Published in final edited form as:

Popul Environ. 2016 March ; 37(3): 362–390. doi:10.1007/s11111-015-0242-7.

At the margins: Agriculture, subsidies and the shifting fate of North America's Native Grassland

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Abstract

We examined patterns of shifting cropland cultivation in the US Great Plains from the dust bowl to the beginning of the 21st century, by comparing land-cover data from 400 sample sites across the region from the 1930s, 1950s, 1970s and, 1990s and 2000s. We argue that understanding the use of marginal land for cultivation in the Great Plains since the Great Depression requires understanding the interacting dynamics of demography, technology, and policy. The small area land-cover data are nested within 50 target counties across the region. We draw on these dynamics, and their interactions with a range of policy programs aimed at reducing environmental impacts of agriculture, to tell the story of how and when marginal lands have been brought into use. In a multi-level panel design, macro- and micro-level covariates were used to predict levels of encroachment on marginal soils. We conclude that land retirement programs (like the Conservation Reserve Program) have had a generally stabilizing effect on the micro-level patterns of land use in recent decades, but that increased levels of encroachment on marginal soils and native grassland remain a problem in areas with higher or increasing population densities.

Keywords

Native grassland; Marginal Land; Conservation policy; Aerial Photography; Soil Quality; Population density; Multilevel Modeling

Introduction

Concern for soil erosion and agricultural productivity in the Great Plains has driven agricultural conservation policy for most of the late 20th century. Following the drought and dust storms of the 1930s, land retirement became the main policy mechanism used to balance soil conservation and levels of agricultural production. Since the passage of the Agricultural Adjustment Act (AAA) of 1938 (P.L. 75-430), the federal government has

encouraged farmers to limit the expansion of cropland and to remove marginal land from use in the production of small grains, row crops, and other tillage cultivation. Each successive effort to retire land has slowed the growth and resulted in declines in reported cropland acres. During the New Deal, the AAA prompted farmers across the US to retire nearly 40 million acres per year between 1936 and 1942 (Claassen et al 2008: 737). Not all early land retirement initiatives led to cropland reduction (Cunfer 2001), but programs that followed like the Soil Bank Program (1956–1972) and the Conservation Reserve Program (1985–1996) led to impressive cropland reductions. The more direct and verified nature of the Conservation Reserve Program in the late 1980s converted nearly 34 million acres from crop production to perennial cover before 1992 (Sullivan 2004, Claassen et al 2008, Lubowski et al 2008).

While the experience of the 1930s contributed substantially to motivating land-use policy over the last 80 years, many other factors have contributed to the ways that land use has since changed, and the extent to which poor farm land has come into or gone out of cultivation. Technological changes have transformed farming over the past century and therefore have been a key factor driving changes in agricultural land use. The introduction of mechanization, the expansion of irrigation with gasoline, diesel, and electric-powered pumps, improved crop varieties, and inorganic fertilizer production (among other drivers) have made it possible for farmers to make greater use of marginal land, whether it was originally too wet, too dry, or too poorly endowed with organic matter and nutrients. Equally important, in terms of the more sensitive landscapes of the western Great Plains, the growth of suburban and exurban housing densities, and the mix of residential, commercial, and public land uses, has increased pressure to convert marginal land near urban areas to productive uses (Theobald 2001; Brown et al. 2005). Increasingly, development also takes land away from agricultural uses, in spite of efforts to protect farmland in the urban shadow.

In this paper we argue that understanding rates at which marginal lands in the Great Plains are used for cultivation since the Great Depression requires understanding the interacting dynamics of demography, technology, and policy. Demography and technology together resulted in a depopulation of rural areas and, in some areas, expansion of urban settlement. We draw on these dynamics, and their interactions with a range of policy programs aimed at reducing environmental impacts of agriculture, to tell the story of how and when marginal lands have been brought into use, allowing for the potentially contradictory result that that population change had one impact on the total area of cropland and another on the area of low quality land use for crops.

Over time the attention of policy has shifted away from soil conservation to the broader environmental performance of working agricultural land. In part, program managers have responded by defending the costs of conservation payments by emphasizing the wider environmental benefits of promoting the adoption of conservation tillage, nutrient management, and other practices (Sheriff 2005, Johansson & Kaplan 2004). More recently the US Congress has pushed for better monitoring of the cost-effectiveness of conservation spending, formalizing the shift in 1996 with the establishment of the Environmental Quality Incentives Program. Policy now relies on a competitive bidding process to assess what producers are willing to adopt and what level of payment will improve the efficient use of

available conservation funds. USDA generally establishes bid limits, and producers interested in enrolling their land are asked to respond with conservation plans (Claassen et al 2013).

An analysis by Lubowski et al. (2006) showed that lands undergoing the greatest rates of conversion have tended to be those that are most marginal (i.e., least productive) and also those that are most susceptible to soil erosion. Even with the more targeted nature of contemporary conservation payments, some analysts have emphasized that production supports reduce the effectiveness of conservation efforts, resulting in the continued use of marginal land (Lubowski et al. 2008). Because initial enrollments in CRP were based on land *with* a history of crop production, conservation programs have, in some cases, unintentionally shifted production to land *without* a recent history of crop production, as experienced producers shifted cropland into the reserve and then plowed up other land in order to maintain overall production. Wu and colleagues have described this process as ‘slippage’ (Wu 2000, Wu & Lin 2010). In recent years, there is also growing concern that biofuel mandates have contributed to an expansion of cropland in sparsely populated areas in the northern plains. As corn and soybean cropping expands westward into wetland areas of North and South Dakota, to the east of the Missouri River, farmers have drained and plowed native grassland in the Prairie Pothole region (Stephens, Walker et al. 2008; Rashford, Walker et al. 2011; Wright and Wimberly 2013).

By shifting the focus of observation away from farmers (the managers of agricultural land) to the dynamics of land-use and population change, we ask whether the objectives of soil conservation policies and programs have been met over the long term. We proceed in two ways. On the one hand, there is considerable interest in knowing whether the conservation initiatives of the last 70 years have had an appreciable impact on the patterns of land-use change in the region. Do the trends in long-term land-use fit the larger narrative of conservation policy in the region? When did levels of cropland begin to peak in the region? Secondly, have the recent efforts to introduce more targeted reductions of cropping on marginal soils had the intended effects?

We provide a new baseline for analysis by extending observations of land-use change back to the 1930s, allowing us to analyze trends in land cover over seventy years. A sample of study areas was selected for mapping land-use change beginning with the first nation-wide coverages of air photo imagery gathered by the Soil Conservation Service and Farm Service Agency in the 1930s, and subsequent national coverages developed by the USDA and USGS in the 1950s, 1970s, 1990s and 2000s. With this time series of air photo mosaics we developed a high-resolution record of land-use change across the Great Plains region. The changes visible in the 400 sample areas reflect the shifting imperatives of public policy, demography, and other drivers of land-use change before and after the Green Revolution. Because of the enormous variability across the region, we rely heavily on previous research in population change and agricultural land use in the different ecoregions of the plains to stratify the sample and identify drivers of change (Sylvester, Brown, Deane & Kornak 2013, Drummond 2007, Parton et al 2007).

Data

This paper makes use of a unique time series of aerial photographs from 1936 to 2006. The data were chosen to permit a comparable analysis of land use reaching back in time to the first comprehensive aerial surveys conducted by the Soil Conservation Service and the USDA in the 1930s. The sample design is based on randomly selected study areas, nested within 50 counties, and distributed across the major grassland biomes in the region. To characterize variability in ecosystems, the sample frame begins with Küchler's (1964) classic delineation of native vegetation zones in the United States. The shortgrass, mixed grass and tallgrass embrace major biogeographic variations across the larger Great Plains region, and we chose three clusters of counties within each ecoregion, and added a tenth cluster in southwestern Kansas that embraces all three ecoregions (see Figure 1). Eight 3 mile by 3 mile sample areas were selected within each county, chosen by attaching a random number field to the Public Land Survey System parcel grid and sorting on the new field. The random numbers attached to each parcel description (1 mile by 1 mile) in the PLSS created the spatial dispersion of the sample areas visible in each of the 50 target counties (Figure 1). If each randomly selected parcel was surrounded by agricultural land in adjacent parcels, the randomly selected parcel became the center of the 3 mile by 3 mile study area. Our interest in measuring agricultural change led us to exclude parcels interpreted as urban or developed in recent aerial imagery (most taken in 2006). We also excluded parcels that were situated on county boundaries. The random selection procedure was pursued to reduce the cost of acquiring and manually interpreting the time-series imagery, and increase the likelihood of generating representative samples of land use conditions within each county.

This process was repeated across the region until we had selected 400 sample areas - eight three-by-three mile sample areas in each of the 50 counties (Figure 1). Though not as comprehensive geographically as satellite surveys undertaken by the USDA or USGS since the 1970s, the sample is representative of the broad changes which occurred in each bioregion and has the advantage of greater time depth, a nested structure and fixed study areas. This sample design allows for more precise change over time analysis. Panchromatic air photos taken at a scale of 1:24,000 on negative film can resolve ground objects smaller than a meter (Caylor 2000; Morgan, Gergel et al. 2010), and these more highly resolved measurements are repeated for fixed locations. The nested nature of the sample design also permits the use of higher-level covariates in multilevel models, like measures of economic, agricultural and population change at the county level that are published in the US census.

In the end, the counties we selected in each ecoregion (see Figure 1) turned out to be more intensively managed than recent satellite surveys indicate is the case for the larger mixed grass and the shortgrass bioregions as a whole. Nevertheless, within each bioregion, the sample design captures the dynamics of change over time in ways that are similar to the change dynamics documented in satellite image analyses, as we illustrate below. In general, recent satellite time-series demonstrate more land conversion occurred in the western high plains of Colorado, Texas and Kansas, than in the more intensively managed eastern plains. According to one recent study conversion rates in the eastern plains remain low - only 1.4% of land cover was altered in the Red River Valley, and 3.2% of land in the Corn Belt of Iowa, Minnesota and Nebraska (Drummond et al 2012) since satellite observation was

initiated in the 1970s. By contrast, conversion rates captured in the same study in the western plains remained high – measured at 13.6% in Montana and western North Dakota, and 11.6% in the western high plains of Texas, western Kansas and northeastern Colorado (Drummond et al, 2012, 714–5).

The interpretation of aerial photography is less forgiving of past cultivation or disturbance than is the interpretation of satellite imagery. Land cover based on aerial photos represents a more cumulative measurement of the extent of plowing because the signs of tillage are visible for much longer than in satellite image interpretation. Our protocols for land-use classification were based on the distinction between grassland and cropland, and relied on central findings from grassland ecology about vegetation recovery. A number of studies have shown that the signatures of tillage systems remain in the vegetation profile of grassland landscapes for some time (up to 50 years in semi-arid settings) after plowing activity has ceased (Costello 1944, Costello & Turner 1944, McGinnies et al. 1991, Shantz & Turner 1958). These studies showed that a sharp contrast between abandoned fields and unplowed vegetation could be observed in 1930s aerial photographs, allowing identification of abandoned cropland sites 53 years later with considerable precision, as confirmed by soil nutrient analysis (Burke et al. 1995, Coffin et al. 1996, Lauenroth & Adler 2008).

Vegetation during early succession – following the abandonment of a plowed field - appears more homogeneous because the species that colonize disturbed sites are more likely to be mixed and tallgrass species, like Big bluestem (*andropogon gerardii*) and Sideoats grama (*bouteloua curtipendula*), which are known for more rapid seed dispersal. The characteristic patchiness or uneven appearance of dominant perennial grasses is generally not evident until the end of the recovery period. Dominant perennial shortgrasses such as Buffalo grass (*buchoe dactyloides*) and Blue grama (*bouteloua gracillis*), are more tolerant to grazing and drought, and will eventually dominate the composition of recovering grassland in dryland settings.

Interpreted land use for four representative sample sites, one each in Montana, Iowa, Colorado, and Oklahoma, in the 1930s, 1970s, and 2000s, provide a glimpse of the analytical value of this approach. The main visual impression conveyed in time-series maps of the land use data is that each of the subregions shared patterns of land use intensification over time. The sample sites in Figure 2 are the same four used to illustrate the geographic distribution of the sample sites in Figure 1. They appear again below to illustrate differences in soil quality. The reduction of grassland in Figure 2 is particularly striking in the sample site in Liberty County, MT, between the 1930s and the 2000s, but also apparent in Lyon County, IA, and Morgan County, CO. The intensification is also evident in the grassland/forest mosaic that originally characterized the landscape in Kingfisher, OK, in the 1930s, which witnessed significant reductions in tree cover in the 70 years that followed. Each of the transitions visualized in Figure 2 represent spatially explicit and fixed areas of observation that can be summarized at various spatial scales and used to measure change over time in a longitudinal fashion. As we show later in this paper, the strength of the approach is that there is no confusion about the unit of analysis and the field level change can be measured in relation to changes tracked at higher levels of aggregation (Sylvester, Brown, Dean, and Kornak 2013).

In order to create a uniform spatial unit for analysis, we subdivided each of the 400 sample sites into 36 smaller units (“sample units”). Each of these units was roughly the size of a quarter section in the public land survey system, or just under 160 acres in size. This subdivision was necessary, in practice, because the 400 sample sites were not uniform in size. The public land survey did not produce a geometrically perfect grid across the interior of the continent. New base lines were introduced every 24 miles to correct obvious locational errors as the surveys made their way west (White 1983). In order to fit subdivided units within the target 3-mile by 3-mile grids, geometrically uniform sample units were generated in ArcGIS and were made slightly smaller than the statutory half-mile by half-mile quarter-section specified in U.S. public land law. The size of the uniform sample units is illustrated in Figure 2 (and Figure 3 below). These 14,400 sample units serve as the basis for field level and repeated measurement.

To add environmental context, the interpreted land-use data were also intersected (geometrically integrated) with USDA digital soil data from the sample counties (SSURGO, Soil Survey Staff, NRCS) to measure the amount (in square meters) of cropland on poor soil, defined as soils not rated for continued crop use. The guidance for farm practice offered in the land capability ratings reaches back historically to the original Soil Conservation Service, which concentrated not just on developing a national taxonomy, but providing guidance for farm practice. When the agency’s *Soil Conservation Survey Handbook* was published in 1939, it introduced an eight-class land capability system to assist in farm planning and conservation. Generally speaking, the classification system considers slope, soil depth, soil texture and landscape location in assessing the limitations on agricultural use. More than 70 years later the updated land capability class ratings are still used in the National Resource Inventory, the Farmland Protection Policy Act, and the Natural Resources Conservation Service conservation planning programs to identify vulnerable lands and appropriate forms of management.

The analysis described here makes use of a reasonably conservative measure of better soils, limiting the definition of good soil to land capability classes 1 to 3. Soils rated as Class 4 or higher were treated as poor soils, unsuitable for crop use (USDA Soil Handbook, accessed online 7-24-2014). Figure 3 shows where crops are tilled or planted on low-capability soil, in the four representative sites presented earlier. The distribution of poor soil is illustrated in the top row of the panel in Figure 3, with poor soil classes identified as class 4 and above (light green, yellow, orange and red). There is essentially no poor soil in the sample site selected from Lyon County, IA, and therefore the intersection of the NRCS SSURGO data and the interpreted land use data identified no cropland on poor soil. In both of the shortgrass locations the distribution of cropland on poor soils (highlighted in crimson) seems to have shifted somewhat between 1930s and the 2000s, as seen in the bottom two rows of Figure 3. But the incidence of poor practice (defined in this very specific way) increased more substantially in Kingfisher, OK, where intensification meant that pockets of poor soil were more likely to be incorporated into expanded crop fields in the 2000s than they were in the 1930s.

In the multilevel analysis presented below, we also control for key economic and social drivers by introducing county-level covariates drawn from the agricultural and the

population censuses. In many cases, these data are part of a larger county-level data series collected in the Great Plains Population and Environment project (Gutmann, 2005, 2007). Each of these long-term measures of county-level change represents a strong indicator of the differences in management practice and intensification of agriculture in the seventy years since the 1930s. Many of the questions were first introduced to the U.S. census of agriculture in the 1920s in order to track the mechanization and modernization of farm organization and the place of the traditional family farm in agricultural production. Accordingly, capital investments by farm operators have been tracked by asking about the total value of farm implements, together with reporting on the size of farm operations, including a consistent question on counts of the number of farms of 1,000 acres or more in size. In spite of the small numbers of farms that were irrigating crops in the 1930s (mostly stream-fed at the time) the census also has also consistently tracked the number of acres in irrigation on farms over time. Each of these represents important shifts in the level of agricultural intensification over the balance of the twentieth century.

In addition to agricultural variables, we used indicators of social and demographic context at the county level to further contextualize observed land-use changes. A measure of population density was included to help account for the variation in levels of urbanization and population change across the region. Parton and his colleagues have shown that proximity to developed population regions has an impact on agricultural change (Parton, Gutmann and Travis 2003; Parton, Gutmann and Ojima 2007). A brief examination of the population census figures in Table 1 illustrates that 28 of the sample counties lost population during the period and the other 22 gained population.¹ Table 1 illustrates the patterns in each of the study counties. At least one or two of the counties selected in each ecoregion experienced growing population densities. This is true even in the northwestern plains of Montana, which has the lowest population density of any cluster in the sample. Even though population densities remained lower than 5 persons per square mile in the sample Montana counties, densities were higher in Cascade County because of its county seat, the city of Great Falls. The most dramatic increases in population density between 1940 and 2000 were in Lubbock County, Texas, and in Adams and Arapahoe County, Colorado.

Methods

We began our analysis of trends by looking at land-use change from the 1930s to the 2000s, both the overall change in cropland and the ways that the change in cropland encroached on land classified as having poor soils. At this level of analysis, it is not possible to see the impact of population and other factors beyond the time trend, so to examine how these pressures on marginal soils have changed over time, we turned to a multivariate statistical analysis. We experimented with several contextual variables like the counts of operators by age in a given county (reported only in more recent censuses) and chose to focus on variables that have been measured consistently since the 1930s. The county-level measures

¹Several counties experienced substantial population increases over the period between 1940 and 2000, of 25,000 or more residents, because of their proximity to metropolitan areas. Adams and Arapahoe Counties in Colorado are just east of Denver, Weld County, Colorado, is east of Boulder and Fort Collins, Clay County, Minnesota, and Cass County, North Dakota, surround the city of Fargo, Grand Forks County, North Dakota, contains the city of Grand Forks, Kingfisher and Canadian County, Oklahoma, are just west of Oklahoma City, and Cascade County, Montana, is home to the city of Great Falls.

offer important time-varying covariates for the micro-level outcomes of interest in our analysis, which are the field level measures of cropland and cropland on poor soil. More explicit details on the micro and county level variables are available in Appendix B below, together with descriptive statistics.

We developed four hybrid fixed-effects models (Allison 2009), which are relatively new tools for panel data and repeated measurement analysis that combine several of the virtues of the fixed- and random-effects models. The decision about which approach is better typically boils down to a tradeoff between efficiency and bias. The standard random-effects model assumes no correlation between observed and unobserved variables, and is generally a more efficient estimator than the fixed-effects model. But if the introduction of an additional variable ‘explains’ away the contribution of an observed predictor (changes the magnitude of a coefficient significantly), the chances are that some unobserved variable is interacting with one of the predictors. A conventional fixed-effects model assumes that all unobserved covariates may be correlated with observed variables, and ‘controls’ for all unobserved heterogeneity, by controlling for each unit of analysis. In a dataset like ours, the approach would be equivalent to adding 14,399 dummy variables (14,400 sample units observed on five occasions). Many statistical packages like Stata have incorporated an alternative algorithm – the mean deviation method – that produces the same results, and works around the computational burden of handling excessively large numbers of dummy variables.

The virtue of the hybrid model is that it preserves elements of both approaches. It incorporates the strength of the fixed-effects model by transforming time-varying explanatory variables into deviations from their unit-specific means, while leaving the response or outcome variable untransformed. And it allows for the use of time-invariant predictors, which represent the characteristics of the between-unit variation modeled in a random-effects model. The benefit of this approach in a large dataset, with many sources of unobserved heterogeneity, is that it helps us get better estimates of the effects of the within-unit variation (over time) and the between-unit variation (between geographical contexts). While random-effects models produce estimates that represent a weighted averages of the ‘within’ and ‘between’ coefficients, the hybrid approach preserves the emphasis on generating unbiased estimates (of the within-unit variation over time) and permits the inclusion of time-invariant covariates (to directly estimate between-unit variation).

The hybrid approach, or “within-between” estimation, applies the random effect estimator to panel data where $\bar{x}_j$ is the group level mean of each of the included explanatory variables. In order to obtain the correct within-cluster coefficient from the simplified equation (1), the between effect (γ) must be subtracted from the β attached to the deviations from the group-level means ($x_{jn} - \bar{x}_j$).

$$y_{jn} = \beta(x_{jn} - \bar{x}_j) + \gamma\bar{x}_j + \omega_{jn} \quad \text{where } \omega_{jn} = \mu_j + \varepsilon_{jn} \quad (1)$$

Adjusting for the clustering of the observations in this way assures that the hybrid model is asymptotically equivalent to a fixed effect model. In the simplified version of the hybrid

equation (1) $\hat{\beta}$ is the within effect, and assesses change within the group (as the fixed effects estimator does), and the $\hat{\gamma}$ measures the effect of x between groups (Snijders & Boskers 2011). Moreover, the inclusion of the group mean as an explanatory variable assures that the explanatory variables are fully independent of the unobserved group-level effects in the equation, μ_j , and the residual error, ε_{jn} . Recent simulation work has demonstrated the fixed effects and hybrid approaches are equivalent in finite samples (Dieleman & Templin 2014).

We developed four models (A through D), all of which incorporate 72,000 observations from the 1930s to the 2000s (14,440 sample units multiplied by five different observation times). The first two models (Models A and B) use the cropland interpreted in the air photo mosaics as the outcome of interest, over the entire study period. In this first set of models we want to understand the forces that led farmers to increase or decrease the amount of cropland they cultivated. Our second set of models (Models C and D) investigates the predictors of cropland on poor soil. In these models we want to understand what led farmers to plant crops on poor soils. The estimates from these models treat the area with cropland on poor soil ($LCC \geq 4$) as the untransformed response variable in a hybrid growth model (Table 4).

Results and Discussion

Descriptive Results-Revealing the long-term trend

Land in crops increased from the 1930s to the 1990s in every region, before stabilizing or declining by the 2000s. As Table 2 illustrates, the increase in cropland was most rapid in the shortgrass region, especially between the 1930s and the 1950s, probably because this was the region – especially in the western and northern shortgrass -- where significant arable land was still available to be plowed out after the 1930s. Classes omitted from the summaries in Table 2 include those illustrated in Figure 2 (developed, transportation, orchard, forest, forested grassland/rangeland, waterbody, and non-forested wetlands). Cropland observed in the shortgrass study areas expanded from 331,468 acres at the end of the 1930s to 405,252 acres at the end of the 1950s, a nearly 22 percent increase. This expansion brought with it an even greater cultivation of marginal land, because the shortgrass region has a much higher proportion of poor soil. In the immediate postwar period, cropland on poor soil (soil that was eventually rated by the Natural Resources Conservation Service as class 4 or higher) grew from 80,309 acres in the late 1930s to 107,491 acres in the late 1950s in the shortgrass region study sites. This represented a 34 percent increase relative to the earlier level of cropping on poor soil. What makes this story complicated is the possibility that some of the expansion was achieved through the introduction of groundwater irrigation, making otherwise poor soils productive. It is not possible in our analysis to compare irrigated with dryland soils, because the soil survey has a separate and more forgiving irrigated capability class scale, which rates soils where irrigation is possible more favorably than the non-irrigated capability classes.² Below we make some adjustments for the reported levels of irrigated farmland in a given county but

²Our standard of interpretation sets a conservative standard consistent with the historical baseline of practice in the late 1930s, when center pivot or other groundwater technologies were not in use, and we maintain this metric throughout the period observed. It is a standard that imposes a kind of taxonomic assessment on the patterns of change rather than assessing the on-the-ground adjustments and innovations that farm operators used to expand cultivation.

we did not try to assess whether the irrigation land capability class ratings differed dramatically from the non-irrigated ratings. The irrigated ratings are simply not as widely available in the soil survey data.

Part of our interest in applying this comparison of interpreted land use and soil ratings across the region is to compare the results with findings in a similar study for 25 study areas across Kansas that looked at the footprint of cultivation at the end of the dust bowl era (Sylvester & Rupley 2012). It concluded that the cropping of poor soils was actually more cautious in the drier western regions of Kansas than in the east. Some of the difference can be attributed to the rockier terrain and the sloping landscapes of eastern Kansas. In comparison to the level terrain in the western and central Kansas, farmers in eastern Kansas worked on land with higher proportions of poor soil and faced more risks in cultivating soils on steeper slopes. But whether this east-west contrast held throughout the whole Great Plains remains an open question.

The results reported here indicate that the cautious patterns seen in western Kansas in the 1930s were not shared across the western shortgrass region. For one thing, the proportions of poorly rated soils in the shortgrass are much higher in the far western part of the region than in Kansas. Soils in western Kansas have more in common with the rich black earth soils of tallgrass plains, like the Red River Valley (along the North Dakota and Minnesota border), than those of the high plains of Texas, Colorado and Montana. For example, the proportion of poor soil was as high as 42 percent in the Colorado study areas, compared with southwestern Kansas, where the proportion of poor soil was only 8 percent in the five county cluster studied here.

Our intersection of land-use data with soils data illustrates that there were significant reductions in the proportion of cropland on poor soil in the period between the late 1930s and 1950s: a drop of 1 percent in the northern mixed grass, a 6 percent reduction in the southern mixed grass and 9 percent drop in the eastern tallgrass. Once conditions in the farm economy began to improve in the 1960s, however, all ecoregions experienced expanded cropland, and this growth was accompanied by more poor soils under cultivation. Figure 4 illustrates the effects of renewed cropland expansion on the proportion of poor soils under cultivation during the period between the 1950s and the 1990s. In every part of the region, the cultivation of poor soils in the sample areas exceeded levels that existed in the 1930s until the most recent period of observation. Even with much smaller proportions of poor soil in the mixed grass and the tallgrass regions, nearly half of the available poor soil in every ecoregion was cropped at some point in the latter half of the 20th century. At this regional scale, the risks appear to have been evenly distributed. Moreover, the northern mixed grass region did not see a decline in cropping on poor soils in the era immediately before the passage of biofuel mandates (Wright and Wimberly 2013).

Multilevel Modeling Results: Understanding the causal process

The time trends revealed in the first of our multilevel models (Model A) appear very similar to those revealed in the descriptive analysis. The estimates in Table 3 treat the 1930s as the reference decade and match the sequence seen in the summary statistics in Table 2. Compared to the reference decade, the cropland area increased into the 1950s, the 1970s and

the 1990s, before dropping substantially in the most recent decade. The negative coefficient of 3,787 square meters (or 0.935 acres) indicates a mean reduction of about an acre per year over the time between the air photo scenes observed in the mid-1990s and the mid-2000s. The reduction provides some confirmation of the positive effect of conservation payments in slowing cropland expansion across the region (Lubowski et al 2008, Claassen et al 2013). The mean area in cropland (intercept) over the entire period in the region is estimated at 496,451.50 square meters, or about 122.7 acres. With each of the 14,400 sample units covering an area equal to 142.8 acres, the intercept suggests that the mean sample unit was 85.9 percent cropland over the period observed. When we begin to control for the other factors affecting the specific outcomes at each sample site, the local outcomes are adjusted away from the mean or intercept.

A dummy variable for the Tallgrass region suggests no statistically significant difference from the omitted mixed grass regions, and the dummy for the Shortgrass suggests that we add 16,386 square meters (about 4 acres) of cropland to every observation in the western part of the region, and another 13,931 square meters (about 3.5 acres) of cropland to every observation in Colorado. The models also control for the higher levels of grassland in the western third of the plains with a sample-unit-level covariate, and the inclusion of the grassland covariate suggests that we subtract 0.77 square meters from our estimate of cropland for every square meter of grassland reported. The high Z score for this predictor suggests that it has a strong contribution to the overall fit of the model.

To ensure that the effects of the deviation from the within-unit means are unbiased, Allison (2009) recommends including the within-unit means in the hybrid model. The other unit-level covariate introduced is the time-varying measure of cropland on poor soil. The estimate for the effect of the deviation in cropping on poor soil is that for every additional square meter above the long term (1936–2006) within-unit mean, the level of cropland is 0.36 square meters greater. The estimate of the mean is also positive and highly significant, indicating that sample units with higher levels of cropping on poor soil were the ones more likely to experience growth in the levels of cropland.

The other time-invariant controls in the model are for null ratings in the soil survey (meaning that no land capability data were available) and for the area in poor soil. There were only a few areas in the sample where null ratings affected the local availability of land capability data. The negative coefficient suggests that in most instances the null ratings were associated with poor soil conditions. When we visually examined the air photo images ourselves, we see some that were low-lying or wetland areas, while others were cropped or were irrigated. The negative coefficient of -0.15 for the area in poor soil ($LCC \geq 4$) indicates that poor soil ratings account for a mean reduction 15 percent in the amount of cropland across the entire Great Plains region.

To decompose the variation further, we also introduce measures of between-unit or higher-level processes, to examine how they influence the micro-level outcomes. Examining the county-level covariates in Model A we see that many of the variables typically associated with intensive agriculture had little impact on the sample-unit-level expansion of cropland. Increases in the number of large farms (the number of farm greater than 1000 acres in size)

did not contribute to cropland growth in the sample units, nor did increases in the deviation or the mean of irrigated acres. The only county-level predictor that did contribute to cropland expansion was implement values per farm, reported in the agricultural census in nominal dollars, which predicts an additional 0.47 square meter for every additional mean dollar invested between counties. The higher coefficient for the mean (rather than the deviation from the mean) suggests that geographic variations in capital investments persisted, and that within-county variation over time was less important.

The second model (Model B) presents a significant contrast with the introduction of the county-level population density variable. The very different patterns of population growth and decline in the data are captured to some degree by the negative coefficient for the deviation from the within-county mean and the positive coefficient for the mean population density. Counties that maintained population densities close to their long-term means (during the period from 1940 to 2000) continued to experience modest cropland expansion, whereas counties with significant increases in population density (above their long-term mean) experienced significant reductions in cropland. For every point in population density (expressed as persons per square mile) above the mean, the cropland area is predicted to decrease by 39.44 square meters. This may not seem like a large reduction in cropland, but population density essentially negates the time trend for the 2000s. Instead of the most recent decade appearing as a successful conservation era, in which cropland finally began to fall below the levels of the 1930s, the 2000s are not statistically different from the 1930s, and the mean estimates of expansion are revised upwards for the 1970s and 1990s. It seems that much of the reduction in cropland in the air photo data is associated with increasing population densities near large and growing metropolitan areas and not with the timing of government conservation programs. This is consistent with the more general findings on the effects of population growth and development on agriculture in Parton, Gutmann and Travis (2005), and in Parton, Gutmann and Ojima (2007). It also reflects the cumulative nature of the cropland footprint measured in the aerial photograph time series, which was less likely to reclassify land as grassland during the early stages of natural vegetation recovery or restoration.

Table 4 illustrates the pattern of change when we treat cropland on poor soil as the dependent variable. In comparison to the 1930s, Model C suggests that the first era of soil conservation set asides in the 1950s and 1970s was more successful in reducing the actual levels of cultivation on marginal lands across the region, than the era that followed introduction of the Conservation Reserve Program in 1985 or the Environmental Quality Incentives Program in 1996. In fact, Model C predicts a mean increase in the rate of poor soils under crop use of 1,767 square meters (0.44 of an acre) per year between the 1970s and 1990s, and 6,289 square meters (1.55 acres) per year between the 1990s and the 2000s. The coefficient for the sample-unit-level amount of cropland indicates that every square meter deviation higher from the mean raises the proportion of cropping on poor soil by 0.37 square meters, and raises the proportion of cropland on poor soil by nearly a third. The time-invariant coefficient for the level of poor soil in a given sample unit, tells us very much the same thing we observed earlier. For every square meter of poor soil, we can expect 0.48 square meters to be cropped across the region as a whole. The contrasts between Kuchler vegetation zones and the county covariates present few surprises. The cropping of poor soils

is higher in the Shortgrass, even when we control for the reported levels of poor soil. It is much higher in the Colorado Shortgrass region – the five counties in the northeastern corner of the state. But these regional contrasts would merely return the estimate for any given sample unit to a constant of zero because the model is centered at an intercept of $-91,013$ square meters (or just over 22 acres). Accordingly, the county-level covariates have only modest effects on the outcome. It is encouraging from a conservation perspective that higher implement values are associated with reductions in use of marginal land. This is consistent with the widely held notion that more intensive forms of farming tend to spare land for conservation. Irrigation does not appear to have contributed significantly to use of poor soil, except where increases have been significantly above the long-term mean. Increases in the numbers of large farms similarly appear to be associated with modest increases in use of marginal land.

As was the case when we took area cropped as the dependent variable, the patterns of covariance in Table 4 are also affected when population density is included in Model D. What is interesting here is that, instead of suggesting greater risk taking in recent decades, we see steady reductions in marginal land use in areas where population densities have decreased or not increased significantly, over the last 70 years. First, the coefficient for mean population density is quite different from the effect of deviations from the mean. This contrast highlights how different the population trends were in the sample counties. The estimates for the mean and deviation from the mean would be more similar if the units were more alike (see Allison 2009, chapter 2). But population trends were not similar in the sample counties, as observed above. In isolation, the estimate for mean population density is not very informative. Its inclusion is nonetheless important because it improves the estimates of within-unit or time-varying change. In multilevel modeling, the practice of including and subtracting the effects of unit-specific means from a time varying variable is sometimes referred to as group mean centering (Kreft and Leeuw 1998; Raudenbush and Anthony 2002). When both population density estimates (mean and deviation from the mean) are included in Model D they suggest that counties with higher deviations above the mean – areas like the predominantly urban Colorado counties near the cities of Denver, Boulder and Fort Collins - were more likely to expand marginal land use than areas where population was declining or growing more slowly, like counties in western Kansas, southeastern Nebraska, central North Dakota, South Dakota, or northeastern Iowa (see Table 1).

More importantly, the introduction of both population density covariates significantly alters the magnitude and direction of the time trends. It increases the estimated reductions of marginal land use in the 1950s and 1970s, and reverses the direction of predicted changes in marginal land use in the 1990s and 2000s. Rather than the increases seen in Model C, the Model D estimates with population density as covariates predict statistically significant declines between the 1990s and the 2000s. Instead of a story of riskier behavior over time, the hybrid model suggests outcomes heavily influenced by the heterogeneity (the between-unit variation) that characterizes the region and the pressures of growing population densities in specific areas of the Great Plains. To emphasize this point it is worth noting that the population density covariate re-centers the constant, and raises the levels of the regional contrasts. While this does not affect the tallgrass estimate very much, controlling for

population density actually raises the estimate of the effects of a sample unit's location within the shortgrass and Colorado shortgrass regions. The omitted categories are the two mixed-grass regions in the center of the plains, which have experienced less population change over the later part of the 20th century.

Conclusions

Returning to the scientific ambitions of soil conservation in the 1930s is a fitting way to judge the ecological well-being of the Great Plains at the beginning of a new century, especially when seen in the broader context of changing population density. The proportions of grassland that have escaped tillage have not been as large as conservation policy makers may have hoped since the 1930s. One of the advantages of undertaking this study is that it has shifted our focus of investigation away from farm operators and reported farm activity towards repeated measure of specific landscapes over a very long period of time. This new window on long-term patterns of change enables us to construct a historical time series for assessing just how much has changed. One measure of the contribution of this research is the degree to which it emphasizes the mix of demographic, technological, and policy factors that contribute to land use dynamics, and how these interact with the biophysical environment to affect land management. Land-management policy today tries to help individual producers establish the right mix of conservation practice and economic growth, adding to the knowledge possessed by those who intimately understand the capabilities of the land. Our challenge is to understand those earlier conservation ambitions in terms of the greater precision we can now bring to our research questions (Nowak 2013).

A key finding of this research is that for all of the change of the last 70 years, the choices people make about where to live are having a growing and negative impact on farm land in the urban shadow. Highly sensitive landscapes, those with larger shares of native grassland, poor soil, and high population densities have been most at risk of moving in and out of cultivation. It is worth noting that several conservation policy regimes have produced declines in the cropping of poor soils, but more recent policy efforts have taken place in an era when urban population pressure serves as a countervailing force. We have shown that greater population densities are associated on the one hand with overall reductions in cropland, while on the other they are associated with an increase in the use of marginal land for cropping, possibly in a substitution process where higher quality land goes into urban and suburban uses, and lower quality land is then shifted into cropping. Yet this is not true throughout the region. In the big “in-between” parts of the plains region, where soil conditions and climates are more favorable, land management has generally been responsive to the original ambitions or benchmarks of conservation scientists in the 1930s. The use of marginal land has changed little over 70 years in the mixed or tallgrass regions. Although cropland has continued to expand in every part of the region until very recently, there have been steady reductions in the proportion of cropping on marginal soils, except for the northern mixed grass region. Away from large and growing metropolitan areas, the reduced use of marginal land remains the largest trend in the working landscapes of the region. We may take some comfort in this. Whether the guiding policy was the land retirement of the post-war years or targeted payments of more recent conservation, reductions in marginal land use have been the norm in the plains region since the 1930s. But this conclusion is not

grounds for complacency. More work needs to be done to adjust to the effects of population density and protect sensitive land near urban centers – phenomena not anticipated in the legislative ambitions of conservation scientists in the 1930s.

Acknowledgments

This publication was made possible by Grant Number R01 HD033554 from the Eunice Kennedy Shriver National Institute of Child Health and Human Development (NICHD). Its contents are solely the responsibility of the authors and do not reflect the views of the NICHD. The authors are grateful to the many undergraduate students who worked on the aerial photo interpretation, for archival research at the National Archives performed by then Ph.D. candidate (at the University of Maryland) Jacqueline Waite (to identify images from the 1930s photo maps), the coordination and leadership of project manager Rachel Kornak at the University of Michigan, and for statistical advice, in recommending the hybrid approach, we thank Glenn D. Deane, Professor of Sociology, State University of New York, Albany.

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Appendix A. Air Photo Source Dates

State	County	Imagery				
		1930s	1950s	1970s	1990s	2000s
Colorado	Adams	1937	1963	1977	1993	2005
	Arapahoe	1937	1963	1977	1993	2006
	Logan	1937	1963	1978	1993	2006
	Morgan	1937	1963	1979	1989	2006
	Weld	1937	1963	1977	1993	2006
Iowa	Lyon	1936–1941	1962	1978	1994	2006
	O'Brien	1936–1941	1962	1978	1994	2006
	Osceola	1936–1941	1962	1978	1994	2006
	Sioux	1936–1941	1962	1978	1994	2006
Kansas	Ford	1938	1960	1981	1991	2006
	Gray	1939	1960	1981	1991	2006
	Haskell	1936	1960	1981	1991	2006
	Marshall	1937	1962	1978	1991	2006
	Seward	1936	1960	1981	1991	2006
	Stevens	1936	1960	1981	1991	2006
Minnesota	Clay	1939	1958	1981	1991	2003
	Nobles	1938	1962	1979	1991	2003
	Norman	1939	1958	1974	1991	2006
Montana	Cascade	1937	1957	1977	1995	2005
	Choteau	1937	1956	1979	1996	2006

State	County	Imagery				
		1930s	1950s	1970s	1990s	2000s
Nebraska	Hill	1939	1960	1979	1997	2006
	Liberty	1940	1957	1979	1997	2006
	Toole	1937	1957	1979	1991	2006
	Gage	1940	1959	1979	1993	2003
	Jefferson	1938	1962	1977	1993	2007
	Saline	1938	1962	1977	1993	2007
	Seward	1938	1959	1977	1999	2006
	Cass	1937	1962	1980	1991	2006
	Dunn	1939	1958	1977	1995	2006
	Grand Forks	1937	1962	1980	1997	2006
North Dakota	McLean	1938	1958	1976	1995	2005
	Mercer	1938	1958	1976	1995	2006
	Morton	1938	1957	1980	1997	2006
	Oliver	1938	1957	1980	1995	2006
	Traill	1937	1962	1980	1997	2005
	Blaine	1937	1957	1979	1995	2006
	Canadian	1937	1957	1979	1995	2006
	Garfield	1937	1961	1981	1995	2006
	Kingfisher	1937	1957	1979	1995	2003
	Noble	1937	1961	1980	1995	2006
South Dakota	Faulk	1939	1957	1978	1996	2006
	Hand	1939	1957	1978	1996	2006
	Hyde	1939	1957	1978	1998	2006
	Potter	1939	1962	1976	1997	2006
	Sully	1939	1962	1976	1997	2006
	Crosby	1939	1963	1980	1996	2006
	Dawson	1939	1962	1980	1995	2006
	Lubbock	1940	1962	1979	1995	2006
	Lynn	1940	1962	1980	1995	2006
	Terry	1940	1962	1980	1996	2006

Note: The 1930s Iowa mosaics were downloaded from the Iowa State University Geographic Information Support & Research Facility <http://ortho.gis.iastate.edu/>

Metadata indicate source is USDA but provide a date range for the source imagery in the 1930s, not a specific year.

Appendix B. Multilevel Regression Variables: Descriptive Statistics

	Variable Name	Description	Units	Obs	Mean	Std. Dev.	Min	Max
Time	1950s	Dummy variable for 1950s						
	1970s	Dummy variable for 1970s						
	1990s	Dummy variable for 1990s						
	2000s	Dummy variable for 2000s						
Micro	Dev. Crop	Deviation from long term mean, Cropland	square meters	72,000	−0.000063	88,658.7	−462,440.9	486,303.0
	Dev. Grass	Deviation from long term mean, Grassland	square meters	72,000	−0.000038	89,420.0	−462,439.3	462,440.9
	Mean Crop	Long term mean, 1936–2006, Cropland	square meters	72,000	385,486.5	182,774.2	0.0	578,061.3
	Mean Grass	Long term Mean, 1936–2006, Grassland	square meters	72,000	159,299.1	173,041.1	0.0	578,061.5
	Null Soil Ratings	Missing soil ratings, per sample unit	square meters	72,000	2,673.9	22,179.0	0.0	542,586.0
	Poor Soil (LCC>=4)	Cropland on poor soil (LCC4 or higher)	square meters	72,000	60,028.3	115,523.4	0.0	578,061.5
County	Dev. Implement Values	Deviation from long term mean, 1940–2007	nominal dollars	250	0.000234	67,972.1	−148,600.6	217,454.1
	Dev. Large Farms	Deviation from long term mean, 1940–2007	number, farms > 1,000 acres	250	0.000000	50.8	−207.6	102.8
	Dev. Irrigated Farm Land	Deviation from long term mean, 1940–2007	acres	250	−0.000209	30,388.4	−182,423.4	135,058.6
	Dev. Population Density	Deviation from long term mean, 1940–2000	persons per square mile	250	0.000000	35.6	−290.4	282.1
	Mean Implement Values	Mean implement values, per farm, 1940, 1959, 1978, 1992, 2007	nominal dollars	250	71,408.1	24,968.7	33,823.4	149,755.6
	Mean Large Farms	Mean number of large farms,	number, farms > 1,000 acres	250	173.4	123.1	21.6	602.0

Variable Name		Description	Units	Obs	Mean	Std. Dev.	Min	Max
	Mean Irrigated Farm Land	Mean irrigated farmland, 1940, 1959, 1978, 1992, 2007	acres	250	37,780.5	64,917.4	0.0	366,517.0
	Mean Population Density	Mean population density, 1940, 1960, 1980, 1990, 2000	persons per square mile	250	30.6	55.5	1.6	329.3
	Region							
	Shortgrass Region	Dummy variable for Shortgrass bioregion						
	Colorado Shortgrass	Dummy variable for Colorado Shortgrass cluster						
	Tallgrass Region	Dummy variable for Tallgrass bioregion

Figure 1.

Figure 2.

Figure 3.

Figure 4.

Table 1

Population and Population Density (persons per square mile) in 50 study counties, by State and Year.

State	County	Population				Population Density					
		1940	1960	1980	1990	2000	1940	1960	1980	1990	2000
Colorado	Adams	22,481	120,296	245,944	265,038	363,857	18.0	96.6	199.6	222.3	311.7
	Arapahoe	32,150	113,426	293,621	391,511	487,967	38.9	139.3	369.3	487.5	611.4
	Logan	18,370	20,302	19,800	17,567	20,504	10.1	11.1	10.9	9.6	11.2
	Morgan	17,214	21,192	22,513	21,939	27,171	13.4	16.5	17.6	17.1	21.2
	Weld	63,747	72,344	123,438	131,821	180,936	15.9	18.1	30.8	33.0	45.4
Iowa	Lyon	15,374	14,468	12,896	12,329	11,763	26.1	24.6	21.9	21.0	20.0
	O'Brien	19,293	18,840	16,972	16,037	15,102	33.6	32.8	29.5	28.0	26.4
	Osceola	10,607	10,064	8,371	7,687	7,003	26.7	25.4	21.0	19.3	17.6
	Sioux	27,209	26,375	30,813	31,201	31,589	35.5	34.4	40.2	40.6	41.1
Kansas	Ford	17,254	20,938	24,315	27,463	32,458	15.9	19.3	22.3	25.0	29.6
	Gray	4,773	4,380	5,138	5,396	5,904	5.5	5.0	5.9	6.2	6.8
	Haskell	2,088	2,990	3,814	3,886	4,307	3.6	5.2	6.6	6.7	7.5
	Marshall	20,986	15,598	12,787	11,705	10,965	23.0	17.1	14.5	13.0	12.2
	Seward	6,540	15,930	17,071	18,743	22,510	10.2	24.9	26.4	29.3	35.2
Minnesota	Stevens	3,193	4,400	4,736	5,048	5,463	4.4	6.0	6.5	6.9	7.5
	Clay	25,337	39,080	49,327	50,278	51,229	24.1	37.2	47.2	48.1	49.0
	Nobles	21,215	23,365	21,840	21,336	20,832	29.8	32.8	30.7	29.8	29.1
	Norman	14,746	11,253	9,379	8,410	7,442	16.7	12.7	10.6	9.6	8.5
Montana											
	Cascade	41,999	73,418	80,696	77,691	80,357	15.8	27.6	30.3	28.8	29.8
	Choteau	7,316	7,348	6,092	5,452	5,970	1.9	1.9	1.6	1.4	1.5
	Hill	13,304	18,653	17,985	17,654	16,673	4.5	6.4	6.1	6.1	5.8
	Liberty	2,209	2,624	2,329	2,295	2,158	1.5	1.8	1.6	1.6	1.5
Nebraska	Toole	6,769	7,904	5,559	5,046	5,267	3.4	4.1	2.9	2.6	2.8
	Gage	29,588	26,818	24,456	22,794	22,993	34.5	31.3	28.5	26.6	27.0

State	County	Population				Population Density					
		1940	1960	1980	1990	2000	1940	1960	1980	1990	2000
North Dakota	Jefferson	15,532	11,620	9,817	8,759	8,333	26.9	20.1	17.0	15.3	14.6
	Saline	15,010	12,542	13,131	12,715	13,843	26.1	21.8	22.8	22.1	24.1
	Seward	14,167	13,581	15,789	15,450	16,496	24.8	23.7	27.7	26.9	28.9
	Cass	52,849	66,947	88,247	102,874	123,138	30.2	38.3	50.5	58.3	69.8
	Dunn	8,376	6,350	4,627	4,005	3,600	4.1	3.2	2.3	2.0	1.8
	Grand Forks	34,518	48,677	66,100	70,683	66,109	24.0	33.9	46.0	49.2	46.0
	McLean	16,082	14,030	12,383	10,457	9,311	7.0	6.7	6.0	5.0	4.4
	Mercer	9,611	6,805	9,404	9,808	8,644	8.8	6.5	9.0	9.4	8.3
	Morton	20,184	20,992	25,177	23,700	25,303	10.4	10.9	13.1	12.3	13.1
	Oliver	3,859	2,610	2,495	2,381	2,065	5.4	3.6	3.5	3.3	2.9
Oklahoma	Traill	12,300	10,583	9,624	8,752	8,477	14.3	12.3	11.2	10.2	9.8
	Blaine	18,543	12,077	13,443	11,470	11,976	20.0	13.3	14.7	12.4	12.9
	Canadian	27,329	24,727	56,452	74,409	87,697	30.9	27.9	62.9	82.7	97.8
	Garfield	45,484	52,975	62,820	56,735	57,813	43.2	50.3	59.6	53.6	54.6
	Kingfisher	15,617	10,635	14,187	13,212	13,926	17.5	11.9	15.7	14.6	15.5
	Noble	14,826	10,376	11,573	11,045	11,411	19.9	13.9	15.6	15.1	15.5
	Faulk	5,168	4,397	3,327	2,744	2,640	5.2	4.4	3.3	2.7	2.7
	Hand	7,166	6,712	4,948	4,272	3,741	5.0	4.7	3.5	3.0	2.6
	Hyde	3,113	2,602	2,069	1,696	1,671	3.6	3.0	2.4	2.0	1.9
	Potter	4,614	4,926	3,674	3,190	2,693	5.2	5.6	4.2	3.7	3.1
South Dakota	Sully	2,668	2,607	1,990	1,589	1,556	2.5	2.5	2.0	1.6	1.5
	Crosby	10,046	10,347	8,859	7,304	7,072	11.0	11.4	9.7	8.1	7.9
	Dawson	15,367	19,185	16,184	14,349	14,985	17.1	21.4	17.9	15.9	16.6
	Lubbock	51,782	156,271	211,651	222,636	242,628	58.1	175.2	237.0	247.5	270.9
	Lynn	11,931	10,914	8,605	6,758	6,550	13.0	11.9	9.4	7.6	7.3
	Terry	11,160	16,286	14,581	13,218	12,761	12.4	18.1	16.2	14.9	14.4

Source: US Census, Population, 1940, 1960, 1980, 1990 and 2000.

Table 2

Land Use Trends in Study Areas, by Kuchler Zone and Year.

Kuchler Zone	Decade	Crops on poor soil		Poor soil		Area		Crop		Grass		Crop		Crops Poor Soil	
		acres	%	acres	%	acres	%	acres	%	acres	%	acres	%	acres	%
Shortgrass	1930	80,309		246,611		657,299		331,121		301,468		-		-	
	1950	107,491		246,611		657,299		405,252		234,008		22		34	
	1970	117,622		246,611		657,299		427,492		210,781		5		9	
	1990	128,742		246,611		657,299		442,318		199,661		3		9	
	2000	108,973		246,611		657,299		392,897		240,186		-11		-15	
North Mixed Grass	1930	38,548		88,216		494,210		266,873		197,684		-		-	
	1950	38,301		88,216		494,210		269,344		194,225		1		-1	
	1970	41,019		88,216		494,210		284,171		187,058		6		7	
	1990	42,255		88,216		494,210		291,584		173,715		3		3	
	2000	42,996		88,216		494,210		291,584		177,421		0		2	
South Mixed Grass	1930	24,117		44,726		289,113		182,363		77,344		-		-	
	1950	22,635		44,726		289,113		182,858		74,873		0		-6	
	1970	25,205		44,726		289,113		189,282		71,413		4		11	
	1990	26,934		44,726		289,113		191,753		66,965		1		7	
	2000	20,164		44,726		289,113		171,738		84,263		-10		-25	
Tallgrass	1930	42,502		82,780		617,763		501,623		81,792		-		-	
	1950	38,795		82,780		617,763		504,094		75,614		0		-9	
	1970	41,514		82,780		617,763		513,978		62,765		2		7	
	1990	42,749		82,780		617,763		513,978		55,599		0		3	
	2000	37,560		82,780		617,763		504,094		67,460		-2		-12	

Source: Great Plains Land-Use Geodatabase.

Land cover classes not included in Table 2: developed, transportation, orchard, pasture, forest, forested grassland, shelterbelt, waterbody and non-forested wetlands.

Table 3

Predicting the Growth of Cropland, 1936–2006

Level	Cropland (square meters)	Model A no population density			Model B population density added		
		Coefficient	z	P	Coefficient	z	P
Time	1950s	6,084.12	9.0	0.000	6,766.62	10.0	0.000
	1970s	8,320.17	10.2	0.000	10,011.48	11.8	0.000
	1990s	2,960.17	2.8	0.005	5,440.47	4.9	0.000
	2000s	-3,876.42	-2.9	0.004	-416.70	-0.3	0.773
Micro	Dev. Crops on Poor Soil	0.36	72.5	0.000	0.37	72.7	0.000
	Dev. Grass	-0.77	-277.9	0.000	-0.77	-277.3	0.000
	Mean Crops on Poor Soil	0.10	33.5	0.000	0.10	33.5	0.000
	Mean Grass	-0.95	-491.3	0.000	-0.95	-491.3	0.000
County	Null Soil Ratings	-0.14	-12.9	0.000	-0.14	-12.9	0.000
	Poor Soil (LCC=4)	-0.09	-44.3	0.000	-0.09	-44.3	0.000
	Dev. Implement Values	0.05	6.7	0.000	0.03	4.7	0.000
	Dev. Large Farms	-43.95	-9.9	0.000	-48.29	-10.7	0.000
Regional	Dev. Irrigated Farm Land	-0.03	-3.9	0.000	-0.03	-3.7	0.000
	Dev. Population Density	-	-	-	-39.32	-7.1	0.000
	Mean Implement Values	0.52	8.5	0.000	0.54	8.7	0.000
	Mean Large Farms	-3.88	-0.3	0.764	3.66	0.3	0.789
Regional	Mean Irrigated Farm Land	0.01	0.3	0.769	0.01	0.6	0.572
	Mean Population Density	-	-	-	53.61	1.7	0.091
	Shortgrass Region	15,877.74	3.9	0.000	14,126.40	3.4	0.001
	Colorado Shortgrass	11,905.15	2.0	0.045	7,741.22	1.2	0.227
Regional	Tallgrass Region	2,924.26	0.8	0.418	2,904.10	0.8	0.420
	Constant	496,451.50	96.3	0.000	491,087.50	87.7	0.000
Number of obs		72,000			72,000		
Number of groups		400			400		
obs per group		180			180		
R-sq: within		0.893			0.893		

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Level	Cropland (square meters)	Model A no population density			Model B population density added		
		Coefficient	z	P	Coefficient	z	P
	between	0.956			0.956		
	overall	0.923			0.923		
	sigma_u	27577.147			27511.285		
	sigma_e	48340.507			48323.879		
	rho	0.2455358			0.2447782		

Table 4

Predicting the growth of cropland on poor soil, 1936–2006

Crops on Poor Soil (LCC>=4)	Model C no population density			Model D population density added		
	Coefficient	z	P	Coefficient	z	P
1950s	-4,385.85	-4.6	0.000	-7,241.05	-7.5	0.000
1970s	-3,275.15	-2.8	0.005	-10,512.88	-8.7	0.000
1990s	1,759.01	1.2	0.239	-8,973.42	-5.7	0.000
2000s	6,327.76	3.3	0.001	-8,696.07	-4.2	0.000
Dev. Crop	0.38	52.2	0.000	0.37	51.8	0.000
Dev. Grass	-0.03	-4.6	0.000	-0.03	-4.4	0.000
Mean Crop	0.29	39.9	0.000	0.29	40.0	0.000
Mean Grass	-0.03	-3.5	0.000	-0.03	-3.5	0.000
Null Soil Ratings	-0.31	-19.6	0.000	-0.31	-19.6	0.000
Poor Soil (LCC>=4)	0.37	142.0	0.000	0.37	142.5	0.000
Dev. Implement Values	-0.07	-6.5	0.000	-0.01	-0.8	0.441
Dev. Large Farms	15.87	2.5	0.013	34.36	5.4	0.000
Dev. Irrigation Farm Land	0.05	4.8	0.000	0.04	4.2	0.000
Dev. Population Density	-	-	-	169.07	21.8	0.000
Mean Implement Values	-0.51	-4.9	0.000	-0.54	-5.1	0.000
Mean Large Farms	15.07	0.7	0.496	4.94	0.2	0.833
Mean Irrigated Farm Land	-0.06	-1.4	0.153	-0.07	-1.6	0.105
Mean Population Density	-	-	-	-71.96	-1.3	0.187
Shortgrass Region	16,755.50	2.4	0.015	19,105.36	2.7	0.008
Colorado Shortgrass	67,563.97	6.7	0.000	73,147.15	6.7	0.000
Tallgrass Region	-20,318.87	-3.3	0.001	-20,289.30	-3.3	0.001
Constant	-58961.53	-6.2	0	-46,860.47	-4.6	0.000
Number of obs	72,000			72,000		
Number of groups	400			400		
obs per group	180			180		
R-sq: within	0.395			0.399		

Crops on Poor Soil (LCC>=4)	Model C no population density			Model D population density added		
	Coefficient	z	P	Coefficient	z	P
between	0.525			0.527		
overall	0.445			0.448		
sigma_u	47324.17			47385.545		
sigma_e	68776.658			68550.507		
rho	0.3213256			0.3233307		