Population and Environment in the U.S. Great Plains

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Introduction

In the known histories of the impact of human intervention on the landscape, that of the Great Plains of the United States is among the most frequently described. The striking episodes of the 1930s, when clouds of dust rose off the recently-plowed land to catch the attention of media and politicians as far away as Washington, D.C., permanently focused attention on the ways that human interaction with environmental conditions and environmental change could have consequences for both people and the environment (Worster 1979; Hurt, 1981; Gutmann and Cunfer 1999; Cunfer 2002).

The Great Plains of North America are a large environmental region spanning the area from where the Midwest Savannah and southern pine forests end to the front range of the Rocky Mountains (east to west), and from northern Canada to Central Texas (north to south) (Riebsame 1990). The climate of the Great Plains is one where winters are the dry season and summers the wet. It is shaped by three air masses, each leading to its own seasonal dynamics. A Pacific air mass originating in the Gulf of Alaska is dominant in the winter, its air dried by crossing several mountain ranges. An additional polar air mass also shapes winter weather, creating a strong north-south gradient in air temperature and snow cover. In summer, the westerly flow weakens and polar air retreats to the north, allowing an air mass that comes from the subtropical Atlantic Ocean to bring moisture into the region.

The distribution of both natural ecosystems and land use management is controlled in large part by the two major climatic gradients: an east-west gradient of increasing precipitation and a north-south gradient of increasing temperature (Fig. 1). Mean annual precipitation ranges from more than 1200 mm/y to less than 300 mm/yr, and mean annual temperature from less than 0^{o} C to greater than 20^{o} C. Plant species composition varies from tallgrass prairie to shortgrass steppe, with decreasing precipitation. In addition to influencing ecosystem type, these gradients have large influences on net primary production and soil organic carbon. (Sala et al. 1988; Burke et al. 1989).

There is a conventional story-telling of the development of the Great Plains.[2] Originally lightly settled by native people, the region was colonized by the European-origin population of the United States in the decades following the Civil War (Powell 1878; Webb 1931). This settlement was encouraged by the institutional context of the United States in the nineteenth century, in which a combination of economic, social, and political processes combined to make land and transportation available for individuals and families who thought that they might benefit from moving west out of more densely populated parts of the country (Opie 1987). These settlers discovered a semi-arid grassland landscape with agricultural possibilities that ranged from consistent arable cropping in the east to limited cropping and steady pasturing in the west. Despite the role of aridity in delaying settlement, demographic pressure in the more eastern U.S. pushed people west. With what seemed like good years of rainfall, and with increasing agricultural prices in the 1910s and 1920s, an aggressive stream of would-be farmers and ranchers acquired land and attempted to farm it (Gutmann and Sample 1995; Worster 1992). In this conventional history, the plow-up of the grasslands for wheat, combined with the drought of the 1930s, provoked disastrous dust storms and social dislocation. While we might not agree that those were the only causes, or that the greatest areas of wheat farming suffered the worst drought and dust storms, there was a causal relationship. Plowed land is a much greater source of blowing dust than uncultivated grassland.

Despite the social and economic disruptions of the 1930s, land use changed little as a result of the Dust Bowl. Acreage planted in crops dipped during the worst of the 1930s drought, but by 1945 had recovered fully to pre-drought levels. The balance between cropland and pasture remained virtually stable from the 1920s through 1990s in most plains counties (Cunfer 2005). People responded to the problems of the 1930s by changing some of their cultivation practices (Hargreaves 1992). Some of them migrated out of the region, although there may have been less out-migration during the drought of the 1930s than during the drought of the 1950s, when post-war economic development in the U.S. provided places to go (Gutmann, Deane and Lauster 2002). Those who remained changed their farming practices between the 1930s and 1970s, by introducing techniques that reduced the risk of dust and made better use of soil moisture, and by increasing the use of irrigation where groundwater was available (Green 1973). Improved agricultural practices and its shorter duration made the drought of the 1950s less severe for the land, but the adoption of more intense irrigation since the 1940s has led to groundwater depletion and other land-use changes that provoked further damage by the 1980s. The Ogallala aquifer has been the largest source of groundwater for irrigation, and it has suffered steady declines in level since the 1970s and 1980s (Opie 1993; Riebsame 1991; Cunfer 2005).

Whether consistently provoked by environmental conditions or spurred by broader social change, the Great Plains region has experienced significant demographic changes since its colonization by people of European descent beginning in the mid-nineteenth century. The region has grown in population overall, but that growth masks two defining population patterns within the region. In the first pattern, most of the long-term growth occurred in a small number of metropolitan areas, led by Denver, Colorado, and since the 1960s in those counties closest to the front range of the Rocky Mountains, spurred by the growth of recreational industries and by industrial development that has taken place in the same areas in order to provide an attractive lifestyle to residents. The second pattern of demographic change generally characterizes rural areas, where population grew with settlement until the 1930s and has generally declined since. While the story is more complex than that told by the media to general audiences, the overall pattern since the 1930s in rural areas has been one of a declining and aging population, with less and less agricultural employment and growing poverty.[3]

This history of land use and demographic transformation in a context of environmental change animates our study of population and environment in the Great Plains of the United States. In quite obvious ways population change has acted through land use to influence the environment. Conversely, environmental conditions have influenced demographic change. Yet all this has taken place over more than a century of rapid economic and social change in the United States. The challenge is to measure changes in population, land use and environment, *and* to disentangle their impacts from the underlying social changes that would have happened anyway. Our approach is to raise as broad a range of demographic and environmental questions as possible, and to use our broadly interdisciplinary research team to answer as many of them as we can.

Conceptualizing the Connections and Thinking about the Data

This project has three main research components, and in this paper we will emphasize two of them. Those three components are:

- an analysis of county-scale processes based on historical population, land use, environmental and other data;
- a series of historical studies of individual localities, of the experiences of farmers and their families, and of agricultural practices throughout the region; and
- interviews of about 180 farm families in six different parts of the region.

This paper is primarily about the first component, with some information from the second and only brief references to the third.

The Great Plains region (see Figure 1) as we define it covers much of ten states of the United States, comprising nearly one in seven U.S. counties. From the outset our goal has been to represent a large portion of that region, and our strategy has been to make use of readily available aggregate data about the counties in order to make large-scale analysis possible. In doing so, we recognize that we are unable to analyze the behavior and experiences of individual persons, families, farms, or environmental settings. Our points of reference are the experiences of counties rather than those people, farms, livestock, or crops.

This emphasis on county-scale processes is straightforward and has determined how we conceptualize the connections between population, land use, and environment. We have systematically asked how demographic, land use, and environmental processes interact when measured at the scale of the county. Much of our analysis thus far has been about the correlations (and hopefully causalities) that link one kind of county characteristics to another. Do more people -- or different kinds of people -- lead to different kinds of land use? What has been the role of environmental conditions relative to population in determining land use? How have variations in environment (for example, drought), correlated with changes in population (for example emigration)? The data that are available to us are much better at measuring land use, population, and the complex connections of weather and climate than they are at measuring environmental conditions that might be changed by human action. For those, such as soil conditions, we have chosen to use modeled estimates of soil chemistry linked to the historical land use experience.

We believe that our approach is thoroughly interdisciplinary, but still anchored in disciplinary strengths (Riebsame et al 1994). The interdisciplinary team that we assembled has a core of historians, ecologists, and sociologists, but also includes individuals from geography and anthropology. As we venture further into the impact of humans on the environment through land use change, we build on the cross-disciplinary tools that enable a historian's deep knowledge of the past and the agricultural practices of the last century to inform the ecosystem modeler's task of model specification.

Data, Design, and Statistical Techniques.

While we have made use of many varieties of data for this project, our primary sources of data have been drawn from county tabulations of information collected as part of the U.S. Censuses of Population and Agriculture, with additional data from the Census of Housing and the economic censuses. We have collected those data for the decennial population censuses from 1880 through 2000, and for the agricultural censuses (which are decennial until 1920 and then more frequent thereafter) from 1880 through 1997.[4] In addition to census-based sources, we have collected other county-level tabulations of social characteristics. We use the population and social indicators data to understand population structure and change, and the agricultural census data to understand agricultural land use. Their consistency and the effectiveness and long-term quality of the U.S. Census products have made this part of our project relatively straightforward. Some of these data -- especially the most recent -- were available to us in digital form, while many others we collected in print form and then hand-keyed into our database. All of these data are described in Gutmann et al (1998). In the five years since that document was published, we have added data from recent censuses (1997 Agriculture and 2000 Population), but generally maintained the content and structure of the data. Although our study area is not coterminous with the ten states, we have generally collected data that covered the entire area of the ten Great Plains states, and often neighboring states. We have begun adding data from Iowa and Minnesota, which have a few counties that are environmentally similar to those of neighboring states that we have included in our study area.

While the basic data about population size and structure have stayed the same over the roughly120-year time period that we are studying, we are well aware of the changes that have occurred in the tabulated record during such a long time. On the population side, only in 1910 and since 1980 are good data on ethnicity available, and even then the measurement varies. Moreover, no five year age categories were tabulated from 1880 through 1920, with substantial but incomplete improvement in 1930; we corrected this by interpolating the ages using statewide data. On the agricultural side, the definition of major categories of farmland into cropland, pasture, and other types changed significantly in the 1920s, and the yields of irrigated crops have always been difficult to estimate. One of the challenges of our research has been to find ways to overcome these limitations.

Environmental data have not been as easy to acquire as those about land use and population, merely because they are not normally tabulated at the scale of the county (Gutmann 2000). Our main goal has been to have data about temperature and precipitation at reasonable intervals of time and space. We have done this by taking the century-long series of data from the VEMAP Project (http://www.cgd.ucar.edu/vemap/) and interpolating them to historical county boundaries. We have also acquired recent soil structure and elevation data, as well as data giving locations of bodies of water and streams, and interpolated them to historical county boundaries in order to have information about soil texture for some of our analyses. Finally, we have acquired selected other weather data (dust storms, for example), where we could find them and made use of those data in some of our analyses (see Gutmann and Cunfer 1999, and Deane and Gutmann 2003).

No single method has worked in all our analyses. Some of what we have done is descriptive, based on examining tabular and graphical series of results that display change over time or variation through space. On the other hand, we have consistently attempted to make use of statistical approaches that are appropriate for the data and the hypotheses involved. One challenge has been to take account of the role of time and space in our analysis, with appropriate study of temporal and spatial autocorrelation. We often analyze our data in a Geographical Information Systems (GIS) environment in order to integrate both spatial and temporal variation. We have also pursued innovative ideas in the role of causality in Deane and Gutmann (2003). One of our most important goals has been to integrate what we can learn from the historical data about population and land use with the most advanced ecosystem modeling techniques. We have just begun to publish those results (Parton et al 2004), which make use of techniques drawn from ecosystem modeling, supported by good old-fashioned historical research about cropping practices and data quality.

Major Findings

This project has produced a number of published and unpublished reports about findings, a large proportion of which deal with demographic consequences of environmental conditions or environmental change, or with the impact on the region or the U.S. as a whole of changing social and demographic conditions. This paper has as its goal another subject, the environmental impacts of demographic change.

In writing about our major findings, we begin with the broadest view of what we have learned about the impact of population on environment over the last one hundred years, and then turn to two additional questions. From this wide angle view, we show that a growing European-origin population has massively changed the environment of about a third of the Great Plains region, both through the replacement of open grasslands with fenced and heavily managed croplands, and through the creation of significant areas of urban and suburban development. While we cannot always directly measure *environmental* outcomes, this analysis, based largely on land use change, is dramatic. The other two thirds of the Great Plains, used primarily for extensive livestock grazing, has seen only limited environmental change, as cattle mimicked the ecological impacts of the native bison they replaced.

The next point we raise in our summary of findings deals with the complexities of gauging the relative importance of population versus the environment in the shaping of land use decisions. We note a paradox in our conclusion that population change has shaped the environment through land use change by defining ways that the environment limits human action. Humans can decide to plant crops, for example, but they will not succeed in raising crops in most of the Great Plains.

Our final discussion will show the progress we have made in finding new ways to measure the environmental impact of population on the environment of the Great Plains. In our most recent research we have run the Century Ecosystem model with appropriate parameters based on historical land uses in a small number of Great Plains counties. The results of these model runs allow us to begin the process of estimating historical and current soil composition and greenhouse gas scenarios for the region.

How Population Changed the Great Plains

The Great Plains, by our definition, consists of approximately 390 million acres of land. In 1880, U.S. farmers reported that they had about nineteen million of those acres in farms (see Figure 3) . By 1910 they had ten times as much, and by 1930 they reported 288 million acres of farms, nearly three-fourths of the region's land area. At its peak in 1959, nearly eight out of every nine acres of land in the region was reportedly in a farm. For census purposes, pasture and ranch land is included in farmland, so a considerable majority of this farmland was not plowed. The conversion of native grassland to cropland happened somewhat later. Although farmers began plowing out sod in the 1870s, it was a Herculean effort, and as late as 1900 only 8 percent of the region, some 31 million acres, were used for crops. Most of the plow-up of the Great Plains happened in the first three decades of the twentieth century, when farmers brought about 88 million addtional acres into crop production, peaking at 31 percent of total land area in 1935 (Cunfer 2005).

The demographic change that accompanied the change in land use is just as dramatic. The region experienced steady population growth as land use changed through 1930, followed by a rapid transformation from overall population growth to urban population growth. As is widely reported, the region's rural population has been shrinking since the 1930s, in some decades quite rapidly. We follow the U.S. Census Bureau's definition of an urban place as one having a population of 2,500 inhabitants, a relatively low threshold that moves small towns with populations over 2,500 into the "urban" category.

The comparisons between population and land use trends displayed in Figure 3 show that the growth in farmland generally increased with overall population size, but continued to increase long after the rural population stopped growing in 1930. Cropland, however, stopped increasing after 1940, only a decade after the peak rural population. Put another way, the link between rural population change and land use change that led to conversion to cropland was tighter than that between rural population and overall conversion of land to farm uses, or between the overall population change and either farmland or cropland conversions. However, the reverse process was not true. As rural population declined after 1930 the amount of land in crops remained stable. Depopulation did not equate to land abandonment in the second half of the twentieth century, as remaining farmers continued to plant acreage relinquished by emigrant neighbors.

Figure 3 shows that most of the direct impact of rural population change on land use and consequently on the environment took place during the era of rapid settlement from 1880 through 1930, and then diminished. This is true in other areas as well (Moran, this volume). Yet the demographic impact on an agricultural region such as the U.S. Great Plains isn't limited to the direct results of local population change. The environmental changes are as much the result of large-scale changes in the market for agricultural products (driven by populations and tastes elsewhere) as they are the result of local or regional population change (Cronon 1991). Local demographic change is usually the symptom that spurs immediate changes in land use, for example because one needs farmers to make the change from native grassland to crops. That's what we can measure. We can also measure the role of local population changes in the conversion of land from agricultural to urban and suburban uses. This is a topic not dealt with directly in this paper, but on our research agenda for the future.

Not all the conversion to farmland produced dramatic change in land character with environmental consequences. The amount of cropland reported, however, is a strong indication of the intensity of environmental change that took place in the Great Plains between 1880 and 1992. At its peak in the late 1930s between 31 and 38 percent of the total land in the region had been converted from native grassland to cropland.[5] The geographical distribution of that cropland varies from sub-region to sub-region because the eastern Great Plains has more rainfall than the west, and is better suited for cropping. Figure 4 shows the growth of total area cropped in the Great Plains from 1880 through 1992, dividing the region into an eastern tier of states (North Dakota, South Dakota, Nebraska, Kansas, Oklahoma, and Texas), and a western tier of states (Montana, Wyoming, Colorado, and New Mexico). Figure 5 shows the spatial distribution of cropping in the Great Plains in 1930; a few counties in the east had as much as three-fourths of their land in cropland, while those in the west had ten percent or less. While not displayed in the figures, there was also a significant increase in the amount of land that is irrigated in small parts of the Great Plains, reaching a peak over seventeen million acres in the late 1970s. While this represents only about 4 percent of the entire Great Plains, the increase in irrigation has had environmental consequences of local importance.

The conversion from native grassland to cropland and other farm uses is as dramatic over the long term as that reported by others in this volume (Moran; Seto; Walsh) for regions -- such as the Amazon -- where deforestation and other kinds of land use conversion has taken place.

While it can be difficult to measure the environmental consequences of this change at the large scale that we have chosen to study, we know in general terms what happens when native grasses are plowed and replaced with crops:

- soil texture changes and topsoil may be lost to wind and water erosion;
- carbon, nitrogen, and other minerals change composition as plowing and cropping alter soil chemistry;
- natural processes related to fire are suppressed;
- hydrological systems are disrupted or altered
- species diversity diminishes as introduced crop species replace native plants; and
- wildlife distribution patterns change as farmers replace habitat and build roads, fences, and other barriers to migration.

In the two-thirds of the grassland that farmers could not successfully plow for crops environmental change has been much less dramatic. While nearly all of that land has been used for extensive grazing by cattle, and in much smaller proportions by sheep and horses, most of it remains in native vegetative cover. Grazing livestock can have the following environmental impacts on grasslands:

- interference with wildlife, especially competing large grazers (bison, pronghorn) and predators (wolves, grizzly bears);

- changes in plant diversity, species composition, and ground cover, especially increases in invasive species; and
- disruption of riparian and aquatic habitats along rivers and streams.

Yet unlike with cropping, grazing has little impact on soil texture and depth, or on carbon and nitrogen systems, and is much less disruptive of plant and animal biodiversity (Lauenroth et al. 1994; Cunfer 2005). Whereas nearly all forest ecosystems in the continental U.S. have been logged in the past 400 years, some two-thirds of the Great Plains remains in unplowed native vegetation.

These consequences are by no means all that has happened to the environment of the Great Plains as a consequence of the region's growing population and its long-term conversion from native grassland to cropland, managed rangeland, and later urban and suburban development. While we have only partially quantified them, their impact is important and they constitute the starting point for our understanding.

The Paradox of Population and Environment

The message in the previous section is clear: the change in population that took place in the Great Plains when the European-origin population grew transformed the environment in ways that have had local consequences and global consequences: they range from the local disruption of faunal wildlife to the global alteration of the carbon cycle, and probably every scale in between.

Despite this simplicity and certainty, our results show that environmental constraints limit the impact of the human population on the environment through large-scale changes in land use. These constraints may be unsurprising, but are worthy of note. They operate by limiting the flexibility that farmers had to choose how they used the land. Put simply, farmers on the Great Plains were unable to convert all their land to cropland -- or to any other single use that they desired -- because the land was not environmentally suited to every possible use. In a straightforward way, we see this limitation through the range of variation in cropland in Figures 4 and 5, and in the parallel knowledge that few Great Plains farms or counties were ever transformed into a single-crop monoculture. This is the important finding in Cunfer's (2005) research.

Our own research and that of others shows that while change in population is the most important determinant of the overall likelihood of *any* change in land use in the historical time period, a limited group of environmental characteristics are the most important determinants of the *specific kind* of agricultural land use adopted by farmers. If we measure variation in land use as the choice to use the land for cropping or pasture, almost all the variation in agricultural land use in the Great Plains is explained by environmental variables, especially precipitation, temperature, soil texture, and slope (Burke et al 1994; Burke, Lauenroth, and Parton 1997; Gutmann et al 2004; Lauenroth, Burke and Paruelo 2000; Sala et al 1988; Cunfer 2005). Not much room is left for human intervention beyond deciding whether to irrigate and which crops to plant, and even then, irrigation and cropping choices are themselves largely determined by a mix of environmental and market factors over which the farmer has relatively little control. This is the result we report in Gutmann et al (2004) and Cunfer (2005), confirming earlier work by others, and making clear that even when there are ethnic and cultural preferences for certain crops or land uses, the environmental determinants are very strong.

Refining our Understanding of Environmental Impacts

Thus far the story we have told is very simple, limited to the big picture of the impact of population change on environment, and the constraints of environment on the exact nature of those impacts. Put another way, the influx of European-origin people to the U.S. and especially the Great Plains caused a dramatic change in the way land was used in the region, driven largely by the introduction of crop- and livestock-based agriculture. At the same time, we show that the introduction and continuation of agriculture has limits imposed by the environment.

To refine our measurement of the environmental impact we have undertaken a new series of analyses (Burke et al 2002; Parton et al 2004; Cunfer 2004; Cunfer 2005) that make use of the history of 19th and 20th-century land use change to estimate the impact of population-induced agricultural land use on soil biogeochemistry. Burke et al (2002) and Cunfer (2005) show that at both the regional scale and at the level of individual counties crop farming resulted in significant losses of soil nitrogen. Nitrogen declined most in the northeastern plains where higher rainfall supported more vegetation while cooler temperatures slowed decomposition of plant matter. There soils lost an estimated 1080 kg N per hectare as a result of plowing and cultivation over 75 to 100 years. Losses were much smaller in the western and southern plains because of dryer and warmer conditions and significantly less cropping. Soil nitrogen in grazing systems is roughly in balance, so much of the western plains has lost virtually no N since Euro-American settlement.

Across the entire great plains soil nitrogen declined by about 20 percent from original levels (Burke et al 2002).

Since farmers began using synthetic fertilizer after World War II nitrogen dynamics have changed. While soil nitrogen is now roughly stable at about 20 percent below pre-settlement levels region-wide, farmers annually apply an average of 35 kg N fertilizer per hectare of cropland per year. About half of that goes into crop plants, increasing their growth. The other half is lost to the system, either leaching into waterways or volatilizing into the atmosphere, in either case becoming an environmental pollutant. In the eastern parts of the region some of the excess fertilizer nitrogen may accumulate in soils, restoring some of the soil nitrogen lost due to a century of cropping, but the extent to which this may be happening is unknown.

At the scale of the individual county Cunfer (2004, 2005) shows that before 1940 plains farm systems produced enough livestock manure to fertilize only about 20 percent of their cropland each year. Traditional, organic, small family farms mined soil fertility, extracting more nitrogen each year than they returned, and crop yields fell during the first fifty years of cultivation. Like many previous American agricultural frontiers, the Great Plains may have been on a path toward widespread land abandonment due to depleted soil fertility, but the development of synthetic fertilizers after 1945 allowed farmers to artificially replenish the nitrogen they removed each year. Crop farming has continued, year in and year out, for more than 130 years in the Great Plains, longer than most other American agricultural regions, mainly because of energy-intensive inputs of synthetic nitrogen. Widespread farming in New England and in the U.S. South, for example, lasted only about a century before land abandonment or reversion to forest became widespread. This process has not yet happened in the Great Plains, as crop acreage has remained roughly stable since the 1920s (Cunfer 2005).

In another approach that showcases carbon as well as nitrogen, the analysis in Parton et al (2004) focuses on four counties in the Great Plains region (Hamilton, Nebraska; Ramsey, North Dakota; Pawnee, Kansas; and Hockley, Texas) that have different mixes of agriculture involving dryland and irrigation, grains, grasses, and cotton. Figure 6 summarizes the model results for carbon by reporting a general pattern of large losses (approximately 50%) of soil carbon during the first 50 years following the plowout of native grasslands, with most of the carbon loss occurring during the first 20 to 30 years. Soil N mineralization followed a general pattern of increased N mineralization for 10 to 20 years following the plowout of grassland, and a sharp decrease in N mineralization 20 to 50 years after plow out with N mineralization rates approaching 20% of grassland levels after 50 years of cultivation. These simulated patterns in soil carbon and N mineralization are consistent with other studies (Schimel et al. 2000) that show rapid losses of soil carbon following the plowout of grassland soils, stabilization of soil carbon levels at 50% of initial values after 50 years of cultivation and substantial decreases in soil mineralization after 50 years of dryland cultivation. The high N mineralization rates following plowout of grassland soils is consistent with the observation that N fertilizer responses are minimal for wheat fields after 30 years of dryland cultivation (Metherell et al. 1995) in the Great Plains, and data showing that wheat yields fertilizer responses increase with time since cultivation **(**Greb et al. 1974).

The locally dramatic expansion of irrigated agriculture is one of the major land use changes that has taken place during the past 50 years in some parts of the Great Plains, with corn and alfalfa grown in the Northern and Central Great Plains, and cotton in the Southern Great Plains (Texas and Oklahoma). The land use data suggest that most of the irrigated land in the Northern and Central Great Plains had previously been cultivated using dryland techniques. Model results from Pawnee and Hamilton Counties show that irrigated corn/alfalfa rotations begun in the 1960's produced substantial increases in crop yields, soil carbon levels and soil N mineralization rates. Most of the increases in soil carbon and N mineralization occurred from 1970 to 1990 because of the large increases in the amount of carbon (300 to 400 gm C m^{-2} yr^{-1} added as corn stover) and N (100 to 150 kg N ha^{-1} yr^{-1} fertilizer) added to the system with irrigated agriculture. Model results suggest that soil carbon levels increased by more than 800 gm C m^{-2} for irrigated land in Pawnee and Hamilton Counties from 1970 to 2000. Extrapolating these carbon accumulation rates to the 4 million ha of irrigated land added from 1960 to 1980 for the Central and Northern Great Plains would result in 56.0 t g of carbon sequestered in the soil.

Conclusions

In this paper we have discussed an approach to the study of population-environment relationships that focuses on changes over a large region that makes use of data at the scale of the United States county. Taken to its fullest extent, our approach yields estimates of the consequences for soil chemistry of population-driven changes in land use. As we develop estimates for the specific agricultural practices of more counties, we will be able to gauge the large-scale and long-term impact of the transition into and out of agriculture for the region as a whole, which will provide valuable data to everyone studying the past experience and the future prospects of a major northern temperate region, one where potential carbon storage is a significant question.

The results we have presented do not yet show a tight connection between population change and environmental change. There is a good reason for that, because most of the land use changes that we have signaled are not closely tied to population change, except perhaps during the early years of European settlement. In more recent years population has changed land use patterns in small parts of the Great Plains by forcing the conversion of land from agricultural uses to residential and other uses. This conversion to residential uses has produced other ecosystem consequences that remain to be studied. Our next approach will be to run Century Model estimates of soil chemistry for counties that are converting to those uses, measuring the impact of uses -- such as lawns -- that differ from native grasses, irrigated cropland, and dryland crops. While these land uses are small in the region as a whole (see Parton, Gutmann and Travis 2003), understanding their role will contribute significantly to our knowledge of the region as a whole.

The final question asked by the organizers is about the integration of social and natural science. The great challenge is to spend enough time working together so that all the parties begin to understand the questions asked by the other disciplines, and begin to understand the range of acceptable answers. That takes a long time, and it may never produce successful results. The benefits -- when they arrive at all -- are research results that open the way to answers to important scientific questions. In our case, it has come in finding ways to think about carbon and nitrogen for the region as a whole for a period longer than a century, anchored in a rich historical and demographic record. We don't have all the answers yet, but we see promise of vital new information as we continue to work.

Notes

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[2] For our interpretation of this history, see Gutmann and Cunfer 1999, Cunfer 2002, and Cunfer 2005. For aspects of the conventionally-written history of the Great Plains narrative, see Webb, 1931, Bonnifield 1979, Hurt 1981, Malin 1946, Riney-Kehrberg 1994, and Worster 1979.

[3] See, for example, the New York Times stories by Egan (2003) and Kilborn (2003). They are only a few among many.

[4] Since 1920, the agricultural census was taken every five years until 1950. Beginning in 1954 the censuses are listed for 1954, 1959, 1964, 1969, 1974, 1978, 1982, 1987, 1992, and 1997.

[5] The difference between the 31 and 38 percent depends on the interpretation of land that farmers classified as “cropland used as pasture.” The sources are not clearly (and probably not uniform in their classification) about the extent to which that land was transformed through plowing and planting of non-native species.

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List of Figures

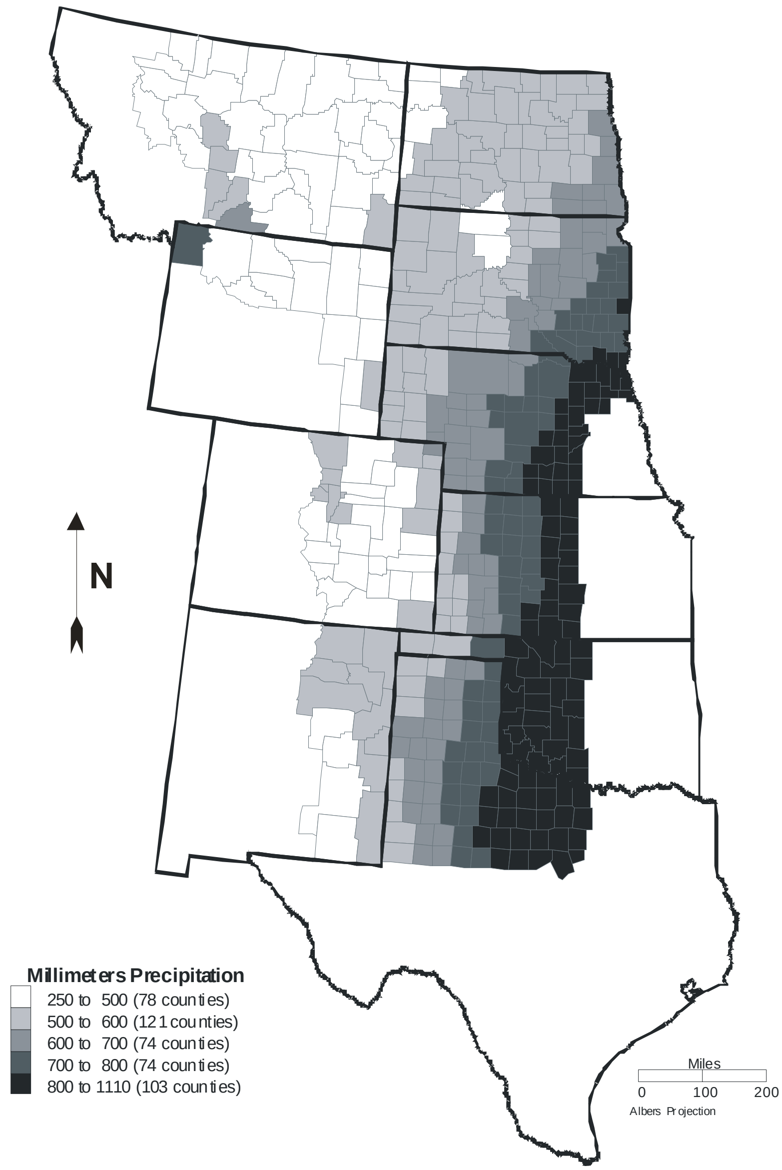

Figure 1: Average Annual Precipitation, 1961-1990

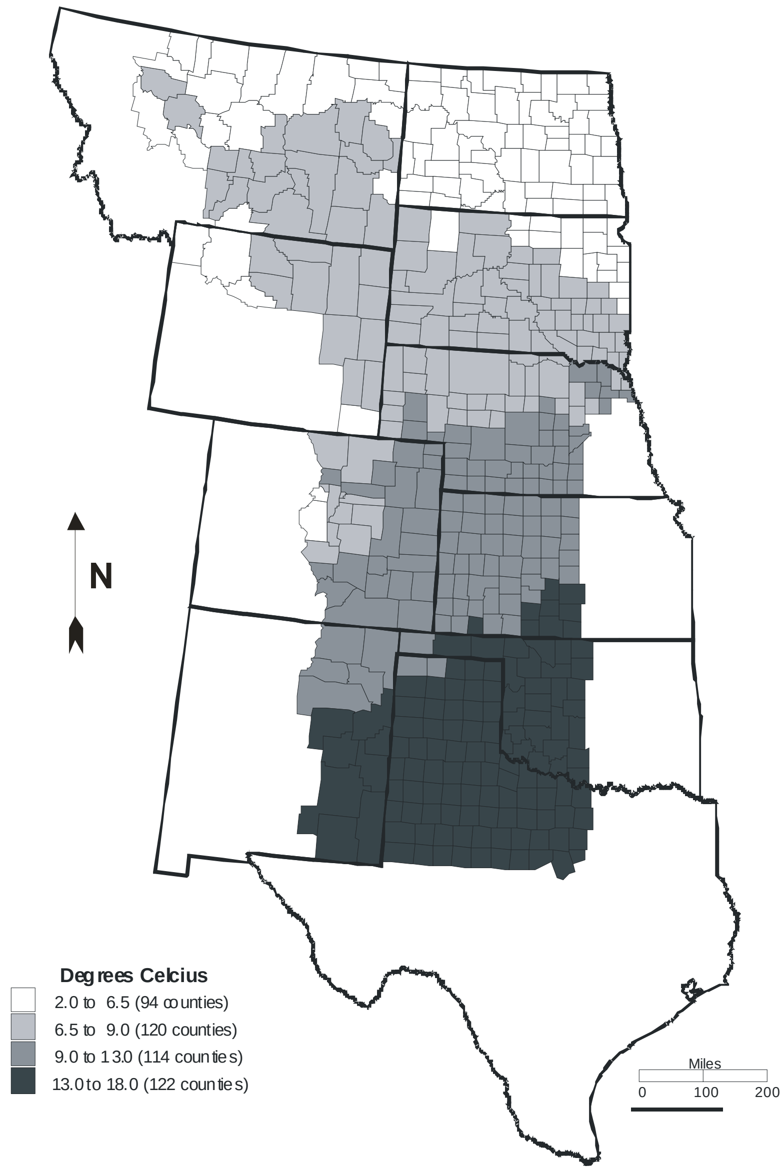

Figure 2: Average Annual Temperature, 1961-1990

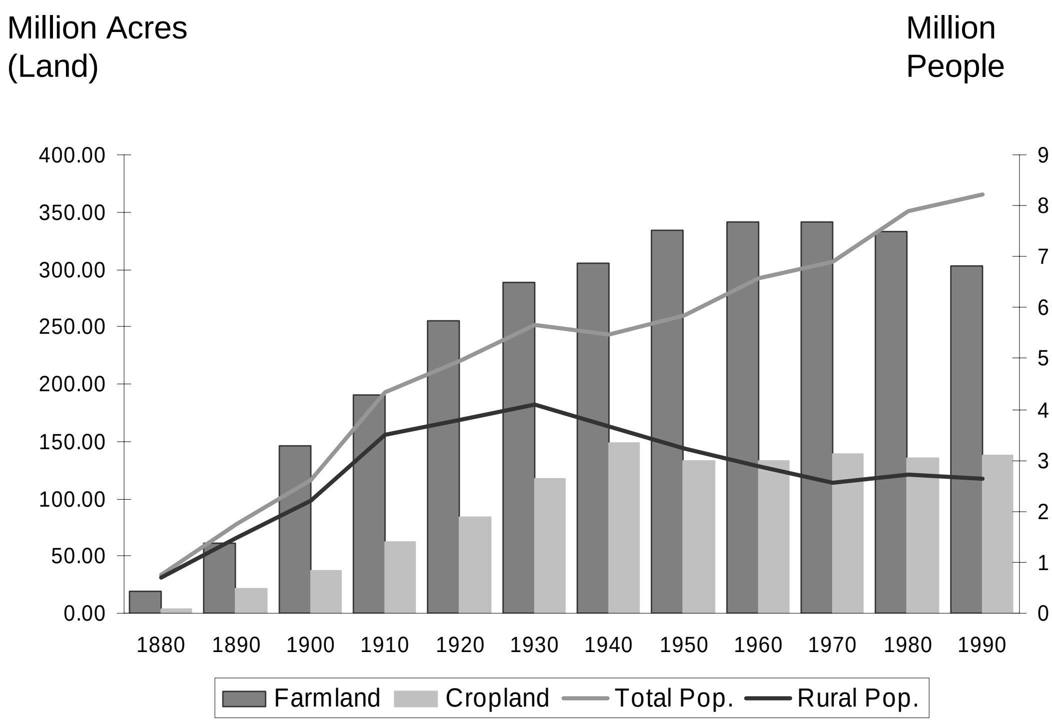

Figure 3: Population, Farmland, and Cropland. The figures for cropland represent the sum of cropland harvested for major crops from 1880 through 1920, and the reported total cropland from 1930 through 1992. About one-tenth of the reported total cropland is cropland used for pasture, which may or may not be land that has been plowed and regularly managed.

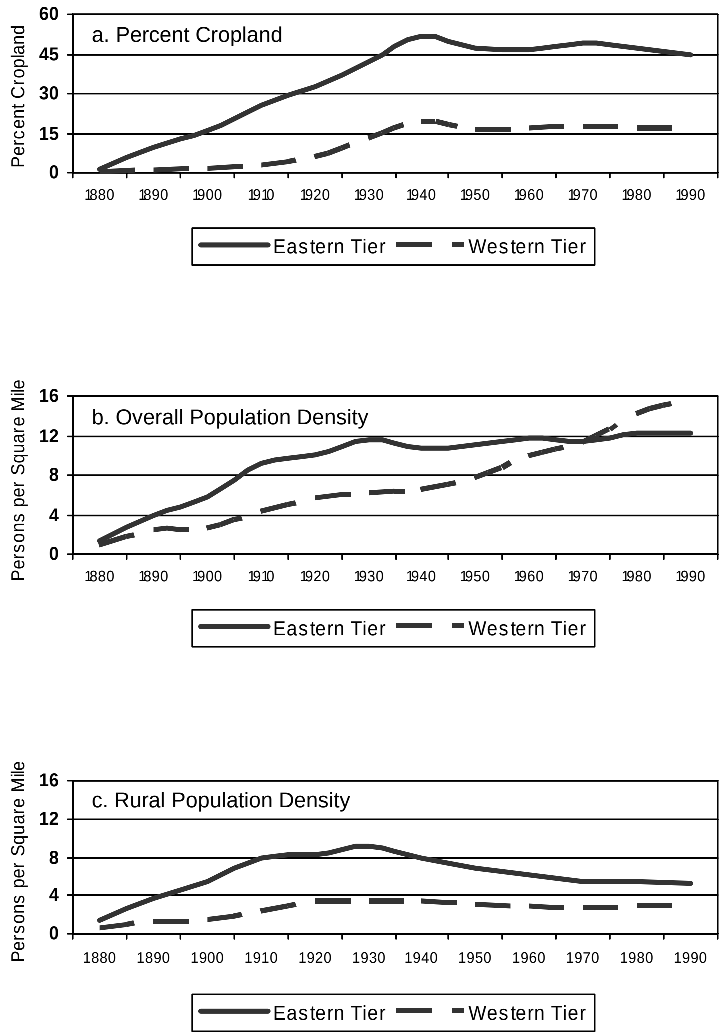

Figure 4: Differences between Eastern Tier and Western Tier States

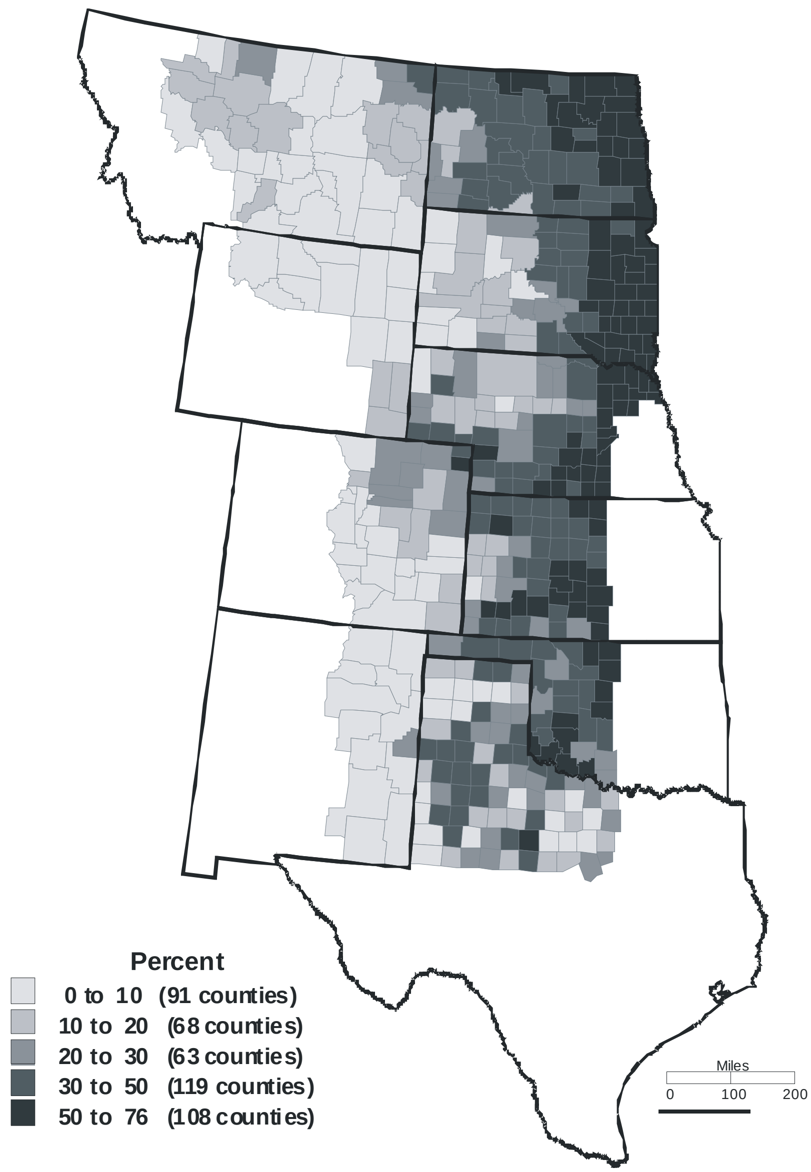

Figure 5: Percent of County Area in Crops, 1930

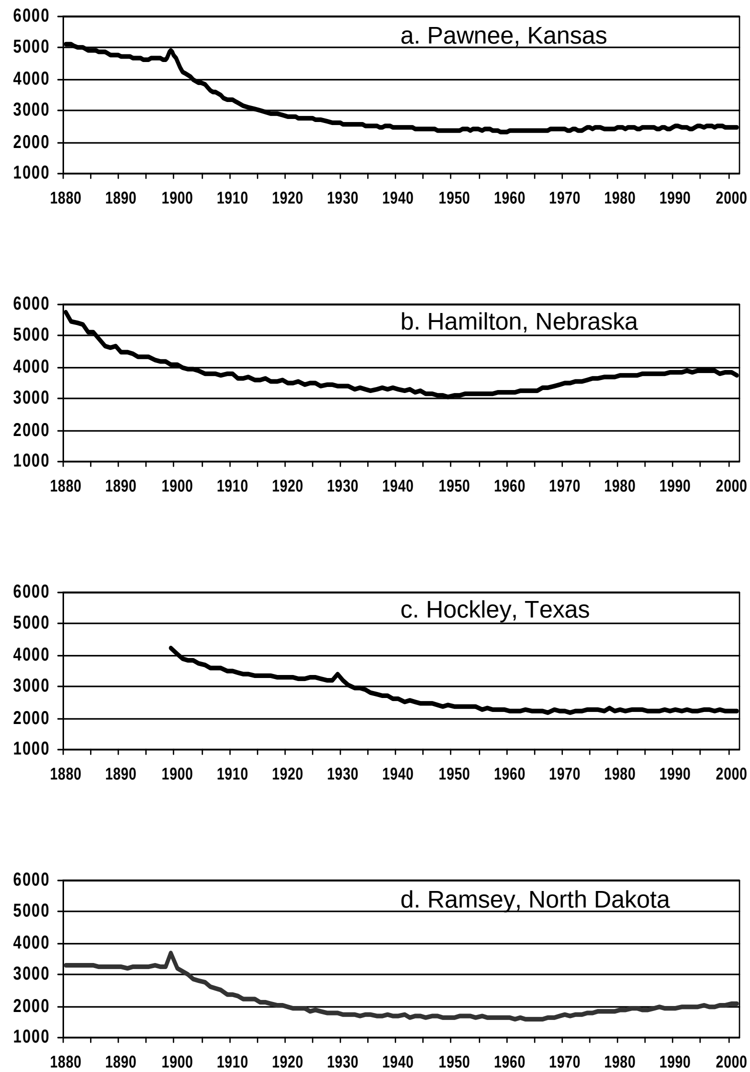

Figure 6: Simulated Soil Carbon – 4 Counties (Grams/m^2)