
Variance	0.321098	1.230264	3.007401	4.156251	4.51445	5.026357	5.39909

ANOVA

Source of Variation	*SS*	*df*	*MS*	*F*	*P-value*	*F crit*
Sample	4231.304	4	1057.826	567.1361	0	2.37455
Columns	16656.26	6	2776.043	1488.33	0	2.101255
Interaction	1003.571	24	41.81544	22.41866	1.01E-90	1.520514
Within	6332.376	3395	1.865207			
Total	28223.51	3429				

Table G.2 Two-way Anova results for Cotton

Anova: Two-Factor With Replication

SUMMARY	10	20	30	40	50	60	70	Total
2016								
Count	70	70	70	70	70	70	70	490
Sum	131.693	336.6144	518.9767	631.0633	732.5988	790.1185	873.1894	4014.254
Average	1.881328	4.808777	7.413952	9.01519	10.4657	11.28741	12.47413	8.192355
Variance	1.008666	2.904497	6.575908	8.149408	8.162414	8.759475	9.917633	18.67669
2017								
Count	70	70	70	70	70	70	70	490
Sum	98.03155	218.0316	320.1577	374.6459	438.7404	505.079	572.3231	2527.009
Average	1.400451	3.114737	4.573681	5.352084	6.26772	7.215414	8.176045	5.157162
Variance	0.733829	2.401454	3.752762	3.656658	3.831145	3.260578	3.218157	7.701844
2018								
Count	70	70	70	70	70	70	70	490
Sum	56.37798	117.7166	207.4017	260.1576	333.701	398.8191	450.0396	1824.214
Average	0.8054	1.681666	2.962881	3.716537	4.767157	5.697416	6.429137	3.722885
Variance	0.750008	1.496907	2.412917	2.900908	2.981659	2.433424	2.181164	5.798903
2019								
Count	70	70	70	70	70	70	70	490
Sum	107.8741	241.8505	400.7876	493.6617	569.7247	650.9452	718.7799	3183.624
Average	1.541058	3.455007	5.725537	7.05231	8.138925	9.299218	10.26828	6.497191
Variance	1.30606	2.158345	3.512426	3.807033	3.947836	3.354731	3.749273	11.59699

2020								
Count	70	70	70	70	70	70	70	490
Sum	76.06303	225.63	335.5907	418.8191	495.7483	538.6223	601.3389	2691.812
Average	1.086615	3.223286	4.794153	5.98313	7.082119	7.694605	8.590556	5.493495
Variance	0.632555	1.280031	1.887105	2.068828	1.85401	2.105205	2.218735	7.749821

Total							
Count	350	350	350	350	350	350	350
Sum	470.0396	1139.843	1782.914	2178.348	2570.513	2883.584	3215.671
Average	1.34297	3.256695	5.094041	6.22385	7.344323	8.238812	9.187632
Variance	1.013875	3.017662	5.729427	7.194809	7.767037	7.591596	8.411815

ANOVA

Source of Variation	*SS*	*df*	*MS*	*F*	*P-value*	*F crit*
Sample	5404.817	4	1351.204	409.911	9.1E-270	2.375613
Columns	16386.73	6	2731.121	828.5324	0	2.102334
Interaction	847.984	24	35.33267	10.71877	1.25E-38	1.521821
Within	7960.65	2415	3.296336			
Total	30600.18	2449				

Table G.3 Two-way Anova results for Peanuts

Anova: Two-Factor With Replication

SUMMARY	10	20	30	40	50	60	70	Total
2016								
Count	70	70	70	70	70	70	70	490
Sum	69.05516	266.8505	501.142	674.8823	809.8036	898.6619	1002.678	4223.073
Average	0.986502	3.812151	7.159171	9.641175	11.56862	12.83803	14.32397	8.618517
Variance	0.963783	2.434405	5.98125	7.68679	8.584269	9.055611	10.85807	26.98323
2017								
Count	70	70	70	70	70	70	70	490
Sum	34.48821	114.0945	249.6852	362.1262	447.9136	524.1341	605.9452	2338.387
Average	0.492689	1.629922	3.566931	5.173231	6.398766	7.487631	8.65636	4.772219
Variance	0.331645	0.942241	2.60169	2.596074	2.632974	3.068528	2.860227	9.981259
2018								
Count	70	70	70	70	70	70	70	490
Sum	27.55907	87.99217	190.3938	291.8112	390.1183	443.7404	505.9845	1937.599
Average	0.393701	1.257031	2.719911	4.168731	5.573119	6.339149	7.22835	3.954285
Variance	0.376269	1.059454	1.499944	2.386448	2.416374	2.28729	2.285938	7.541983
2019								
Count	70	70	70	70	70	70	70	490
Sum	44.29136	168.5434	362.0081	512.953	623.8586	738.1106	812.5201	3262.285
Average	0.632734	2.407763	5.171544	7.3279	8.912266	10.54444	11.60743	6.657725
Variance	0.309881	0.903659	2.496498	2.84001	3.837909	3.257749	3.974436	17.04594

2020								
Count	70	70	70	70	70	70	70	490
Sum	33.46459	196.8505	335.5907	458.6223	551.457	622.3625	684.7641	2883.112
Average	0.478066	2.81215	4.794153	6.551747	7.877957	8.890893	9.782345	5.883902
Variance	0.301657	1.205615	1.635914	1.943548	2.018697	1.832059	2.035481	11.35526

Total							
Count	350	350	350	350	350	350	350
Sum	208.8584	834.3312	1638.82	2300.395	2823.151	3227.01	3611.892
Average	0.596738	2.383803	4.682342	6.572557	8.066146	9.220027	10.31969
Variance	0.495408	2.108836	5.11341	7.005501	8.268787	9.121185	10.43059

ANOVA

Source of Variation	*SS*	*df*	*MS*	*F*	*P-value*	*F crit*
Sample	6366.344	4	1591.586	548.8098	0	2.375613
Columns	27170.44	6	4528.406	1561.483	0	2.102334
Interaction	1477.75	24	61.5729	21.23154	3.98E-83	1.521821
Within	7003.665	2415	2.900068			
Total	42018.2	2449				

Table G.4 Two-way Anova results for Soybeans

Anova: Two-Factor With Replication

SUMMARY	10	20	30	40	50	60	70	Total
2016								
Count	70	70	70	70	70	70	70	490
Sum	117.3623	286.8899	494.9609	650.9059	771.5752	864.6461	945.0793	4131.42
Average	1.676604	4.098427	7.07087	9.298655	11.0225	12.35209	13.50113	8.431468
Variance	0.462373	2.409433	5.74784	8.235705	9.924747	10.79831	12.41816	23.48725
2017								
Count	70	70	70	70	70	70	70	490
Sum	99.72446	218.0316	338.8191	426.4569	506.9294	555.9846	618.8586	2764.805
Average	1.424635	3.114737	4.840273	6.092242	7.241849	7.942636	8.840837	5.642458
Variance	0.616061	2.15844	3.507274	4.403707	4.504399	5.193131	5.760925	9.859287
2018								
Count	70	70	70	70	70	70	70	490
Sum	53.14963	140.5119	240.0395	322.2443	401.9687	473.4648	528.1499	2159.529
Average	0.75928	2.007313	3.429136	4.60349	5.74241	6.763783	7.544998	4.407201
Variance	0.369851	1.046522	1.841412	2.478	3.245318	3.084896	3.031811	7.461813
2019								
Count	70	70	70	70	70	70	70	490
Sum	154.2127	286.3781	455.2758	582.835	670.7878	756.7721	816.0241	3722.285
Average	2.203038	4.091116	6.503941	8.326214	9.582682	10.81103	11.65749	7.596501
Variance	0.375885	0.864082	1.673134	2.302532	2.682155	3.395382	3.581147	12.6737

2020								
Count	70	70	70	70	70	70	70	490
Sum	24.60631	136.2599	236.6143	358.701	445.5514	493.6223	562.0869	2257.442
Average	0.351519	1.94657	3.380204	5.1243	6.36502	7.051747	8.029813	4.607025
Variance	0.281801	1.087278	2.090677	3.127624	3.019397	3.710511	4.544139	9.354659

Total							
Count	350	350	350	350	350	350	350
Sum	449.0554	1068.071	1765.71	2341.143	2796.813	3144.49	3470.199
Average	1.283015	3.051633	5.044885	6.68898	7.990893	8.984257	9.914853
Variance	0.850285	2.396793	5.27611	7.400858	8.630003	10.07632	11.05927

ANOVA

Source of Variation	*SS*	*df*	*MS*	*F*	*P-value*	*F crit*
Sample	6356.44	4	1589.11	448.633	2.1E-289	2.375613
Columns	21137.91	6	3522.985	994.599	0	2.102334
Interaction	1035.034	24	43.12641	12.17532	6.68E-45	1.521821
Within	8554.21	2415	3.542116			
Total	37083.59	2449				