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Adaptation on an Agricultural Frontier: Socio-Ecological Profiles of Great Plains Settlement, 1870–1940

The most important agricultural development of the nineteenth century was a massive and rapid expansion of farmland in the world's grasslands, a process that doubled global land in farms. Displacing indigenous populations, European settlers plowed and fenced extensive new territories in North America's Great Plains, South America's campos and pampas, the Ukrainian and Russian steppes, and parts of Australia and New Zealand. Between 1800 and 1920, arable land increased from 400 million to 950 million hectares (or ha), and pasture land from 950 to 2,300 million ha; much of that expansion occurred in grasslands. These regions became enduring "breadbaskets" for their respective nations, feeding the nineteenth century's 60 percent increase in world population. Never had so much new land come into agricultural production so fast. This episode was one of the most extensive and important environmental transformations in world history.[1]

Frontier settlement took place in the context of modern nation-states intent on expanding their territory, increasing their populations, and developing their economies. Nineteenth-century agricultural

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1 John Richards, *The Unending Frontier: An Environmental History of the Early Modern World* (Berkeley, 2003); David Moon, *The Plough that Broke the Steppes: Agriculture and Environment on Russia's Grasslands, 1700–1914* (New York, 2013); Kees Klein Goldewijk, "Estimating Global Land Use Change Over the Past 300 Years: The HYDE Database," *Global Biogeochemical Cycles,* XV (2001), 417–433. Between 1800 and 1920, world population grew from 1.0 to 1.6 billion. See U.S. Census Bureau, available at www.census.gov/population/international/data/worldpop/table_history.php.

colonization was a state enterprise as much as a folk movement. Governments subsidized pioneer settlement through indigenous displacement, free or low-cost land grants, and such infrastructural development as roads, railroads, and post offices. They also gathered statistics—population and agricultural censuses—that both monitored the process and promoted further immigration. Environmental historians today benefit from an unprecedented, detailed, documentary record that reveals a massive ecological transformation from its very beginning. This article offers a systematic evaluation of the world's nineteenth-century agricultural frontiers based on census data and employing socio-ecological metabolism methods drawn from sustainability science and agro-ecology. It identifies ten measures that define "socio-ecological profiles" of particular farm communities. Although the present examples come from the U.S. Great Plains, the approach is applicable anywhere governments deployed systematic censuses. Socio-ecological profiles reveal the extent to which settlers changed the environment, but especially the ways by which they adapted to accommodate natural constraints. Propelled by personal ambition and national incentive, Great Plains settlers transformed the land, but they also made more accommodations to nature's limits than we often acknowledge.[2]

In North America's grassland farmers converted nearly one-fifth of the continent to agriculture between 1830 and 1930. The transformation of native prairie into managed farmland created hybrid human–natural landscapes that then required further readjustment by settlers to accommodate both natural forces and the new environmental conditions of their own making. It was an adaptive, evolutionary, and recursive process. Environmental history emphasizes the ways in which people altered and damaged natural systems. The interaction between humans and nature, however, operates in both directions. Environmental historians have said less about how nature pushed back, limited options, constrained choices, and thus channeled cultural outcomes. The

2 James C. Scott, *Seeing Like a State: How Certain Schemes to Improve the Human Condition Have Failed* (New Haven, 1998). In the United States, digitized population and agricultural census data for all of the Great Plains counties at twenty-two time points are available from the Inter-University Consortium for Political and Social Research (ICPSR) at the University of Michigan. See Myron P. Gutmann, *Great Plains Population and Environment Data: Agricultural Data, 1870–1997*, ICPSR04254-v1, Ann Arbor, ICPSR, 2005-06-22, doi:10.3886/ICPSR04254.v1; *idem*, *Great Plains Population and Environment Data: Social and Demographic Data, 1870–2000*, ICPSR04296-v2, Ann Arbor, ICPSR, 2007-02-07, doi:10.3886/ICPSR04296.v2.

socio-ecological profiles presented herein reveal how rapidly and extensively frontier farmers adjusted farming practices to fit into their newly occupied environments. Making farms on new land was a back-and-forth process; settlers often compromised their own ambitions to accommodate natural imperatives. Community-scale socio-ecological profiles highlight both processes.[3]

The Great Plains environment that Euro-American settlers encountered when they arrived in the late nineteenth century was already a hybrid human–natural system, a joint creation of long-term natural processes and 10,000 years of active cultural management. Native Americans altered grassland ecosystems by hunting large and small animals (even to extinction); by breeding hundreds of thousands of domesticated horses; through river-valley agriculture (though only to a limited extent); and, especially, through fire management. By intervening in fire regimes to alter their timing and frequency, burning woodlands to create grassland habitat suitable for bison, firing pastures to raise carrying capacity for large grazers, and surgically burning transition zones to create edge habitats, Native Americans inscribed a cultural signature onto what Euro-Americans mistakenly considered pristine wilderness. When settlers built a new socio-ecological regime around private property and family farms, they replaced one cultural landscape with another.[4]

The Great Plains frontier in the late nineteenth century was remarkably cosmopolitan. Alongside Native Americans, now confined to ever-shrinking reservations, and Hispanic descendents of

3 R. Douglas Hurt, *The Big Empty: The Great Plains in the Twentieth Century* (Tucson, 2011); Cunfer, *On the Great Plains: Agriculture and Environment* (College Station, 2005); Mary M. W. Hargreaves, *Dry Farming in the Northern Great Plains: Years of Adjustment, 1920–1990* (Lawrence, 1993); Gerald Friesen, *The Canadian Prairies: A History* (Toronto, 1987); James C. Malin (ed. Robert P. Swierenga), *History and Ecology: Studies of the Grassland* (Lincoln, 1984); Donald Worster, *Dust Bowl: The Southern Plains in the 1930s* (New York, 1979); Hargreaves, *Dry Farming in the Northern Great Plains, 1900–1925* (Cambridge, Mass.,1957); Paul Wallace Gates, *Fifty Million Acres: Conflicts Over Kansas Land Policy, 1854–1890* (Ithaca, 1954); Walter Prescott Webb, *The Great Plains* (Boston, 1931).

4 "Fire regime" refers to the frequency, seasonal timing, and fuel conditions typical of a place, as determined by climate, topography, vegetation, and human management. George Colpitts, *Pemican Empire: Food, Trade, and the Last Bison Hunts in the North American Plains, 1780–1882* (New York, 2014); Pekka Hamalainen, "The Rise and Fall of Plains Indian Horse Cultures," *Journal of American History*, XC (2003), 833–862; James E. Sherow, "Workings of the Geodialectic, High Plains Indians and their Horses in the Region of the Arkansas River Valley, 1800–1870," *Environmental History Review*, XVI (1992), 61–84; Dan Flores, "Bison Ecology and Bison Diplomacy, The Southern Plains from 1800 to 1850," *Journal of American*

Spanish colonists in the Southwest, new settlers poured into the region from near and far. Americans from the eastern states fell into two broad groups—northerners and southerners. From Kansas north to the Dakotas, settlers came from Ohio, Pennsyslvania, and New England, many of them Union Civil War veterans who imported "free soil" beliefs and the ideal of the small family farm as a cornerstone of republican government. Landmark agrarian legislation of the 1860s embedded their ideology: the Homestead Act that opened up free land in the West, the Morrill Act that funded land-grant and agricultural colleges, and President Lincoln's creation of the Department of Agriculture as a cabinet-level agency. In Oklahoma and Texas, immigrants came from the defeated and economically devastated former Confederacy.

The Homestead Act placed no restriction on citizenship; the lure of free land also drew Europeans. In Nebraska, for example, half of the population between 1870 and 1900 was first- or second-generation immigrants; in North Dakota, the proportion of immigrants was as many as three-quarters. The southern plains hosted many fewer foreign immigrants. Immigrant farmers arrived from Germany, Britain, Ireland, Canada, Scandinavia, and Central Europe in great numbers. Despite the cultural diversity and varied agricultural backgrounds evident in frontier communities across the plains, land use on the frontier converged quickly. Within only a few years, it became impossible to distinguish cultural ancestry based on farm structure, land use, or even crop choice. Regardless of their provenance, plains settlers quickly built farms that looked much like those of their neighbors.[5]

History, LXXVIII (1991), 465–485; Hurt, *Indian Agriculture in America: Prehistory to the Present* (Lawrence, 1987), 57–64; Waldo R. Wedel, *Central Plains Prehistory: Holocene Environments and Culture Change in the Republican River Basin* (Lincoln, 1986); Paul S. Martin and Richard G. Klein (eds.), *Quaternary Extinctions: A Prehistoric Revolution* (Tucson, 1984); H. E. Wright, Jr., and David G. Frey (eds.), *The Quaternary of the United States* (Princeton, 1965); Julie Courtwright, *Prairie Fire: A Great Plains History* (Lawrence, 2011); William F. Rannie, "'Awful Splendour': Historical Accounts of Prairie Fire in Southern Manitoba Prior to 1870," *Prairie Forum*, XXVI (2001), 17–42; Stephen J. Pyne, *Fire in America: A Cultural History of Wildland and Rural Fire* (Princeton, 1982), 84–99.

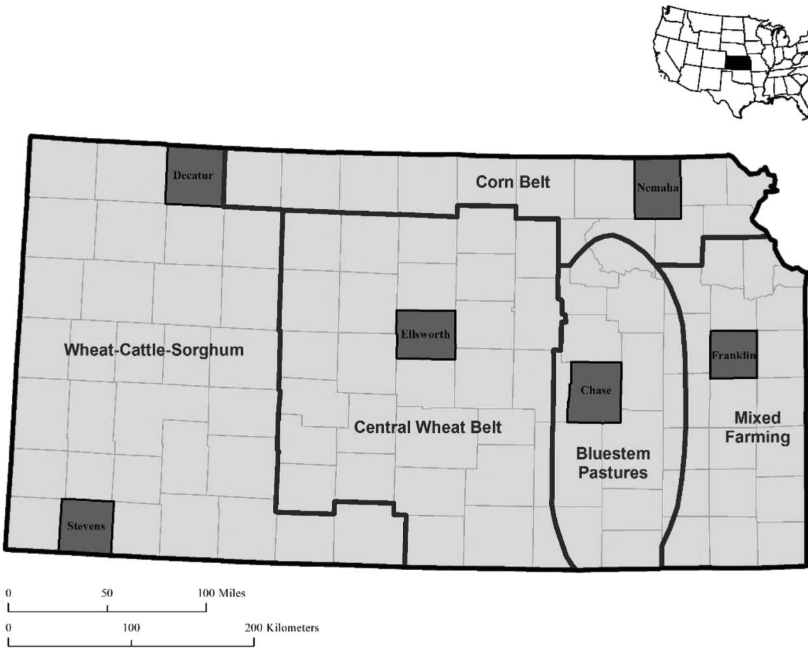
5 Frederick C. Luebke, "Ethnic Group Settlement on the Great Plains," *Western Historical Quarterly*, VIII (1977), 405–430; David J. Wishart (ed.), *Encyclopedia of the Great Plains* (Lincoln, 2007); Gutmann, Sara M. Pullum, Susan Gonzalez Baker, and Ingrid C. Burke, "German-Origin Settlement and Agricultural Land Use in the Twentieth Century Great Plains," in Walter Kamphoefner and Wolfgang Helbich (eds.), *German-American Immigration and Ethnicity in Comparative Perspective* (Madison, 2004), 138–168; Cunfer and Krausmann, "Sustaining Soil Fertility: Agricultural Practice in the Old and New Worlds," *Global Environment*, IV (2009), 8–47.

Kansas, the center of this cultural transition after the Civil War, is a microcosm of the Great Plains environment, spanning wet to dry climate zones and tallgrass to shortgrass vegetation regimes. Rainfall declines from humid eastern Kansas, where average annual precipitation exceeds 40 inches (1,000 mm), to the semi-arid west, where the average rainfall is as low as 16 inches (400 mm). But averages disguise high annual variation. In the middle of a continent, far from hydrating, warming, and moderating oceans, the Great Plains has weather that fluctuates wildly, bringing extended droughts, heat waves, bitterly cold winters, and near constant wind. Water, or lack of it, was always the crucial natural constraint on people's ambitions and land use. Vegetation followed climate patterns, but with significant human-induced alterations. Tallgrass prairie in the east depended upon regular burning by Native Americans. When Euro-American settlers suppressed fire, uncultivated tallgrass prairie grew into low forest and brushland. The mixed-grass transition zone in central Kansas intermingled tallgrasses with shortgrass species. Shortgrass steppe vegetation dominated the dry western third of Kansas, soon to become part of America's "wheat belt." Settlers discovered a gradient of vegetation, some of it cutting against climate drivers because of Native American management. Beneath those grasses lay deep, rich soils holding 10,000 years' worth of stockpiled nutrients, including nitrogen, phosphorous, potassium, and a dozen micronutrients essential to plant growth. Kansas had some of the richest soils in the world. Farmers immediately recognized their good fortune when they plowed the land. After climate, soil was the most important natural factor guiding land-use decisions. Soil conditions were also dynamic in the frontier context, changing during the first sixty years as a result of agricultural practices.[6]

What were the biophysical dynamics of newcomers' interaction with nature on this agricultural frontier? Given the extent, social significance, and environmental impact of frontier settlement, this is a significant question for environmental history. Agricultural land now occupies one-third of the earth's surface and feeds most of its population, making it a fundamental intermediary between people and nature. In ancient agricultural landscapes, initial colonization happened in so remote a past that few historical sources

6 Courtwright, *Prairie Fire*, 169–187; Samuel L. Tisdale, Werner L. Nelson, James D. Beaton, and John L. Havlin, *Soil Fertility and Fertilizers* (New York, 1993; orig. pub. 1956), 46–48.

Fig. 1 Case-Study Counties in Kansas, within Agro-Ecological Zones



SOURCE James Malin, *Winter Wheat in the Golden Belt of Kansas: A Study in Adaptation to Subhumid Geographical Environment* (Lawrence, 1944) 1–5.

remain from which to reconstruct biophysical processes. Well-documented cases of agricultural expansion into new lands thus deserve careful attention.

Published land-use data for all counties in the United States are available from 1840 to the present, with information sufficient for socio-ecological analysis from 1880 onward. Kansas, more diligently than other states, compiled its own annual agricultural censuses from 1874 to 1983, representing every county in the state, each year, for more than a century. This documentary basis enables construction of socio-ecological profiles of pioneer land conversion in six counties that represent each of Kansas's agro-ecological zones (Figure 1).[7]

7 Worster, "Transformations of the Earth: Toward an Agroecological Perspective in History," *Journal of American History*, LXXVI (1990), 1087–1106; N. Ramankutty, A.T. Evan, C. Monfreda, and J. A. Foley, "Global Land-Cover Change: Recent Progress, Remaining Challenges," in Eric F. Lambin and Helmut J. Geist (eds.), *Land-Use and Land-Cover Change: Local Processes and Global Impacts* (Berlin, 2010), also available at http://dx.doi.org/10.1007/3-540-32202-7; Jed O. Kaplan, Kristin M. Krumhardt, and Niklaus Zimmermann, "The Prehistoric

SOCIO-ECOLOGICAL PROFILES OF HISTORICAL AGRO-ECOSYSTEMS Socio-ecological metabolism (SEM) draws together analytical approaches from agro-ecology and sustainability science. Agro-ecologists evaluate farms in much the same way that ecologists study natural ecosystems. They recognize ecological processes at work, even in highly managed landscapes. Sustainability disciplines, such as ecological economics and industrial ecology, employ "social metabolism" methods that focus on the economy's biophysical exchanges, such as material and energy flows embedded in international trade and in domestic extraction and consumption. SEM brings these two approaches together to measure material flows (carbon and nitrogen) and energy flows (plant biomass, food, and fossil fuels) through socio-ecological systems, not unlike ecologists' tracking of such processes in natural forests, wetlands, or grasslands. SEM then relates those biophysical processes to socio-economic parameters like population, land use, and economic development. Marx suggested such an analysis of agricultural systems as early as the mid-nineteenth century. He proposed that capitalist agriculture created a material imbalance between rural landscapes where farmers deplete soil nutrients and export them to urban markets. Foster characterized this imbalance as a "metabolic rift," arguing that Marx anticipated modern sustainability and ecological analysis. However, only in recent years have scholars adopted a metabolic analysis of socio-ecological systems.[8]

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and Preindustrial Deforestation of Europe," *Quaternary Science Reviews*, XXVIII (2009), 3016–3034. For environmental histories of agricultural colonization, see Moon, *The Plough that Broke the Steppe*; Brian Donahue, *The Great Meadow: Farmers and the Land in Colonial Concord* (New Haven, 2007); Worster, *Dust Bowl*. However, none of these studies employs a socio-ecological metabolism methodology. U.S. Bureau of the Census, *Census of the United States* (Washington, D. C., 1840–1940 [decennial]); *idem*, *United States Census of Agriculture* (Washington, D.C., 1925, 1935, 1945, 1950, 1954, 1959, 1964, 1969, 1974, 1978, 1982, 1987, 1992, 1997, 2002, 2007, 2012); Kansas State Board of Agriculture, *Annual and Biennial Reports* (Topeka, 1877–1973); Kenneth M. Sylvester, Susan Hautaniemi Leonard, Gutmann, and Cunfer, "Demography and Environment in Grassland Settlement: Using Linked Longitudinal and Cross-Sectional Data to Explore Household and Agricultural Systems," *History and Computing*, XIV (2006), 31–60; Stephen J. DeCanio, William N. Parker, and Joseph Trojanowski, *Adjustments to Resource Depletion: The Case of American Agriculture—Kansas, 1874–1936*, ICPSR07594-v1, Ann Arbor, ICPSR, 2000, doi:10.3886/ICPSR07594.v1.

8 Manuel Gonzalez de Molina and Victor Toledo, *The Social Metabolism: A Socio-Ecological Theory of Historical Change* (New York, 2014); Peter Baccini and Paul H. Brunner, *The Metabolism of the Anthroposphere: Analysis, Evaluation, Design* (Cambridge, Mass., 2012); Marina Fischer-Kowalski and Helmut Haberl, *Socioecological Transitions and Global Change: Trajectories*

Most agro-ecologists and sustainability scientists focus on the present and the future. This article adapts their approach to understand agricultural change in the past, integrating socio-economic and physical-ecological characteristics that reveal both natural and cultural drivers of change. Socio-ecological profiles embrace land use, soil nitrogen, and food energy as key characteristics of agricultural sustainability. Ten descriptive measures link biophysical and socio-economic processes in farm communities to create socio-ecological profiles that reveal the effects of human activity on nature as well as environmental endowments, opportunities, constraints, and limitations that influenced settlers' choices.[9]

Three basic measures capture the dominant shape of agricultural settlement. *Population density* (people per km^2) represents the demographic occupation of new territory by an immigrant population. *Percent cropland* (percentage of total county area) reveals the extent to which those immigrants converted native vegetation into managed crop fields. *Livestock density* (animals per km^2) emphasizes the integration of domesticated animals within mixed farms and grazing intensity on ranchland. Since livestock transported nutrients across the landscape—for example, from grazed pastures to barnyards—livestock density is also important for understanding the soil-nutrient dynamics on farms. These three characteristics

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of Social Metabolism and Land Use (Cheltenham, 2007); Haberl et al., "From LTER to LTSER: Conceptualizing the Socio-Economic Dimension of Long-Term Socio-Ecological Research," *Ecology and Society*, XI (2006), art. 13, available at www.ecologyandsociety.org/vol11/iss2/art13/; *idem* et al., "Socioeconomic Metabolism and the Human Appropriation of Net Primary Production: What Promise Do They Hold for LTSER?" in Simron J. Singh et al. (eds.), *Long Term Socio-Ecological Research: Studies in Society-Nature Interactions Across Spatial and Temporal Scales* (New York, 2013), 29–52; *idem* et al., "Local Studies Manual: A Researcher's Guide for Investigating the Social Metabolism of Local Rural Systems," IFF Social Ecology Working Paper no. 120 (Vienna, 2010); Karl Marx, *Capital: A Critique of Political Economy* (New York, 1981; orig. pub. 1864), III, 949; John Bellamy Foster, *Marx's Ecology: Materialism and Nature* (New York, 2000); *idem*, "Marx's Theory of Metabolic Rift: Classical Foundations for Environmental Sociology," *American Journal of Sociology*, CV (1999), 366–405.

9 The treatment of agriculture as a socio-ecological or coupled human–environment system has a long tradition. See Timothy P. Bayliss-Smith, *The Ecology of Agricultural Systems* (New York, 1982); Billie L. Turner et al., "Illustrating the Coupled Human-Environment System for Vulnerability Analysis: Three Case Studies," *Proceedings of the National Academy of Sciences*, C (2003), 8080–8085; Xavier Cusso, Ramon Garrabou, and Enric Tello, "Social Metabolism in an Agrarian Region of Catalonia (Spain) in 1860 to 1870: Flows, Energy Balance and Land Use," *Ecological Economics*, LVIII (2006), 49–65; Singh et al., *Long-Term Socio-Ecological Research*; *idem* et al., "Local Studies Manual"; Cunfer and Krausmann, "Sustaining Soil Fertility"; Fischer-Kowalski and Haberl, *Socioecological Transitions*.

constitute the skeleton of a socio-ecological profile, revealing a community's basic shape and intensity.[10]

As soon as farmers occupied new land they began to manage soils, most intensively on cropland. *Crop diversity* (an index score between 0 and 1) captures several important processes in agro-ecosystems. It addresses the economic orientation of farms—whether aimed at local subsistence or marketable cash crops—and connects to soil-fertility management, since crop rotation required diversity and provided opportunities for legumes or other soil-building crops. Since nitrogen is usually the limiting nutrient for crops, *Nitrogen return* (the percentage of extracted nitrogen returned to cropland soil) is a crucial measure of sustainability. Harvesting grain and forage removed plant nutrients. Various land-management techniques—including manure application, legume rotation, and vegetation transfers—returned nitrogen to the soil. Synthetic fertilizers, however, were virtually unknown in the plains before World War II. When farmers returned less than 100 percent of the nitrogen extracted each year, they depleted soil fertility; when they returned more than 100 percent, they built soils.[11]

The main purpose of agricultural colonization and ongoing farm maintenance was to produce food energy and nutrition for local people and for export to the broader society. In crop-focused systems, *grain yield* (kg per ha) was the most immediate measure of success, and it was of direct interest to farmers. *Area productivity* (food energy output per ha) incorporates both crop and livestock products, providing a comprehensive comparison of grain farms, mixed farms, and cattle ranches. *Labor productivity* (food energy output per worker) reflects the efficiency of farm work. Both area and labor productivity measure the output of food energy (nutritional value) in gigajoules (gj). For comparison, an adult typically requires 3.5 gj of food energy per year for subsistence. Thus dividing labor productivity by 3.5 indicates how many people one laborer could support. Likewise, dividing area productivity by 3.5 reveals the number of people a hectare of farmland could feed.[12]

10 Livestock numbers are normalized to 500 kg-equivalent "livestock units."

11 Vaclav Smil, *Enriching the Earth: Fritz Haber, Carl Bosch, and the Transformation of World Food Production* (Cambridge, Mass., 2001). Cultivation and natural weathering also caused nitrogen losses, but due to lack of historical data, this article does not account for nitrogen lost through leaching and volatilization.

12 *Area productivity* and *labor productivity* are defined herein in conformity with their usage in the socio-ecological literature, but economists employ these terms differently. Ideally, labor

Historical farms required significant internal recycling of agricultural produce. Some cropland served to feed livestock and to produce seed for next year, and some livestock metabolism simply allowed animals to grow and live, before they could produce work, meat, milk, or manure. Additional farm produce went to feed, clothe, and shelter the local community. These subsistence requirements consumed all or a portion of annual farm production. Any excess, beyond local needs, was available for sale. *Marketable crop production* (percentage of cereal crop available for export) measures the extent to which farmers had surplus production for transport to the outside world. Finally, since Great Plains farms were businesses as well as family and community institutions, *farm income* (dollars per person, inflation adjusted to 2010) provides an economic measure of success.[13]

Together, these ten descriptive measures present a snapshot of the hybrid human–natural agro-ecosystem, revealing the most important demographic, biophysical, and economic structures (see appendixes for full annual statistics and details about their definition and construction). Tracing these characteristics from the beginning of agricultural colonization through sixty years reveals a pattern of expansion and growth, maturity, and adaptation. Agricultural systems are seldom static. Farmers interact with constantly varying natural forces and with social processes always in flux.

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productivity would account for the actual hours of work invested in farm labor, distinguishing between crops and various technological and management contexts. Unfortunately, because such precise information is not available for historical farms, labor productivity is calculated simply by dividing farm produce by the number of people of working age in the community. Although less precise, this measure is a common indicator of labor productivity, used by, among others, the Ogranization for Economic Co-operation and Development (OECD). See, for example, Rebecca Freeman, *Labour Productivity Indicators: Comparison of Two OECD Databases; Productivity Differentials and the Balassa-Samuelson* Effect (Paris, 2008). One gigajoule (gj) is equivalent to 239,000 kilo-calories. See Haberl, "The Energetic Metabolism of Societies, Part II: Empirical Examples," *Journal of Industrial Ecology*, V (2001), 71–88.

13 Farm income depended, in part, on farmers' ability to grow products and, in part, on the market demand for those products, as revealed in commodity prices. Since prices fluctuated through time, improvements in income could result from increased productivity on the farm or simply from higher prices in the market. Farmers had little control over prices, but to remain viable, they had to generate income somehow, sometimes by adjusting crop choice and land-use practices to fit market incentives. An indicator like "farm income" has no easy way to disentangle the role of production from the role of prices. Nonetheless, income was of major concern to farm families and to the region's broad economic success or failure. For further discussion of this issue, see Thomas L. Haskell, "Were Slaves More Efficient? Some Doubts about 'Time on the Cross,'" *New York Review of Books*, 9 Sept. 1974.

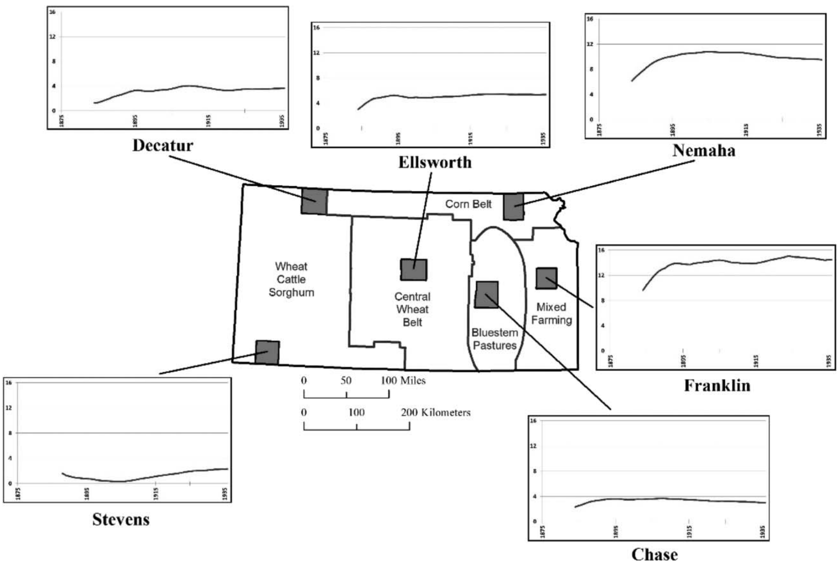
The Kansas agricultural frontier reveals adjustments and re-adjustments to an ever-changing world and, especially, to environmental forces beyond settlers' control. Three distinct socio-ecological profiles emerged in Kansas: (1) high-productivity mixed farming, (2) low-productivity ranching, and (3) market-oriented dryland wheat farming. The following narrative addresses each profile in chronological order and from east to west across the state, revealing settlers' rapid adaptation to environmental constraints; accompanying figures allow simultaneous spatial comparison.

HIGH-PRODUCTIVITY, MIXED-FARM AGRO-ECOSYSTEMS In Franklin and Nemaha Counties, located in relatively wet eastern Kansas, Euro-American settlers found low rolling hills, rich soils, and tallgrass prairie, with small trees growing along prairie rivers and on steep hillsides. The U.S. Census Bureau famously identified the settlement frontier in the American West as the border between places with population density above and below two people per square mile, or five people per square kilometer ($2/\text{km}^2$). By that standard, eastern Kansas was on the edge of the frontier when census observations began. Franklin County was already at $7/\text{km}^2$ in 1875 and Nemaha County first exceeded $5/\text{km}^2$ in 1879. Thereafter, a flood of immigration quickly raised population. Franklin County's population density grew to $15/\text{km}^2$ by the mid-1880s, and Nemaha peaked at just above 10 in 1889. Franklin County was a few years ahead of Nemaha, but both places filled with farmers and small towns in the first twenty years of agricultural colonization (see Figure 2).[14]

Settlers slowly altered the environment, creating an agricultural mosaic of crop fields, pastures, woodlands, and farmyards, criss-crossed by dirt roads and railroad lines. The most ecologically important activities were the plowing of prairie grasses for cropland and the suppression of landscape fire. In Franklin County, cropland occupied about 20 percent of the total area by 1875, rising to a peak around 50 percent in 1900. Nemaha County followed a similar trajectory, with cropland area rising from 15 percent in the 1870s to 60 percent in 1900. By the beginning of the twentieth century, settlers had transformed the ecological system on slightly more than half of the

14 Frederick Jackson Turner, "The Significance of the Frontier in American History," repr. in George Rogers Taylor (ed.), *The Turner Thesis: Concerning the Role of the Frontier in American History* (Lexington, Mass., 1972).

Fig. 2 Population Density in Six Kansas Agro-Ecosystems (People per Square Kilometer)



region's land—the single most dramatic environmental effect of agricultural occupation. The remaining land, the 40 to 50 percent not plowed for crops, did not sit idle; settlers grazed livestock there, mostly beef cattle. Grazing animals can affect a local ecological system considerably, but this environmental change was less intrusive than the plow. Great Plains grasses were adapted to large grazers, having supported bison for thousands of years and Native American horses for two centuries. To a considerable extent, domestic cattle filled the ecological niche vacated by bison. Nonetheless, cattle brought in their wake fences, artificial water supplies, fire suppression, and intensified grazing and trampling. In both Franklin and Nemaha Counties, livestock density rose from 10 to 15 animals per km^2 in 1875 to 25 to 30 by the late 1880s. On half of eastern Kansas' land, farmers plowed sod for crops (see Figure 3); on the other half, they filled pastures to carrying capacity with cattle (see Figure 4).[15]

15 Cunfer, *On the Great Plains*; Courtwright, *Prairie Fire;* Matthew Todd, "Now May Be Heard a Discouraging Word: The Impact of Climate Fluctuation on Texas Ranching in the 1880s," unpub. M.A. thesis (Univ. of Saskatchewan, 2010).

Fig. 3 Percent Cropland in Six Kansas Agro-Ecosystems (Percent of Total County Area)

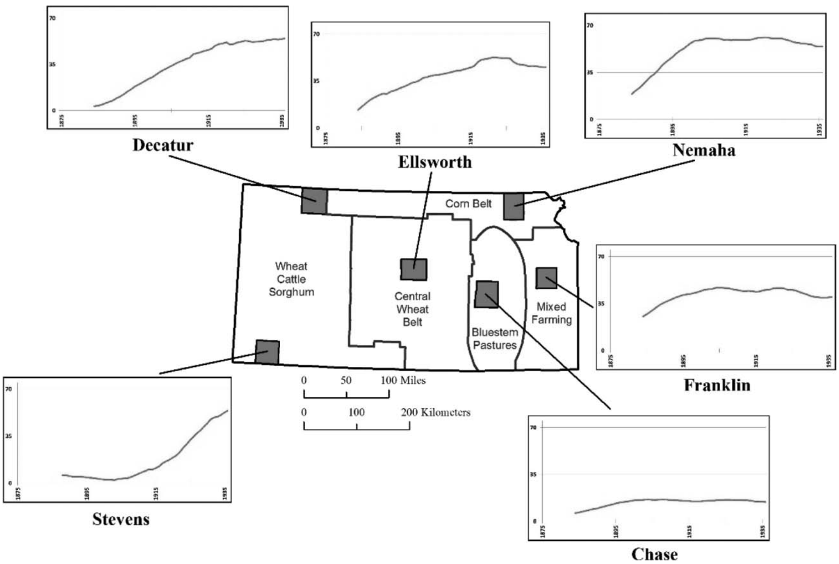


Fig. 4 Livestock Density in Six Kansas Agro-Ecosystems (Livestock Units (500 kg) per Square Kilometer of Agricultural Land)

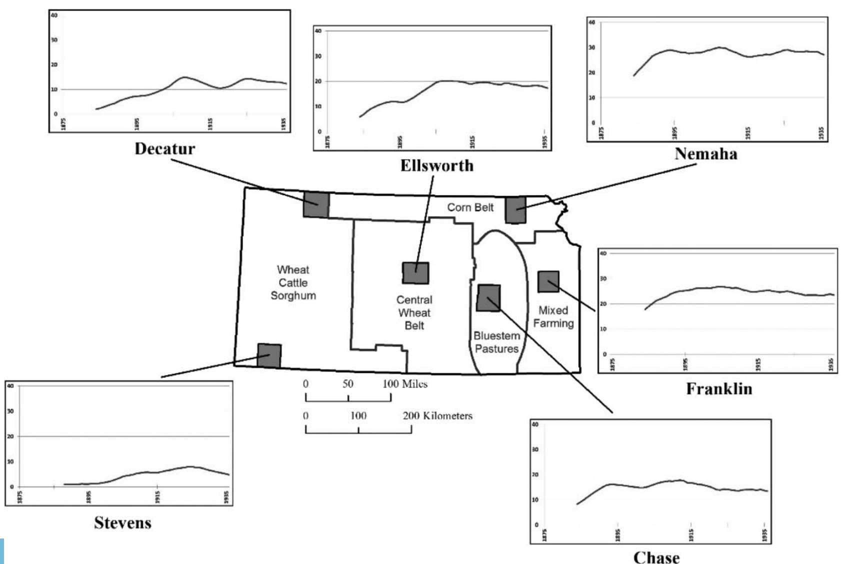
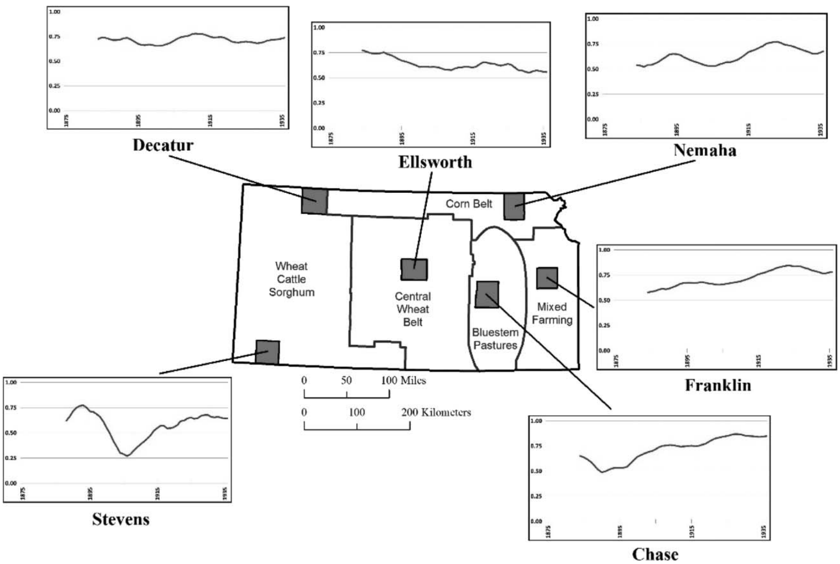
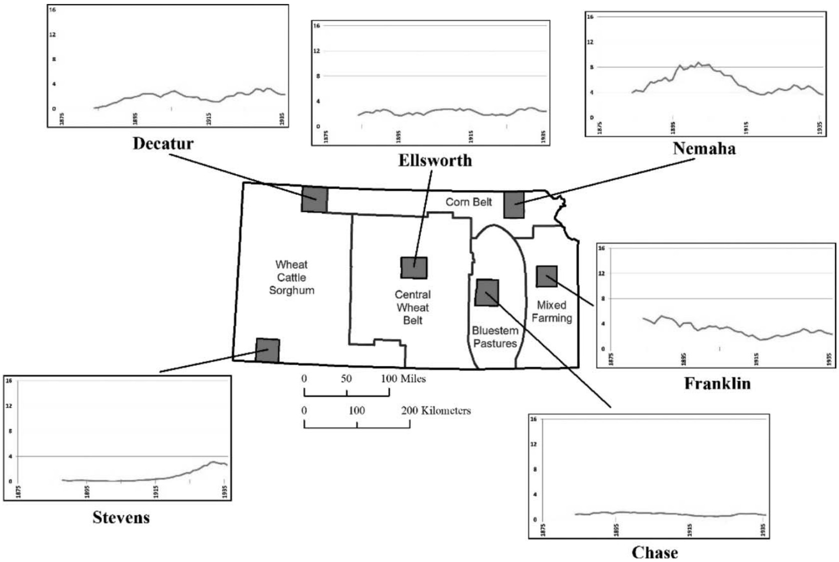


Fig. 5 Crop Diversity in Six Kansas Agro-Ecosystems (Index Score between 0 and 1)



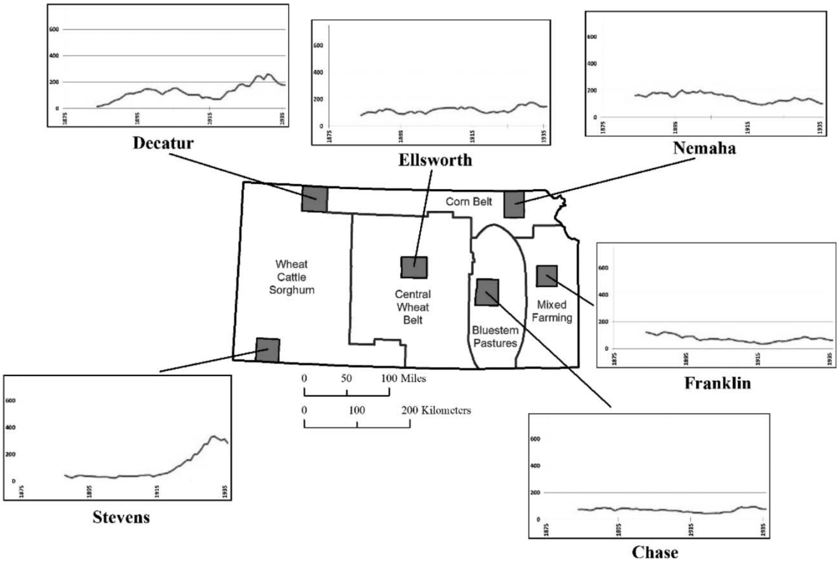
Crop diversity was low. Farmers planted corn on 60 to 70 percent of their cropland and hay and oats on the remainder. Crop-diversity index scores hovered around 0.6 in both Franklin and Nemaha Counties in the first two decades (see Figure 5). The dominant corn crop provided feed for livestock, and surplus grains flowed into national markets via railroads. This early agricultural system was highly productive. Rich soil, adequate rainfall, and an abundance of sunshine fueled crop growth, and farmers' ingenuity and hard work brought in abundant harvests. Area productivity varied with fluctuating rainfall, but averaged around 5 gj per ha per year in Franklin County and 4 gj in Nemaha until the late 1880s (see Figure 6). Labor productivity was even more impressive, at about 120 gj per farm worker per year in Franklin County and 150 gj in Nemaha County. Put another way, each farm laborer produced enough to feed forty people. Although the general characteristics and trajectories of the two counties were similar, Nemaha was slightly more productive than Franklin, aided by its higher cropland percentage (see Figure 7).

Fig. 6 Area Productivity in Six Kansas Agro-Ecosystems (Gigajoules per Hectare of Agricultural Land)



These productivity measures aggregate total farm produce, including crops and livestock products, but most of the output came from grain, particularly corn. Yields fluctuated with rainfall but were high in the early years. Franklin and Nemaha Counties each produced over 3,000 kg/ha in their best years during the 1870s and 1880s. Averages were above 2,500 kg/ha. These remarkable results meant that farmers not only met the feed requirements of their livestock but also accumulated surpluses to sell (see Figure 8). Marketable crop production averaged 55 percent in Franklin County and just under 50 percent in Nemaha before 1885; farmers could sell about half of their harvest for cash. Such results created modest prosperity even among the rude conditions of an agricultural frontier. Farmers reinvested their earnings in infrastructure—houses, barns, fences, wells, roads, and such community assets as churches, schools, and nearby market towns (see Figure 9). Farm income was around $2,200 per person per year in Franklin County and $2,700 in Nemaha (in 2010-equivalent dollars). As immigrants converted native grassland to cultivated

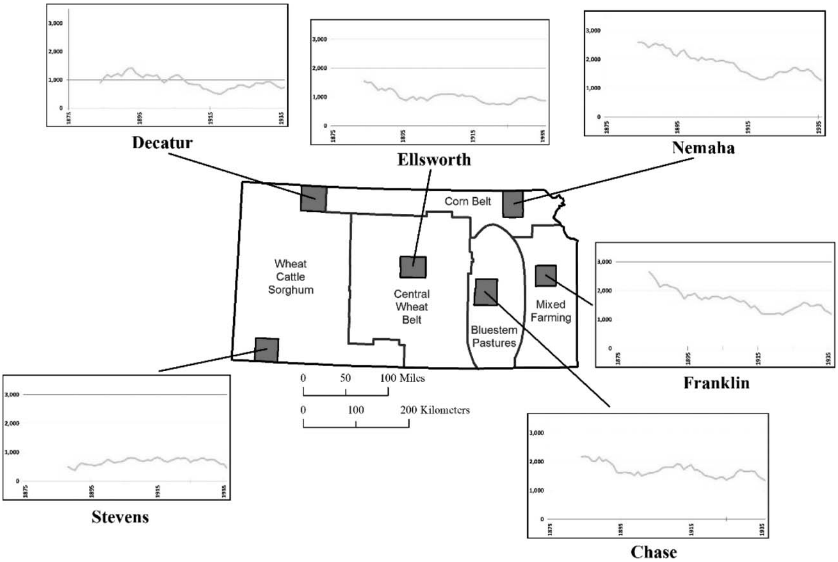
Fig. 7 Labor Productivity in Six Kansas Agro-Ecosystems (Gigajoules per Agricultural Worker)



farms, they combined cultural skill with rich natural resources to create prosperous and growing communities (see Figure 10).

Success did not come without environmental costs, however. Social and economic gains exerted ecological pressure on soils. During the first two decades, farmers extracted more soil nutrients than they replaced. Franklin and Nemaha farmers returned only about 20 percent of extracted nitrogen each season. Because Plains soils were initially rich, yields were high, but behind those productivity numbers was a soil-mining process that diminished fertility each year. Hence, the most important, and distressing, change that settlers observed after initial colonization was declining farm productivity. Grain production fell from the early yields above 2,500 kg/ha to averages below 2,000 in 1900 and below 1,500 by the 1910s. Farmers could not sustain bumper crops because corn consumed more soil fertility than they replaced. Soil nitrogen and organic carbon dropped rapidly during the first twenty years, and then more slowly, but still persistently, for the next forty years. As farmers altered soil chemistry

Fig. 8 Grain Yield in Six Kansas Agro-Ecosystems (Kilograms per Hectare)



their ability to produce food and cash crops declined (see Figure 11).[16]

In Franklin County, area productivity traced a downward path from an average of about 5 gj/ha to only 3 around 1900 and then under 2 gj/ha in the 1910s. Labor productivity followed suit, from above 100 gj per laborer down to about 50 gj in 1915. area and labor productivity in Nemaha County, however, took a different path. Area productivity rose temporarily, from about 4 gj/ha to an average of 8 around 1900, before declining rapidly again to below 4 gj/ha in 1920. Likewise labor productivity in Nemaha increased from 150 gj per worker to around 200 in the 1890s, then slumped to under 100 gj by 1920. Even with falling corn yields, Nemaha farmers found a way to raise area and labor productivity for a while, although they could not sustain the higher results. One consequence of these troubling declines was

16 Cunfer and Krausmann, "Sustaining Soil Fertility"; Howard J. Haas, C. E. Evans, and E. F. Miles, *Nitrogen and Carbon Changes in Great Plains Soils as Influenced by Cropping and Soil Treatments*, USDA Technical Bulletin 1164 (Washington, D.C., 1957); Cunfer, "Manure Matters on the Great Plains Frontier," *Journal of Interdisciplinary History*, XXXIV (2004), 539–567.

Fig. 9 Marketable Crop Production in Six Kansas Agro-Ecosystems (Percentage of Cereal Crop Available for Export)

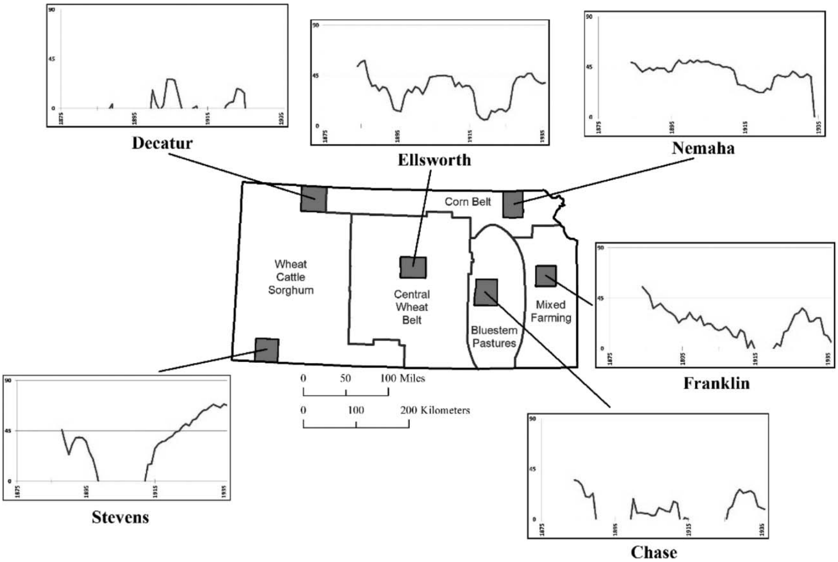


Fig. 10 Farm Income in Six Kansas Agro-Ecosystems (Dollars per Person [2010 equivalent])

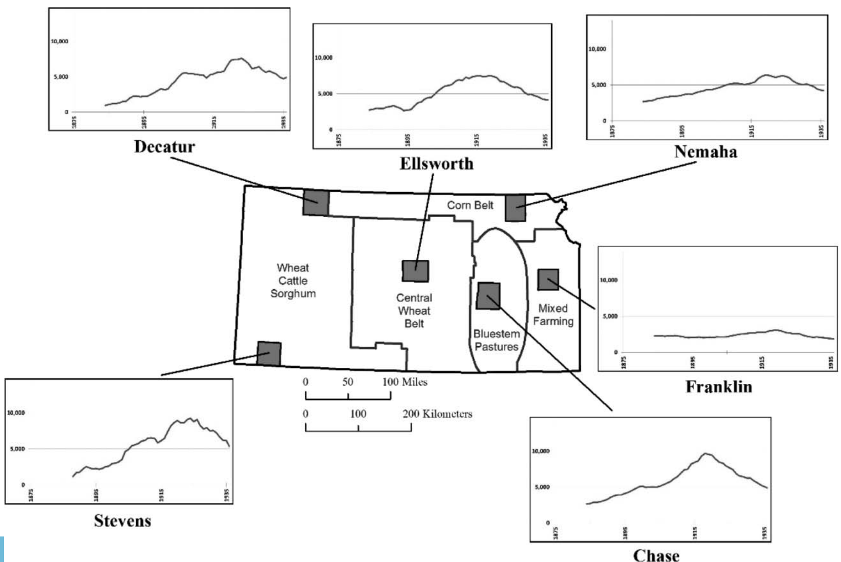
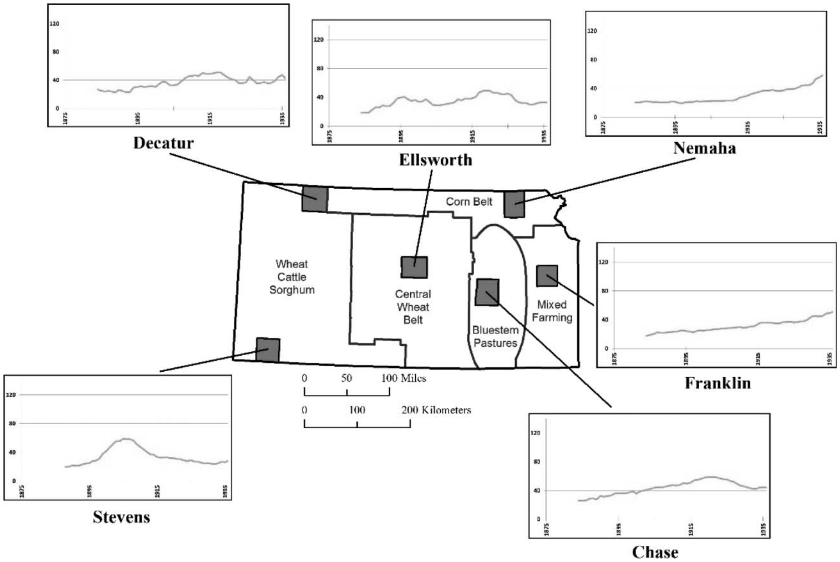


Fig. 11 Nitrogen Return on Cropland in Six Kansas Agro-Ecosystems (Percentage of Extracted Nitrogen Returned to Soil)



the reduced surpluses available for sale. In Franklin County, marketable crop production fell from around 55 percent in the 1870s to virtually 0 by the 1910s. Nemaha County sustained a marketable crop production from 40 to 50 percent until the early 1900s, before seeing it drop to around 25 percent in the 1910s. Although both Franklin and Nemaha Counties followed similar paths during their first six decades, Nemaha possessed superior natural endowments that sustained area and labor productivity and marketable crop production longer than could Franklin, even in the face of falling yields.

Despite troublesome productivity developments, both counties maintained their social and economic structures. Falling productivity caused neither population decline nor reduced farm income. In Franklin County, population density rose to about 15/km^2 by 1886 and remained there—between 14 and 16—for the next fifty years. Nemaha's trend was similar, though at a lower level. There population density climbed to nearly 11 by the late 1880s, then hovered between 10 and 11 for the next half century. Farm income fared even better. In Franklin County, incomes hovered just over $2,000 per person from the 1870s through the early 1900s, and then rose during the 1910s before drifting back toward a long-term average around $2,000 by the 1930s. There was no marked growth in income, but the county held its own. Nemaha did much better. There per capita income was already higher—around $3,000 per person—during the 1870s. It rose for the next fifty years, reaching an average around $6,000 by the early 1920s, boosted by a World War I windfall that briefly raised income above $10,000 per person in 1917. Lower agricultural productivity did not lead to out-migration or economic decline in either place. Population rose quickly, peaked, and then held steady. Farm income rose modestly in Franklin County and doubled in Nemaha County between 1875 and the 1910s, despite diminishing soil fertility on cropland and slumping grain yields. How did the community manage such an outcome?

Newly arrived farmers, whatever their ethnic background, quickly gauged the local environment to determine what combination of crops and livestock the land and climate would support. In just two decades, they restructured nature to fit their agricultural goals, building fences, farmsteads and towns, plowing cropland, and deploying livestock. The environmental re-organization had the expected outcomes, namely, a burst of agricultural and economic productivity. It also had unexpected, or at least undesired, outcomes, including falling soil fertility and grain yields. After the first twenty years, those results generated an adaptation and re-adjustment whereby natural forces and human-created environmental conditions led farmers to change their agro-ecosystem. Environment pushed back against culture, and farmers responded quickly. Percent cropland reached an early peak in the 1890s, at 50 percent in Franklin County and 64 percent in Nemaha. But farmers overshot the mark, and thereafter cropland area contracted slightly. By the 1920s, Franklin had stabilized at a level of about 40 percent cropland; Nemaha was at about 55 percent. A similar overshoot followed by modest retrenchment is evident in livestock density as well. Franklin County peaked at 31/km^2 in 1891, but densities drifted downward during the next forty years, to about 24/km^2 in the 1930s. Nemaha County saw a peak in 1889 at 34/km^2, followed by averages that fluctuated between 26 and 30 for half a century. In both percent cropland and livestock density, farmers reduced land-use intensity by 15 to 20 percent.

More drastic were the adjustments that farmers made on cropland, diversifying crop choice and increasing nitrogen return to soils. In Franklin County, corn fell from about 65 percent of cropland during the 1870s to 55 percent in the early 1900s and 45 percent by the 1930s. Taking its place was hay, which soon made up 30 percent of cropland, along with oats and wheat. Franklin County's crop-diversity index score rose from under 0.6 in the 1870s to above 0.7 by 1905, hovering around 0.8 after 1912. Crop diversification responded to two environmental forces. Farmers shifted from a row crop—corn—that requires considerable soil nutrients and rain, to hay and small grains that require less of each. Farmers adapted to Kansas' variable rainfall and "hot winds" that corn growers dreaded by reducing corn acreage. Crop diversification also addressed soil-nutrient depletion. Farmers moved from corn, a crop highly demanding of soil nutrients, toward others that extracted less nitrogen and carbon. Nemaha's crop mix followed the same pattern, as corn dropped from about 65 percent of cropland in the 1870s to 55 percent in the 1930s. Meanwhile a combination of hay, oats, and wheat increased to 45 percent of cropland. Crop-diversity index scores rose from around 0.55 in the early years to frequently above 0.7 after 1910. As a result, the nitrogen return improved. In 1875, farmers in Franklin and Nemaha Counties returned just under 20 percent of the nitrogen that they extracted. In Franklin County, the return increased steadily through 1910 and rapidly thereafter, to highs around 60 percent by the mid-1930s. Nemaha's rate of nitrogen return stayed flat around 20 percent until 1910 but had turned markedly upward to exceed 60 percent by the late 1930s.

Agricultural colonization was not simply a process of conquering nature; it also required farmers to modify their cultural practices to conform to environmental constraints. According to these measures—percent cropland, livestock density, crop diversity, and nitrogen return on cropland—farmers adapted to a natural force over which they had no control—rainfall—and re-adjusted their land use in response to changed environmental conditions that they themselves had created—soil fertility depletion. In this recursive process, farmers transformed the environment on about half of their land, which generated high agricultural productivity but exploited soils unsustainably. The altered environment then forced a re-adjustment in land use toward higher crop diversity and better soil maintenance, while sustaining both population and economic productivity. These adjustments allowed farmers to revive agricultural surpluses. Franklin County's marketable crop production, which had fallen to 0 in 1910, recovered in the next two decades, bouncing back to higher than 30 percent in several years. Farmers sustained populations and raised incomes by manipulating their agricultural system to fit the environment that they occupied and partially created.

LOW-PRODUCTIVITY, RANCHING AGRO-ECOSYSTEMS Nemaha County stands as the model to which Great Plains settlers aspired. With each incremental move westward, however, Euro-American colonizers had more difficulty filling the grassland with prosperous, productive mixed farms. The greatest challenges were rainfall that diminished toward the west, decreasing plant productivity, and areas of poor soils that were too rocky, sandy, shallow, or steep to support crops. A second socio-ecological profile highlights two counties that each faced one of these challenges.

Chase County, Kansas, is in the midst of the Flint Hills Bluestem Pastures, a limestone uplift running south to north. The underlying bedrock juts out through thin soils clinging to low, rolling hills. Native tallgrasses dominate the terrain today as they did when Native Americans managed the land. Thin topsoil meant low plant productivity and a small area capable of growing crops. Only where eroded sediments accumulated in stream valleys were soils deep enough for crops. Compared to Franklin and Nemaha Counties, just 100 miles away, Chase County and the rest of the Bluestem Pastures offered only meager arable land. As a result, immigration peaked early and low, with a population density of $4/km^2$ in 1887. Thereafter, population drifted downward to $3/km^2$ by the 1930s. Chase County never reached the Census Bureau's definition of a "settled place." Nonetheless, Euro-American settlers came to the county and remade the environment. Their primary economy was, and remains, cattle ranching. As ranchers filled pastures with cattle, livestock density rose from $5/km^2$ in 1875 to a peak of 19 in the 1890s before dropping to 15 to 18 through the 1910s and 14 in the 1920s and 1930s. Although the Bluestem Pastures were quintessential cattle country, livestock densities were lower than the 25 to $30/km^2$ that prevailed in heavily cropped Franklin and Nemaha Counties. Lower rainfall and poorer soils caused diminished pasture-grass productivity.

The persistence of Native American fire regimes in the Bluestem Pastures indicates that settlers transformed the environment only to a limited extent. From the 1870s to the present, ranchers have continued the annual prescribed burning that rejuvenates prairie grasses and maximizes nutrition available to cattle during the coming grazing season.[17]

Nonetheless, a lot of cattle grazed in Chase County, and for part of each year—during winter—ranchers supplemented native grasses with feed grain by plowing the narrow bands of adequate soil along streams and rivers and planting crops. Chase County never reached 20 percent cropland, but plowed fields rose from about 5 percent in 1875 to 18 percent by the 1890s, retreating to a stable 15 percent for the next half century. Chase County settlers transformed the environment, but to a more limited extent than in high-productivity mixed farming areas.

Grain yields in Chase County were good, at around 2,000 kg/ha in the first decade, drifting downward to 1,500 kg/ha by 1918 and for the next twenty years. A comparison with Nemaha County reveals grain yields that were initially higher, around 2,500 kg/ha, but fell faster; from 1915 to 1936, the production per ha from Chase matched that of Nemaha though its crop acreage was only a fraction of Nemaha's. As might be expected, area productivity was low in Chase County, about 1 gj/ha, and stable through the first 60 years of occupation. Labor productivity was likewise low, averaging greater than 80 gj per laborer in the first several decades, dropping to nearly 50 by the 1920s and then rising to more than 90 gj/person in the 1930s. Since crops mainly went to feed cattle, it is not surprising that marketable crop production was low. In good years, it frequently rose as high as 35 or 40 percent, but averages varied between 5 and 25 percent in most years. During the 1890s, it hovered around 0. Occasionally Chase farmers produced surplus crops, but most of their effort went into producing beef, not grain. The 15 percent of cropland in the county produced nearly all of the feed grain needed locally. In a pinch, ranchers could purchase feed grain from nearby crop-intensive parts of Kansas.

Despite the limitations of soil, climate, and plant productivity, settlers in Chase County were not impoverished. Farm income was robust, starting around $2,000 per person in the 1870s and

17 Courtwright, *Prairie Fire*.

rising past $4,000 in the 1890s and to $6,000 by 1910. Income peaked at nearly $14,000 per person in 1917, before dropping through the 1920s and 1930s. But even in the Great Depression, Chase ranchers managed to earn just under $4,000 per person. In this environmentally constrained landscape, settlers still found a way to earn considerably more than their better-endowed counterparts, exceeding Nemaha residents and, by the early twentieth century, tripling the income of those in Franklin County. Chase County's total farm income was lower than that of either Franklin or Nemaha, but it was shared among far fewer people.

Aside from farm income, Chase County's socio-ecological profile did not vary much through sixty years of agricultural colonization. Land use was stable, without the fluctuations evident in the mixed-farming region to the east. Some components of the cropping system changed, however, and in the same direction, if not at the same magnitude, as those already described. Grain yield drifted downward from more than 2,000 kg/ha in the 1880s to below 1,500 by the 1920s. Crop diversity increased from lower than 0.6 in the 1880s to 0.9 in 1936, one of the highest index scores in the state. Nitrogen return moved upward from a little higher than 20 percent in the early years to 60 percent in 1919; then it began falling again, plummeting to 45 percent by 1936.

In far southwestern Kansas, Stevens County did not face the environmental drawback—shallow soils—that pushed settlers toward ranching in Chase County. Yet before 1907, Stevens County's socio-ecological profile matched Chase's in every measure. Population density started low, at less than 2/km^2 in 1888, the first census year, and then drifted downward lower than 1 in 1906. Percent cropland was below 5 percent and livestock density rose, but only to about 5 to 6/km^2. Although Stevens County was ranch country like Chase, it was much less productive, with both human and animal populations that were significantly smaller. The key characteristic behind this socio-ecological profile was variable but always scant rainfall. Stevens County is considerably drier than the other counties considered so far. It could not sustain a vibrant grazing agro-ecosystem like Chase County's, let alone the corn-and-livestock mixed farms created by Franklin and Nemaha farmers.

Area productivity was less than 1 gj/ha and labor productivity averaged under 50 gj per person. Yet farm income in Stevens County compared favorably to that in the rest of the state, beginning around

$2,000 per person in the late 1880s and rising to nearly $6,000 by 1907—a performance that matched Nemaha and Chase Counties and exceeded Franklin County's. Stevens County had fewer people, cattle, and crops than any other county in Kansas, but its economic results were good nonetheless. Remarkably, per capita economic productivity was higher in environmentally challenged locations than in more favorably endowed places. Regions with adequate rainfall and good soils filled up with people, spreading wealth across greater numbers, whereas places like Chase and Stevens Counties concentrated income in fewer hands. Livestock provided an important means to extract wealth from low-productivity landscapes. In each of the four counties considered so far, farm communities configured their imported farm system to maximize economic return, each in its own way, fitting its agricultural regime to accommodate natural forces beyond its control, most prominently climate and soil conditions. The shape of each community's agro-ecosystem varied, not because of ethnic backgrounds but because of local environmental conditions. Nature altered cultural practice. As each new community grew during its first twenty years, it molded farm practices to accommodate local conditions. Nemaha County farmers plowed considerable cropland, those in Franklin County nearly as much, and those in Chase and Stevens Counties just slightly less. Certain areas fostered a ranch economy; others adopted a mixed crop–livestock strategy; and still others borrowed Native American fire management when it suited their needs. Yet in all of these places, settlers produced adequate economic returns and achieved considerable prosperity. Great Plains pioneers achieved their economic goals by adjusting agricultrual practice to fit local environmental conditions.

MARKET-ORIENTED, DRYLAND WHEAT AGRO-ECOSYSTEMS Today Kansas is one of the world's great grain producers; in the western half of the state, wheat became the dominant crop. Ellsworth, Decatur, and Stephens Counties represent the rapid ascent of wheat in successive waves as farmers moved into ever-drier regions. Ellsworth County switched from corn to wheat in 1891, increasing its wheat acreage from 39 percent of cropland to 71 percent in just one year. Dry conditions and summer heat made corn vulnerable; the crop fell from greater than 35 percent there during the 1870s to around 25 percent at the turn of the century. By the

1920s, it had reduced to a mere 15 percent of Ellworth's crop acreage. Drought-hardy sorghum grew on just under 10 percent of its cropland. Farming in Ellsworth did not become a pure monoculture, but wheat was clearly dominant. Crop diversity declined there from greater than 0.8 in the early years to under 0.6 by the 1930s. Farmers continued to grow a mix of corn, sorghum, and other crops on about one-third of their land, but wheat was king.

The plow-up took several decades: Percent cropland rose from 0 when the first settlers arrived in the 1870s to just under 50 percent by World War I. Population density reached 5/km^2 by 1890. Significantly lower rainfall than in eastern Kansas meant lower productivity. Grain yield dropped from 1,500 kg/ha in the early years, when corn was more prominent, to a fluctuating average of around 1,000 by the early 1890s. Area productivity was about 2 gj/ha, and labor productivity between 100 and 150 gj/person. These numbers were lower than that of prosperous and wetter Nemaha County in the east but still robust. Drought was always a concern, but the county's rich soils usually produced abundant wheat harvests. Marketable crop production fluctuated with rainfall, but for most of its first sixty years, Ellsworth farmers could export between 20 and 55 percent of their grain. Farm income rose accordingly from more than $2,000 per person in the 1880s to higher than $8,000 during World War I. It dropped to about $5,000 during the economic crises of the 1920s and 1930s. As in the east, farmers found ways to reduce soil-fertility demands, if only modestly. Livestock density grew to 20/km^2 in 1905, providing only a small amount of manure to replenish harvested fields. Nitrogen return rose from about 20 percent in the 1880s to more than 40 percent by 1920, only to dip again in the 1930s. The modest improvement resulted from replacing nutrient-demanding corn with less-demanding wheat, which was a better fit in a semi-arid climate, and it put less pressure on soil nutrients.

Farther west, and with even less rainfall in most years, Decatur County created virtually the same dryland wheat agro-ecosystem as did Ellsworth County. The process happened a decade later, as settlement continued its westward progress, although population density (under 4/km^2) and livestock density (10 to 15) remained at frontier levels. Percent cropland rose above 5 percent only after 1885; it then jumped to around 50 percent by 1910. It was still moving upward into the 1930s, arriving at 55 percent in 1936, despite that decade's disastrous drought. The transition from corn, the pioneer crop, to wheat happened between 1902 and 1910, after which wheat constituted about 50 percent of cropland, corn 30 percent, and sorghum 10 percent. Crop diversity remained constant, at about 0.7, in accord with this three-way split. Higher crop diversity in comparison with Ellsworth County allowed Decatur farmers to return more nitrogen to the land, about 25 percent in the 1880s and as much as 40 to 50 percent after 1900. In this land of limited and spotty rain, productivity fluctuated. Crop yield drifted downward, from more than 1,500 kg/ha in the nineteenth century to a range of 500 to 1,000 after 1900. Area productivity oscillated between 1 to 3 gj/ha, while labor productivity rose from 100 gj/ha to 250 by the end of the period. Low rainfall confined the land's productive capacity to less than half that of eastern Kansas, but low population densities kept production per person at a similar level. Farm income matched that in Ellsworth. Local variations are evident, but Ellsworth and Decatur Counties in the wheat heartland developed similar socio-ecological profiles, with a lag time of about 15 years.

Stevens County, in the hottest, driest corner of southwestern Kansas, also became a significant wheat producer, but with even greater adaptation to drought. There the transition from grazing land to cropland began in 1907 and was still underway by the mid-1930s, when percent cropland reached a remarkable 60 percent. Corn was never important in Stevens. Because farmers were already aware by the early twentieth century that corn and dry climate were a bad combination, they instead planted sorghum, a drought-hardy feed grain imported from Africa. By the 1910s, Stevens County was virtually a two-crop system—45 percent of its cropland in wheat and 45 percent in sorghum. Crop diversity scores were correspondingly low, rising from 0.3 in 1907 to around 0.65 in the 1930s. Very low livestock density (5 to 8/ km^2) meant little local demand for feed. Hence, marketable crop production rose to more than 70 percent during the late 1920s.

As a market-oriented agricultural system, southwestern Kansas was unexcelled. Farm income accelerated past $6,000 per person by 1910, achieved spectacular levels above $13,000 during World War I, but dropped sharply during the Great Depression. In Stevens County, farmers adapted to limited rainfall, but their rich soils, capable of supporting less-demanding crops and a few livestock to produce manure, meant that they did not have to invest much to maintain soil fertility. Nitrogen return dropped from greater than 60 percent around 1900 to about 25 percent by the 1920s. All of the dryland wheat counties had deep market engagement, low crop diversity, and ample economic prosperity. Environmental adaptation in these areas focused on adjusting to an unpredictable climate. Fortunately, the soils there remained more than adequate for long-term wheat cultivation, requiring little attention from farmers.

When Euro-American settlers built farms across the Great Plains, they made substantial changes to natural systems. By plowing diverse grassland to grow crops, they fundamentally reconfigured plant assemblages. By supressing wildland fires, they altered fire regimes and vegetation on a broader scale. Cultivation changed soil chemistry and depleted soil nutrients. Transformations of nature were significant and extensive, but never complete. As the examples presented herein show, the settlers' effect on nature varied considerably. However, not all of the land succumbed to the plow, and not all of the landscape fire disappeared. Moreover, in large expanses of the Great Plains, soils remained rich and fertile. Key parts of the natural system were well beyond human control, including climate, soil depth, and potential plant productivity. Notwithstanding the settlers' significant impact on nature, equally important for environmental history, though less frequently addressed, is nature's effect on socio-economic patterns.

Natural constraints directed settlement in particular ways. Rainfall was most important; it alone explains most of the variation across Kansas in percent cropland, crop diversity, and livestock density. Soil characteristics, especially soil depth, were also important, explaining the Bluestem Pastures, where the rainfall was sufficient to support more cropland, but soils were not. Natural characteristics created a remarkable number of ways to use land and thus a number of different socio-ecological profiles, even among contiguous communities. People could contemplate building a farm system, a social structure, and an economy in general terms, but the specifics were heavily influenced by local natural forces beyond their control. This intersection between cultural values—including agrarian ideals, capitalist markets, and democratic governments—and natural conditions generated remarkably rapid adaptation. By the end of the pioneer era, the Great Plains was a diverse, complex patchwork of distinct agro-ecosystems, each finely tuned to local environmental conditions. People may mold landscapes, but they are not all-powerful.

The distinctive phase of frontier development came to an end during the 1930s. Economic depression, drought, and dust storms seared that decade into regional memory and national consciousness. It also concluded agricultural colonization of new land. Cropland peaked in 1935, remaining stable thereafter. Federal management of the agricultural economy began in 1933 with the Agricultural Adjustment Act. It inaugurated a suite of government subsidies, incentives, and regulations that evolved through the next eighty years, but never disappeared. As the frontier era ended, a socio-ecological transition toward modern, industrial farming began. Just as pioneer colonization inscribed a new cultural signature onto a plains landscape constructed by Native Americans, industrial agriculture began to over-write the settlement-era landscape. Fossil fuel–powered technologies brought new abilities to deliver irrigation water, apply synthetic fertilizers, control pests, and reconstruct landscapes with tractors, trucks, and mechanical harvesters. A new equilibrium between environmental alteration and adaptation emerged. Industrial agriculture's remarkable ability to alter and manage natural systems depends on a massive mobilization of fossil-fuel energy. But until the mid-twentieth century, environmental forces in the North American grassland were no less powerful than human ambition.

APPENDIX 1: SOCIO-ECOLOGICAL MEASURES FOR EACH COUNTY AND YEAR

Franklin County, Kansas	Population Density	Percent Cropland	Livestock Density	Crop Diversity	N Return on Cropland	Grain Yield	Area Productivity	Labor Productivity	Marketable Crop Production	Farm Income Per Capita			Population Density	Percent Cropland	Livestock Density	Crop Diversity	N Return on Cropland	Grain Yield	Area Productivity	Labor Productivity	Marketable Crop Production	Farm Income Per Capita
1875	6.7	20	13	0.55	14	2,995	4.8	125	67	1,922		1906	13.8	42	24	0.70	24	2,127	4	88	43	2,713
1876	7.5	18	12	0.58	14	3,201	4.7	123	68	1,529		1907	13.8	42	25	0.72	28	1,640	2.3	50	24	2,516
1877	7.8	20	13	0.54	15	2,957	4.4	113	62	1,761		1908	13.9	44	24	0.74	33	1,060	0.7	15	-12	2,690
1878	8.2	21	17	0.56	18	2,562	3.8	99	51	1,922		1909	13.9	43	27	0.70	32	1,324	0.7	15	-3	2,836
1879	9.6	25	18	0.64	17	2,474	3.8	99	50	2,143		1910	13.9	43	23	0.71	29	1,551	2.3	53	29	2,948
1880	11.1	25	21	0.61	22	2,060	2.9	75	39	1,740		1911	13.6	45	26	0.77	35	999	0.6	15	-17	2,627
1881	9.4	30	21	0.60	25	1,538	2.1	54	29	3,081		1912	13.9	44	22	0.78	28	1,756	3.4	80	38	3,461
1882	10.9	31	21	0.58	19	2,534	5.5	138	57	2,607		1913	13.9	48	24	0.79	43	501	0.6	16	-107	2,170
1883	11.8	31	19	0.54	15	3,237	8.8	218	69	3,552		1914	13.7	48	26	0.81	34	1,546	2.5	62	29	3,443
1884	13.5	33	23	0.58	18	2,958	7.5	180	60	2,407		1915	14.6	39	28	0.87	51	993	0.7	19	-33	2,368
1885	14.6	36	25	0.63	26	1,726	2.7	59	29	1,888		1916	14.8	44	26	0.79	48	702	0.6	18	-47	2,511
1886	15.0	37	23	0.64	26	1,576	2.3	52	28	1,689		1917	14.9	50	26	0.82	29	1,498	2.8	76	34	4,197
1887	14.9	40	24	0.67	37	697	0.7	15	-54	1,165		1918	15.4	48	26	0.87	31	1,076	1.1	32	10	3,669
1888	13.9	41	23	0.66	14	3,141	10.6	240	75	2,570		1919	15.4	47	23	0.82	29	1,273	2.8	78	36	3,549
1889	13.8	43	24	0.58	16	2,645	9.2	210	70	2,024		1920	15.2	51	22	0.87	24	1,638	4.7	134	52	2,460
1890	13.4	38	27	0.69	30	1,337	0.7	16	0	2,193		1921	14.7	47	23	0.87	32	1,267	2.5	70	33	1,298
1891	13.6	42	30	0.74	31	1,277	0.8	18	-3	2,269		1922	14.9	44	24	0.86	44	1,140	1.4	39	15	1,682
1892	13.3	42	26	0.71	22	1,999	4.1	96	43	2,203		1923	15.4	43	26	0.86	46	1,347	1.7	49	18	1,834
1893	13.0	44	24	0.72	23	1,667	3.5	83	40	2,376		1924	15.5	38	24	0.81	38	2,161	4	112	45	2,225
1894	13.2	42	25	0.68	28	1,120	0.6	15	1	2,023		1925	13.6	40	23	0.78	43	1,612	3.1	86	38	2,313
1895	13.7	44	26	0.65	16	2,936	8.3	168	62	2,447		1926	13.9	39	24	0.80	49	1,343	1.9	54	24	2,275
1896	14.4	42	25	0.64	21	1,727	2.9	59	33	1,618		1927	14.8	39	23	0.81	40	2,013	4.5	127	48	2,301
1897	14.8	44	27	0.65	26	1,271	0.7	15	1	1,584		1928	14.7	39	22	0.74	35	2,087	5.1	134	51	2,357
1898	15.7	48	27	0.68	29	1,656	2.5	50	25	1,685		1929	14.9	39	24	0.73	53	1,041	1	27	7	2,591
1899	14.5	49	25	0.65	26	1,986	4.8	96	47	2,162		1930	14.7	39	22	0.72	63	635	0.7	17	-38	2,088
1900	14.1	48	27	0.64	25	2,043	4.2	85	41	2,697		1931	14.5	41	23	0.78	42	1,366	3.1	83	37	1,662
1901	14.3	50	31	0.65	43	705	0.9	17	-87	1,699		1932	14.0	40	22	0.77	38	1,561	3.9	103	45	1,067
1902	14.0	46	25	0.67	23	2,854	7.5	150	61	3,165		1933	14.4	40	26	0.72	48	1,148	1.6	39	15	1,311
1903	14.2	46	28	0.65	29	1,786	3.1	62	33	2,238		1934	14.4	38	28	0.82	73	480	0.8	20	-101	1,474
1904	14.1	50	27	0.66	33	848	0.8	15	-38	1,916		1935	14.3	42	24	0.88	50	995	1.8	46	25	2,044
1905	14.0	44	26	0.68	23	2,275	4.7	103	47	2,730		1936	14.1	41	21	0.86	68	475	0.6	14	-32	1,577

APPENDIX 1: (*Continued*)

Nemaha County, Kansas	Population Density	Percent Cropland	Livestock Density	Crop Diversity	N Return on Cropland	Grain Yield	Area Productivity	Labor Productivity	Marketable Crop Production	Farm Income Per Capita			Population Density	Percent Cropland	Livestock Density	Crop Diversity	N Return on Cropland	Grain Yield	Area Productivity	Labor Productivity	Marketable Crop Production	Farm Income Per Capita
1875	3.8	12	11	0.62	17	2,671	2.7	123	59	1,959		1906	10.7	59	28	0.56	19	2,148	8.1	202	54	5,058
1876	4.2	14	12	0.73	21	2,125	2.5	107	53	1,700		1907	10.6	59	28	0.60	20	2,195	8.1	201	53	5,538
1877	4.5	13	13	0.47	18	2,738	3.2	135	58	2,260		1908	10.7	56	29	0.62	26	1,606	4	98	32	5,555
1878	4.7	14	15	0.68	21	2,508	2.5	100	44	1,922		1909	10.7	58	28	0.63	27	1,606	4.8	118	39	5,958
1879	5.7	15	18	0.53	21	2,607	2.8	110	43	2,500		1910	10.8	59	25	0.54	24	1,772	6.7	163	51	5,711
1880	6.6	18	22	0.52	22	2,528	3.2	120	41	2,377		1911	10.8	57	27	0.68	34	1,079	1.3	32	9	4,497
1881	7.2	20	26	0.41	31	1,849	1.6	61	17	3,238		1912	10.7	65	24	0.69	30	1,373	4.8	116	40	5,431
1882	8.0	23	24	0.49	19	2,832	4.9	192	50	3,317		1913	10.7	60	24	0.73	50	505	0.7	16	-71	3,489
1883	8.1	33	23	0.38	17	2,769	8.1	327	63	4,100		1914	10.3	59	25	0.80	38	1,070	2.2	54	23	4,994
1884	8.8	29	24	0.55	16	3,370	8.3	342	62	3,465		1915	9.7	59	25	0.83	31	1,873	7.1	184	54	6,256
1885	9.6	35	28	0.59	20	2,699	6.2	164	49	2,676		1916	10.0	61	27	0.70	41	1,228	2.9	77	27	6,763
1886	9.7	34	26	0.60	29	1,472	1.5	40	13	2,340		1917	10.0	63	32	0.73	35	1,657	6	160	46	10,343
1887	9.3	39	28	0.66	26	1,515	2.2	59	22	2,866		1918	9.8	65	31	0.79	40	1,066	1.5	41	11	8,639
1888	9.7	43	30	0.68	15	3,327	10.6	280	64	4,203		1919	10.3	61	29	0.80	40	1,312	3.1	86	30	7,727
1889	10.5	43	34	0.67	16	3,205	9.7	255	60	3,211		1920	9.8	61	29	0.77	31	1,993	6.9	194	52	5,231
1890	10.4	37	30	0.68	24	1,836	2.1	55	19	3,370		1921	9.8	57	25	0.78	34	1,689	5.2	145	46	3,250
1891	10.2	46	32	0.68	22	2,066	4.8	125	39	3,894		1922	9.8	58	28	0.76	41	1,349	2.8	81	27	4,020
1892	10.2	57	29	0.70	23	1,672	5.7	149	45	4,111		1923	9.7	59	29	0.77	34	1,780	5	143	40	4,797
1893	10.0	58	27	0.64	16	2,649	12.4	323	66	4,339		1924	9.7	60	29	0.70	36	1,804	5.4	150	44	5,716
1894	10.1	51	26	0.60	26	1,334	2.8	72	27	3,717		1925	9.7	56	31	0.65	42	1,753	5.4	150	44	5,351
1895	10.6	56	25	0.58	18	2,126	8.5	183	56	3,671		1926	9.9	54	28	0.62	55	1,187	2.1	59	20	4,783
1896	10.8	59	23	0.53	14	2,957	15.7	341	73	3,667		1927	9.6	55	27	0.67	40	2,236	8.3	232	56	5,888
1897	11.0	61	24	0.45	19	2,100	10.7	232	63	3,591		1928	9.6	55	29	0.67	41	2,054	7.3	201	51	6,083
1898	10.9	58	30	0.51	30	1,376	3.9	85	32	3,774		1929	9.6	56	29	0.66	59	1,061	1.5	41	10	5,891
1899	10.8	65	30	0.51	20	2,196	11	242	60	4,908		1930	9.7	56	28	0.64	56	1,089	2.1	58	19	4,960
1900	10.8	57	32	0.55	24	1,978	7.1	156	49	5,009		1931	9.4	56	27	0.66	42	1,759	6.4	179	51	3,740
1901	10.7	62	33	0.57	34	1,208	2.3	51	18	4,533		1932	9.5	55	27	0.64	40	1,862	6.8	190	52	2,358
1902	10.7	61	29	0.56	16	2,776	13.2	293	66	6,064		1933	9.5	54	28	0.61	56	1,104	1.8	49	14	2,782
1903	10.8	62	31	0.52	22	1,858	7.1	158	49	4,540		1934	9.6	49	30	0.70	101	259	0.8	23	-318	2,520
1904	10.7	60	31	0.54	26	1,410	3.7	82	31	4,147		1935	9.4	55	23	0.78	68	778	0.7	19	2	3,935
1905	10.7	59	28	0.55	18	2,305	9.1	227	57	5,163		1936	9.4	54	23	0.75	84	457	0.5	15	-62	3,932

APPENDIX 1: (*Continued*)

Chase County, Kansas	Population Density	Percent Cropland	Livestock Density	Crop Diversity	N Return on Cropland	Grain Yield	Area Productivity	Labor Productivity	Marketable Crop Production	Farm Income Per Capita
1875	1.5	4	5	0.76	27	2,152	0.5	46	39	3,001
1876	1.7	4	5	0.77	29	1,693	0.3	30	30	1,141
1877	1.8	5	5	0.78	22	2,169	0.8	69	47	2,058
1878	1.8	5	6	0.77	25	1,949	0.6	53	36	2,378
1879	2.4	6	7	0.73	32	1,530	0.3	28	16	1,716
1880	2.9	7	9	0.64	29	1,838	0.6	47	26	2,060
1881	2.8	7	10	0.53	37	1,437	0.2	14	0	2,728
1882	2.6	7	10	0.44	19	2,895	1.6	140	56	3,308
1883	2.9	8	12	0.50	21	2,838	1.6	141	51	3,830
1884	2.8	9	14	0.60	19	3,142	2	172	52	4,499
1885	3.5	9	14	0.62	24	2,336	0.9	58	27	3,265
1886	3.6	10	15	0.56	33	1,433	0.2	15	-6	2,991
1887	4.1	11	16	0.52	46	886	0.2	15	-53	2,085
1888	3.7	12	16	0.38	28	1,827	1.1	73	30	3,213
1889	3.8	12	17	0.36	20	2,938	2.5	168	50	3,265
1890	3.5	12	18	0.38	74	424	0.2	16	-246	3,807
1891	3.5	15	19	0.61	28	1,902	1.3	85	29	5,733
1892	3.6	14	17	0.62	28	2,044	1.5	102	37	5,257
1893	3.5	15	15	0.62	30	1,746	1.5	99	38	5,080
1894	3.3	15	14	0.67	48	779	0.2	14	-45	4,552
1895	3.5	18	12	0.59	25	2,074	2.7	177	57	5,087
1896	3.5	16	14	0.59	33	1,694	1.1	74	30	4,544
1897	3.3	15	14	0.61	48	800	0.2	15	-50	4,568
1898	3.4	15	14	0.72	39	1,589	0.8	54	24	5,882
1899	3.8	17	15	0.70	35	2,182	1.7	119	43	5,815
1900	3.7	16	16	0.71	42	1,665	0.8	55	22	4,859
1901	3.8	17	17	0.77	59	555	0.3	18	-100	3,742
1902	3.5	16	17	0.79	39	2,415	1.7	117	42	5,850
1903	3.6	17	18	0.76	44	2,189	1.2	85	31	5,385
1904	3.9	16	19	0.76	59	966	0.3	20	-47	3,938
1905	3.6	16	17	0.76	39	2,361	1.6	110	40	6,598

	Population Density	Percent Cropland	Livestock Density	Crop Diversity	N Return on Cropland	Grain Yield	Area Productivity	Labor Productivity	Marketable Crop Production	Farm Income Per Capita
1906	3.6	16	19	0.81	41	2,258	1.3	92	32	6,464
1907	3.6	16	18	0.74	46	1,764	0.8	55	18	6,839
1908	3.6	16	17	0.75	50	1,694	0.5	37	9	7,997
1909	3.4	16	17	0.75	46	2,137	1	74	27	9,611
1910	3.5	13	15	0.69	51	1,757	0.5	39	15	7,711
1911	3.6	15	19	0.70	54	1,589	0.4	25	-5	8,680
1912	3.3	15	19	0.72	46	2,263	1.1	81	25	10,585
1913	3.4	15	16	0.78	71	467	0.3	24	-165	6,645
1914	3.2	14	11	0.80	54	2,012	0.6	46	20	10,731
1915	3.5	15	16	0.79	51	2,919	1	90	26	9,133
1916	3.3	15	17	0.75	72	579	0.4	32	-156	8,481
1917	3.2	16	14	0.79	54	1,618	0.6	54	19	13,664
1918	3.2	16	16	0.86	65	884	0.2	19	-52	11,599
1919	3.3	17	13	0.87	63	1,038	0.2	16	-17	8,331
1920	3.0	16	12	0.90	55	1,517	0.7	62	26	6,464
1921	3.3	15	13	0.89	56	1,307	0.4	33	11	3,479
1922	3.2	16	12	0.86	45	1,579	1	89	32	6,282
1923	3.3	19	15	0.86	55	987	0.2	20	-6	5,407
1924	3.3	15	14	0.87	42	2,218	1.4	131	42	6,710
1925	3.3	16	15	0.85	44	1,920	1.1	103	34	6,425
1926	3.1	15	15	0.85	53	1,216	0.3	25	4	5,904
1927	3.1	15	12	0.88	40	2,076	1.4	136	45	7,562
1928	3.0	15	15	0.85	34	2,564	2	205	50	8,681
1929	3.1	16	16	0.82	39	1,852	1.1	114	32	7,386
1930	3.0	15	13	0.80	47	885	0.2	19	-8	4,614
1931	2.8	14	13	0.85	39	1,223	0.5	56	20	3,482
1932	2.9	14	12	0.85	32	1,856	1.3	133	43	2,507
1933	3.0	14	13	0.81	51	766	0.2	18	-30	2,668
1934	3.0	13	17	0.84	61	614	0.2	20	-74	3,573
1935	3.1	15	11	0.89	45	1,035	0.5	47	21	4,194
1936	3.1	14	12	0.90	53	723	0.1	14	-10	3,872

APPENDIX 1: (*Continued*)

Stevens County, Kansas	Population Density	Percent Cropland	Livestock Density	Crop Diversity	N Return on Cropland	Grain Yield	Area Productivity	Labor Productivity	Marketable Crop Production	Farm Income Per Capita			Population Density	Percent Cropland	Livestock Density	Crop Diversity	N Return on Cropland	Grain Yield	Area Productivity	Labor Productivity	Marketable Crop Production	Farm Income Per Capita
1888	1.6	6	1	0.62	20	494	0.2	43	46	1,149		1913	1.2	15	6	0.57	38	421	0.4	45	28	4,060
1889	1.0	6	1	0.70	20	347	0.1	20	21	2,238		1914	1.2	11	5	0.49	29	1,320	0.5	66	44	6,091
1890	0.8	4	1	0.82	24	259	0	9	4	1,940		1915	1.3	14	7	0.58	27	1,317	0.8	97	49	8,731
1891	0.6	4	1	0.86	21	1,033	0.3	72	62	3,547		1916	1.5	18	8	0.74	35	578	0.5	65	31	9,601
1892	0.6	4	1	0.84	21	979	0.3	65	61	3,770		1917	1.6	28	7	0.63	36	213	0.6	78	42	13,872
1893	0.6	6	2	0.81	33	395	0.2	39	41	1,573		1918	1.8	25	8	0.46	34	250	0.6	71	35	13,678
1894	0.4	3	1	0.62	30	442	0.1	20	36	1,257		1919	2.0	25	9	0.57	25	1,019	1.2	150	52	10,979
1895	0.4	2	1	0.44	30	583	0	30	15	2,777		1920	2.0	29	9	0.59	23	1,143	1.7	210	61	9,108
1896	0.4	2	2	0.68	49	217	0	19	-52	1,253		1921	2.1	29	8	0.76	22	977	2	244	63	4,371
1897	0.3	2	2	0.48	36	922	0	19	-36	3,444		1922	2.0	37	8	0.79	34	426	1.1	126	44	5,589
1898	0.3	2	2	0.36	49	620	0	17	-69	3,523		1923	2.1	48	8	0.62	22	785	2.6	279	68	8,512
1899	0.3	2	3	0.22	84	1,119	0	25	-128	3,025		1924	2.2	38	8	0.70	20	943	2.4	255	67	7,985
1900	0.3	2	3	0.19	62	1,179	0	20	-56	5,556		1925	2.2	43	7	0.67	40	171	0.7	70	33	4,060
1901	0.3	2	4	0.27	72	455	0	22	-143	3,982		1926	2.0	45	6	0.62	14	1,337	4.7	492	82	12,636
1902	0.3	3	5	0.12	70	388	0.1	28	-108	5,525		1927	1.9	52	6	0.68	36	173	1.3	127	53	5,482
1903	0.4	3	7	0.23	72	702	0.1	39	-137	4,808		1928	2.1	48	5	0.70	18	859	3.4	382	78	8,742
1904	0.4	12	6	0.03	32	568	0.3	182	39	12,350		1929	2.1	51	5	0.64	15	1,109	5	552	83	12,720
1905	0.4	4	7	0.32	61	917	0.1	7	-87	5,782		1930	2.3	55	5	0.60	28	419	2.2	237	68	4,931
1906	0.4	4	5	0.49	44	1,086	0.1	5	-10	6,283		1931	2.8	59	5	0.58	13	1,286	6.9	748	87	4,932
1907	0.8	5	4	0.65	34	1,001	0.1	15	21	4,920		1932	2.5	51	5	0.72	28	321	1.8	196	67	1,963
1908	1.1	11	5	0.71	33	563	0.3	29	28	5,078		1933	2.4	53	5	0.69	34	79	1	117	53	2,995
1909	1.3	13	7	0.55	34	506	0.3	32	25	6,532		1934	2.4	52	5	0.59	41	151	1.1	123	54	3,527
1910	1.4	13	5	0.49	25	803	0.5	55	46	6,351		1935	2.4	61	4	0.64	34	39	1.4	154	63	3,489
1911	1.2	14	6	0.54	36	396	0.3	37	27	7,372		1936	2.2	59	3	0.60	33	85	1.7	186	72	4,242
1912	1.2	12	6	0.40	34	802	0.4	48	33	5,858												

APPENDIX 1: (*Continued*)

Decatur County, Kansas	Population Density	Percent Cropland	Livestock Density	Crop Diversity	N Return on Cropland	Grain Yield	Area Productivity	Labor Productivity	Marketable Crop Production	Farm Income Per Capita			Population Density	Percent Cropland	Livestock Density	Crop Diversity	N Return on Cropland	Grain Yield	Area Productivity	Labor Productivity	Marketable Crop Production	Farm Income Per Capita
1879	0.9									46		1908	4.4	44	14	0.75	70	329	0.5	29	-87	3,350
1880	1.8	3	1	0.70	24	1,066	0.1	17	28	698		1909	4.0	45	11	0.74	56	436	0.5	28	-12	4,761
1881	1.2	3	1	0.55	36	296	0	3	-113	754		1910	3.8	41	10	0.78	54	408	0.5	27	-17	3,608
1882	1.4	3	2	0.67	28	636	0	4	-20	666		1911	3.5	63	9	0.78	60	310	0.3	19	-15	2,393
1883	1.2	4	3	0.84	31	565	0.1	7	-68	1,243		1912	3.1	47	7	0.74	45	500	0.9	53	27	4,830
1884	1.2	4	3	0.87	15	1,906	0.4	43	45	2,265		1913	3.0	47	8	0.78	64	226	0.3	15	-64	3,754
1885	1.7	5	4	0.81	16	1,907	0.6	45	49	1,902		1914	2.9	46	9	0.68	26	962	3.2	189	59	10,061
1886	2.7	9	6	0.71	17	1,898	1.3	86	51	1,980		1915	3.2	46	12	0.66	24	1,174	4.1	267	60	9,906
1887	3.7	13	7	0.65	31	560	0.7	47	-41	1,361		1916	3.5	50	13	0.71	40	580	0.9	61	18	8,971
1888	3.7	15	8	0.62	16	1,714	2.8	184	53	2,268		1917	3.6	64	13	0.79	73	208	0.3	19	-85	4,880
1889	3.7	17	8	0.71	17	1,643	3	194	54	1,908		1918	3.4	56	13	0.79	66	206	0.3	22	-105	4,851
1890	3.5	20	9	0.74	57	158	1.3	85	-398	1,234		1919	3.4	49	13	0.67	20	1,186	4.4	290	62	13,114
1891	2.6	15	7	0.70	15	2,037	3	189	66	5,113		1920	3.4	49	14	0.61	19	1,329	5.1	340	65	10,709
1892	3.4	21	7	0.71	16	1,725	3.5	214	67	3,315		1921	3.5	46	15	0.56	38	614	0.8	58	16	3,440
1893	3.3	24	7	0.69	35	601	0.8	47	16	1,548		1922	3.5	53	15	0.66	32	722	1.9	135	35	4,921
1894	3.3	22	7	0.64	76	194	0.5	29	-204	1,128		1923	3.6	57	16	0.75	22	1,179	4.8	382	56	5,531
1895	3.0	25	6	0.60	24	1,129	2.5	146	57	2,481		1924	3.6	52	16	0.74	24	1,031	3.4	283	48	6,698
1896	3.1	25	7	0.59	27	1,038	2.4	138	46	2,132		1925	3.6	52	15	0.70	32	726	1.6	137	29	5,743
1897	3.0	27	8	0.62	20	1,645	4	226	64	3,718		1926	3.5	49	13	0.68	122	74	0.2	20	-532	1,948
1898	3.1	32	10	0.68	23	1,404	3.5	196	53	4,852		1927	3.5	57	10	0.73	24	943	4.2	358	62	5,469
1899	3.4	32	13	0.69	25	1,345	3	166	45	4,772		1928	3.5	58	10	0.72	21	1,143	5.7	436	67	6,960
1900	3.7	33	14	0.62	43	541	0.9	47	-44	4,216		1929	3.5	50	11	0.70	24	1,034	4	299	59	8,133
1901	3.9	35	13	0.70	56	421	0.6	32	-57	3,326		1930	3.5	52	12	0.69	34	1,274	1.4	107	14	7,662
1902	3.7	40	13	0.78	49	621	0.6	32	8	4,926		1931	3.6	54	13	0.71	20	1,266	5.8	430	65	5,123
1903	3.7	39	14	0.80	26	1,621	5.1	265	62	7,873		1932	3.8	55	15	0.73	38	606	1	77	18	2,852
1904	3.9	36	15	0.78	36	1,124	2.3	119	33	5,624		1933	3.8	64	14	0.78	50	394	0.3	21	-7	3,131
1905	4.0	40	18	0.81	24	1,754	5.6	311	57	8,682		1934	3.7	47	16	0.77	82	122	0.3	22	-366	2,420
1906	4.5	39	18	0.80	33	1,261	2.8	153	35	6,813		1935	3.7	57	12	0.79	61	230	0.2	14	-72	3,580
1907	4.6	41	17	0.78	59	476	0.6	36	-63	4,661		1936	3.6	53	10	0.76	63	287	0.2	12	-23	4,037

APPENDIX 1: (*Continued*)

Ellsworth County, Kansas	Population Density	Percent Cropland	Livestock Density	Crop Diversity	N Return on Cropland	Grain Yield	Area Productivity	Labor Productivity	Marketable Crop Production	Farm Income Per Capita		Population Density	Percent Cropland	Livestock Density	Crop Diversity	N Return on Cropland	Grain Yield	Area Productivity	Labor Productivity	Marketable Crop Production	Farm Income Per Capita
1875	0.9	2	3	0.89	19	1,962	0.1	6	18	1,445	1906	5.1	40	19	0.57	29	1,199	3.2	159	51	6,563
1876	0.9	3	2	0.89	20	1,310	0.2	10	38	1,506	1907	5.1	41	18	0.53	33	1,103	2.9	147	49	7,028
1877	1.8	5	3	0.84	14	1,686	0.6	27	58	1,752	1908	5.1	44	19	0.56	36	1,050	2.6	132	42	8,303
1878	2.7	8	4	0.74	15	1,778	1.2	58	64	1,943	1909	5.2	45	21	0.59	37	1,094	2.8	144	43	9,157
1879	3.6	12	5	0.71	17	1,620	1.8	87	66	1,960	1910	5.3	43	19	0.76	35	1,182	3.1	160	47	8,304
1880	4.5	17	6	0.69	23	1,088	1.3	66	50	1,739	1911	5.4	47	22	0.67	69	421	0.4	19	-46	4,999
1881	3.8	18	7	0.71	31	713	0.5	26	24	2,537	1912	5.3	48	19	0.66	32	1,170	3.7	194	52	8,891
1882	3.9	30	8	0.73	14	1,623	4.9	222	77	5,694	1913	5.2	48	19	0.63	51	646	0.8	43	13	4,624
1883	4.0	19	10	0.79	18	1,488	2.5	108	63	3,702	1914	5.3	47	14	0.52	26	1,302	4.7	246	62	9,132
1884	4.1	22	11	0.74	12	2,233	4.7	196	75	5,330	1915	5.6	47	20	0.54	36	1,011	2.7	149	42	7,476
1885	5.3	25	12	0.78	20	1,374	2.8	136	57	2,184	1916	5.6	51	23	0.64	51	605	0.6	32	4	7,364
1886	5.6	25	15	0.76	20	1,412	2.5	124	50	2,955	1917	5.6	70	19	0.77	96	160	0.2	14	-147	5,488
1887	5.7	27	13	0.75	57	341	0.3	14	-89	1,576	1918	5.4	63	20	0.78	53	451	0.3	20	2	8,728
1888	6.0	25	11	0.74	50	469	0.2	10	-18	1,835	1919	5.3	48	21	0.55	43	712	1.3	79	25	10,216
1889	5.1	26	12	0.75	13	2,190	5.7	291	76	3,887	1920	5.3	49	17	0.66	30	1,060	3.6	223	55	7,046
1890	4.8	31	11	0.79	51	426	0.2	11	-2	2,471	1921	5.4	54	18	0.66	43	610	1.3	79	27	3,202
1891	5.3	27	12	0.52	21	1,356	3.2	165	61	3,741	1922	5.3	48	17	0.53	33	804	2.1	124	41	4,089
1892	5.0	28	11	0.64	19	1,477	3.5	187	65	4,017	1923	5.4	46	18	0.56	34	850	2	122	38	3,994
1893	5.1	36	12	0.61	60	417	0.2	10	-7	1,840	1924	5.4	45	20	0.60	22	1,406	4.8	278	61	6,424
1894	4.6	29	10	0.53	71	328	0.1	8	-42	1,963	1925	5.3	48	20	0.63	44	630	1	57	21	4,430
1895	4.7	36	11	0.63	35	793	1.7	86	41	3,129	1926	5.5	46	19	0.54	31	878	2.2	127	42	5,482
1896	4.6	37	14	0.66	28	969	2.2	111	46	3,523	1927	5.4	45	17	0.49	28	1,049	3.2	187	53	5,645
1897	4.7	37	17	0.65	24	1,148	2.7	136	49	6,496	1928	5.4	47	17	0.52	22	1,350	5.1	300	65	6,709
1898	4.7	38	19	0.60	28	947	1.9	92	37	6,433	1929	5.3	45	18	0.53	33	845	2.1	125	40	4,933
1899	5.3	39	20	0.63	27	1,138	3	150	50	4,804	1930	5.3	45	17	0.53	30	912	2.5	156	48	4,179
1900	5.1	37	21	0.61	23	1,281	3.1	154	51	6,315	1931	5.3	46	19	0.57	23	1,241	4.3	263	61	3,317
1901	5.0	39	22	0.56	27	1,073	2.4	120	44	6,072	1932	5.3	49	18	0.68	32	793	2.2	134	42	2,226
1902	5.0	47	20	0.64	48	583	0.8	40	14	4,384	1933	5.3	45	18	0.64	50	418	0.3	17	-16	2,435
1903	4.8	40	22	0.56	25	1,295	3.7	181	55	6,323	1934	5.4	41	19	0.55	34	818	1.7	100	37	3,851
1904	4.9	39	19	0.55	29	1,105	2.8	139	48	6,596	1935	5.5	44	15	0.55	46	442	0.4	22	6	3,013
1905	5.0	40	21	0.59	30	1,170	3	147	48	6,756	1936	5.5	46	15	0.52	28	840	2.5	149	52	5,188

APPENDIX 2: SOCIO-ECOLOGICAL PROFILE CONSTRUCTION

Socio-ecological profiles depend on agricultural census data reported by the Kansas State Board of Agriculture for each county in the state. Measures based on crop yields show large annual fluctuations related to variable precipitation. Ten-year moving averages for all measures show long-term trends more clearly, which is why graph lines in Figures 2 through 11 begin in 1885, even though annual census observations began in 1875.

Population Density (people per km^2) Population density equals total population as given in the population census divided by total county area.

Percent Cropland (percentage of total county area) Percent cropland equals the sum total of the area of all reported crops (sown area) divided by total county area.

Livestock Density (500 kg livestock units per km^2 of agricultural land) Total number of livestock reported in the Kansas agricultural census—including cattle, horses, sheep, pigs, and poultry—was converted into standardized "large animal units" of 500 kg live-weight. Livestock density is the sum of large animal units divided by total area of agricultural land, including cropland and pasture.

Crop Diversity (index score between 0 and 1) This diversity index is comparable across time and place. The Kansas agricultural census reported the area planted in the eight most important crops—corn, wheat, barley, oats, rye, sorghum, potatoes, and hay. Dividing each crop's area by total cropland area produces the proportion of cropland devoted to each crop. Adding the squares of the proportions of each crop generates an index score representing diversity. This calculation follows Jack P. Gibbs and Dudley L. Poston, Jr., "The Division of Labor: Conceptualization and Related Measures," *Social Forces*, LIII (1975), 468–476. The sum of the squared proportions becomes the index, further adjusted to a scale from 0 to 1, 0 being the lowest possible diversity (equivalent to 100 percent of land in a single crop) and 1 the highest possible diversity (equivalent to an even distribution of land across all eight crops—12.5 percent in each):

$$1 - [(x - y)/z],$$

where x=the sum of the squares of crop proportions; y=1 divided by 8 (number of crops); z=1 − y.

The following crop distributions would have these crop diversity scores: 1 crop=0.00; 2 crops=0.57; 3 crops=0.76; 4 crops=0.86; 5 crops=0.91; 6 crops=0.95; 7 crops=0.98; 8 crops=1.00. Most examples fall in the 0.60 to 0.80 range, meaning that they supported two or three major crops. None of them was close to a single-crop monoculture. Considering also the grazing land not captured in the index, this farm system was relatively diverse. The index does not capture much subsistence production. Most families had vegetable gardens and fruit trees for their own use, but those land uses, which occupied only 1 to 2 percent of total area, do not appear in the census. Most land was devoted to pasture, feed crops, forage, and cash crops. Cropland usually supported one feed crop (corn or sorghum) and one cash crop (wheat), plus hay for forage. In Nemaha and Franklin Counties, corn was also a cash crop when production exceeded livestock needs. Nearly all county-years had at least two major crops and scored above 0.60 on the crop-diversity index.

Nitrogen Return (percentage of extracted nitrogen returned to soil) Nitrogen (N) return is calculated as total N inputs divided by total N contained in harvested crops and crop residues. Nitrogen inputs include nitrogen contained in applied manure and litter, N contained in seeds, wet and dry deposition, and N input by leguminous crops (nitrogen losses from soils due to erosion, leaching, and volatilization are not part of this analysis because of a lack of sufficient historical data to estimate them). Estimates of manure production depend on livestock numbers, average live-weight per head, excretion rates per kg live-weight, and the nitrogen content of livestock feces. Species-specific assumptions about the share of manure collected in barnyards and nitrogen losses from manure during storage and processing (leaching and volatilization) reduced the amount of N practically available for cropland application. N input by seeds and extraction in harvest was calculated using crop-specific nitrogen content of grain. See R. Garcia-Ruiz, M. González de Molina, G. Guzmán, D. Soto, and J. Infante-Amate, "Guidelines for Constructing Nitrogen, Phosphorus, and Potassium Balances in Historical Agricultural Systems," *Journal of Sustainable Agriculture*, XXXVI (2012), 650–682.

Grain Yield (kg per ha) Grain yield is the sum of harvested cereal crops (corn, wheat, barley, oats, and rye) divided by total area sown in cereals. Grain yield fluctuated from year to year due to variable precipitation.

Area Productivity (product output in gj per ha of agricultural land) Area productivity measures agricultural output per unit of land as gj/ha. Net product output adds net crop production (crop harvest minus seeds and feed for farm animals) and net animal production (carcass weight of meat plus milk production minus milk consumed by calves). Agricultural products are weighted by their nutritional energy content (mj/kg) then divided by total agricultural area. Area productivity fluctuated yearly due to variable precipitation.

Labor Productivity (product output in gj per agricultural worker) Labor productivity measures agricultural production per person in the agricultural labor force. Net product output (see area productivity) is divided by total number of people in the county aged fifteen to sixty-five.

Marketable Crop Production (percentage of cereal crop available for export) In mixed farming systems with crops and livestock, much crop production goes to feed animals. Marketable crop production is the share of annual crops not needed for livestock feed or for next year's seed, and thus available for sale on the market. Since crop yields fluctuated more than livestock numbers, marketable crop production varied widely and was negative in some years. Negative values meant that farmers had to buy feed grain to sustain their animals or consume grain stored in previous years (such storage would have reduced marketable surplus in earlier years).

Farm Income (dollars per person, inflation adjusted to 2010) The Annual and Biennial Reports of the Kansas State Board of Agriculture report total farm income (including income from both crops and livestock) in dollars. These values are divided by each county's total population in the same year. Dollar amounts have been inflation-adjusted to 2010 equivalents. Consumer price index conversion factors come from Robert Sahr, "Inflation Conversion Factors for Years 1774 to estimated 2023," available at http://oregonstate.edu/cla/polisci/download-conversion-factors (accessed August 27, 2013).