Sustaining Soil Fertility: Agricultural Practice in the Old and New Worlds

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Migration

George Thir had a busy year in 1884.[1] Along with his parents, George and Theresia Thir, he emigrated from the corner of central Europe where today Austria, Hungary, and Slovakia come together. He travelled to the United States,

made his way to the far edge of agricultural settlement in western Kansas, and selected a farm that would become his home for the remainder of his life. Kansas had organized its westernmost territory just six years earlier, including the Thirs' new home of Decatur County. The last conflict between Indians and encroaching white settlers in Kansas occurred there in 1878, when fleeing Cheyennes attacked and killed dozens of recent settlers. By the time the Thirs arrived the gently undulating mixed-grass prairie of western Kansas was filling up with farmers. Most came from eastern parts of the United States, but a significant number came directly from Germany, Austria-Hungary, Sweden, and other foreign countries. The Thirs most likely immigrated from Gols, in what is now Austria, where most of their Kansas neighbors originated. They certainly came from somewhere in the German-speaking portion of the Austro-Hungarian empire. Over the course of his life various official documents identified the younger George as German, Hungarian, Austro-Hungarian, and Austrian. The Austro-Hungarians who settled in the northwest corner of Decatur County, Kansas came from a cluster of farming villages within 25 km of one another, including Gols and Zurndorf in what is now Austria, and Ragendorf and Kaltenstein in present-day Hungary.[2] Born in May, 1865, George Thir was 19 when he traveled to Kansas. Within a few months of arrival he chose suitable farmland in Section 17 of Finley Township and, on October 9, 1884, filed a Homestead claim on 65 hectares of grass.[3]

[1] This study is supported by U.S. National Institute of Child Health and Human Development grants no. HD044889 and HD033554. The authors would like to thank three anonymous reviewers who improved the article significantly.

[2] For details on the emigration from this region of the Austro-Hungarian Empire, see W. Dujmovits, *Die Amerikawanderung der Burgenländer*, Desch-Drexler, Pinkafeld 1990; M. Antoni, "Nach Amerika….", Materialien zur Landesausstellung in Güssing, Pädagogisches Institut des Bundes für Burgenland, Eisenstadt 1992.

[3] Decatur County Historical Book Committee, *Decatur County, Kansas*, Craftsman Printers Inc., Lubbock, Texas 1983, pp. 25-31. Homestead records from Kansas GenWeb, http://skyways.lib.ks.us/genweb/decatur/Land%20Records/finley_homesteading.htm (accessed February 16, 2009). The reconstruction of Thir and Demmer family history comes from the following sources: U.S. Population Census manuscript schedules, Decatur County, Kansas, 1880, 1900, 1910, 1920, 1930; Kansas State Board of Agriculture, population census manuscripts, Decatur

Making raw prairie into a farm was slow, hard work. In March, 1885 the new homestead, valued at $50, had no cropland, no livestock, no fences, and no house. Thir worked as a blacksmith and boarded with neighbors—John and Gussie Adams, and Ray, their one-year-old son. Thir had not really started farming his new land yet when the census-taker recorded his presence in the spring of 1885, but the next ten years would see considerable progress on the Thir farm.[4]

In 1888 George married Elizabeth Demmer; he was 23 and she was 20. Born in Gols in 1868, at age 13 she and her family joined the chain migration to far western Kansas. Between the 1870s and 1890s dozens of families left Gols, Ragendorf, Zurndorf, and Kaltenstein for the United States, travelling by ship across the Atlantic, then by train to Nebraska. Many settled near Crete, Nebraska where a community of Austro-Hungarian immigrants welcomed new arrivals. The motivations for migration varied. Most sought free agricultural land and an opportunity for economic improvement. Some fled the military draft. In 1983, for example, Carl Resch recalled his grandfather's reason for leaving: "In 1883 John Resch Sr. immigrated to America with his wife and children to escape conscription into the army of Francis Joseph, Emperor of Austria-Hungary, and in search of good land and a better life—free from militarism that ravaged Europe periodically." Another Gols native, Andreas Wurm, had already been drafted and discharged by the age of 17 when, in 1878, he joined two friends travelling to Nebraska. Like many others, they found Crete already full, and moved southwest to Decatur County, Kansas where free land was still available. Not yet old enough to file a homestead claim, Wurm brought his parents from Austria to Kansas so they could file a claim for him.[5]

George's new wife, Elizabeth Demmer, was also part of a multigenerational migration. She was one of five children born to Math-

County, Kansas, 1885, 1895, 1905, 1915, 1925, held at Kansas State Historical Society, Topeka (hereafter cited as KSHS).

[4] Kansas State Board of Agriculture, Population and Agricultural Census Manuscripts, Decatur County, Kansas, 1885, held at KSHS.

[5] *Decatur County, Kansas* cit., pp. 152, 204, 333-334, 351-352, 374, 425, 428-433.

ias and Maria Ecker Demmer. In 1881 the whole family moved to Crete, Nebraska, and then on to Decatur County, Kansas. Several other branches of the Demmer family made the move between the late 1870s and mid-1880s, finding (and often intermarrying with) former neighbors from Austria. Families from Gols, Ragendorf, and Kaltenstein selected homesteads all around Finley Township, where George and Elizabeth Thir made their new farm (Fig. 1). Elizabeth gave birth to a daughter, Susie M. Thir, in January 1889. A second daughter, born in May 1892, took her mother's name. Their third and final child, George, Jr., was born in May 1895. By that year the farm, now worth $800, was thriving. It boasted cropland planted to corn, spring wheat, sorghum, and potatoes, plus hay and grazing land for 3 horses, 1 milk cow, and 1 hog.[6]

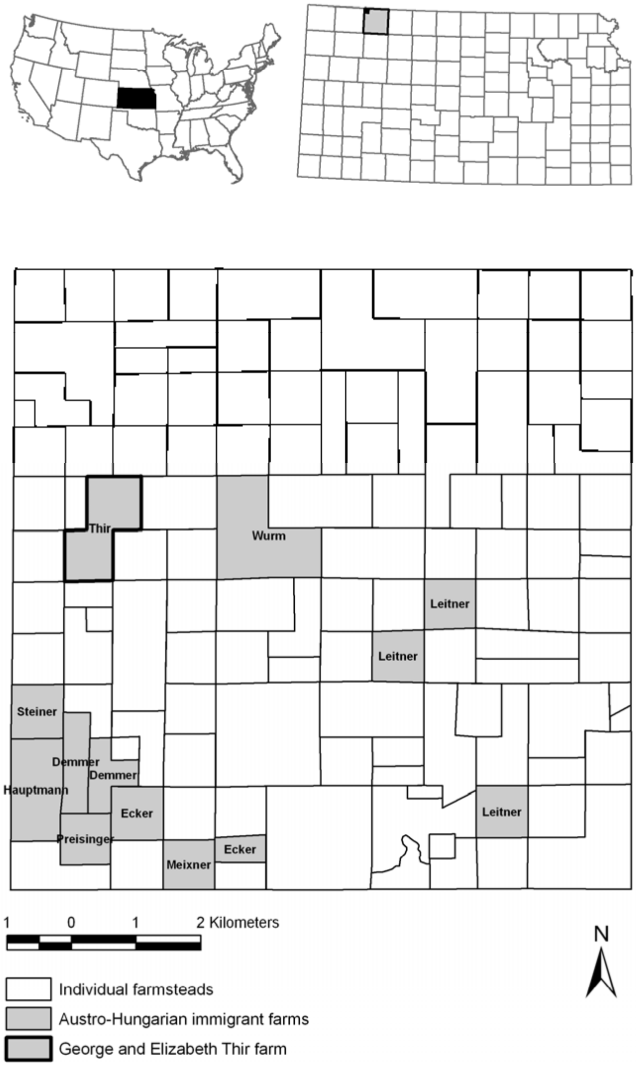
Over the next several decades, as the Thir children grew up, the farm expanded. By 1905 it had doubled in size to 130 hectares, with buildings, implements, a dozen milk cows, 10 beef cattle, 4 horses, 11 hogs, and a variety of cropland, hay land, and pasture, all worth $2,000. Ten years later the farm had doubled in size again, to 259 hectares—one square mile of fertile Kansas farmland. The daughters moved out of the family home in their early twenties to join new husbands. George, Jr., remained single, continued to live with his parents, and farmed in partnership with his father into the 1940s. George, Sr., died in 1949 and Elizabeth in 1953.[7]

George and Elizabeth Thir did more than trade Alpine mountains for vast plains when they migrated across the ocean. They left behind an agro-ecological system in Austria where farmland supported high populations on small holdings, where rainfall was reliable, where nu-

[6] *Decatur County, Kansas* cit., pp. 152, 184, 374, 430. *Standard Atlas of Decatur County, Kansas*, G.A. Ogle & Co., Chicago 1905, held at KSHS. Kansas State Board of Agriculture, Population and Agricultural Census Manuscripts, *Decatur County, Kansas*, 1895. More detailed information on population, livestock and land use for Thir farm and Finley Township is provided in Supporting Table S1 and S2.

[7] Kansas State Board of Agriculture, Population and Agricultural Census Manuscripts, Decatur County, Kansas, 1905, 1915, 1920, 1925, 1930, 1935, 1940. U.S. Population Census Manuscript Schedules, 1900, 1910, 1920, 1930. Herndon Union Cemetery records, Rawlins County, Kansas.

Figure 1. Austro-Hungarian immigrant farms, including the Thir farm, situated within Finley Township. The small locator maps show the location of Kansas within the United States and of Decatur County and Finley Township within the state of Kansas



trients and energy flowed through tightly bound pathways linking soil, plants, animals, and people into a complex and highly evolved system. For centuries rural Austrians had pushed the land to produce as much food as possible to support growing populations, but in a way that could be sustained over many generations. In Austria, land was scarce, labor (and hungry mouths) abundant. Livestock were a crucial component of the system, providing food and clothing, but also physical labor and manure to fertilize cropland.[8]

They arrived in an agro-ecological setting in Kansas that had immense potential but little existing structure. There fertile soil was abundant and cheap, labor hard to come by, and rainfall uncertain. Population density was low, and even livestock were in short supply and expensive. George and Elizabeth spent their lives creating a new agro-ecological system where none had existed. They brought labor to bear: their own strong backs plus three children and a barnyard full of animals. They tapped into a rich stockpile of soil nutrients accumulated under native grassland over geological time. They organized a new farm system alongside neighbors from home and from many different parts of the world, one that meshed their cultural inheritance with a semi-arid plains environment. The result was very different from the agricultural world they had left behind.

Agricultural systems are coupled human-environment systems.[9] This study takes a socio-ecological perspective on agriculture and focuses on biophysical relations between society and its natural en-

[8] F. Krausmann, "Milk, Manure and Muscular Power: Livestock and the Industrialization of Agriculture", in *Human Ecology*, 32, 6, 2004.

[9] H. Haberl, V. Winiwarter, K. Andersson, R.U. Ayres, C.G. Boone, A. Castillio, G. Cunfer, M. Fischer-Kowalski, W.R. Freudenburg, E. Furman, R. Kaufmann, F. Krausmann, E. Langthaler, H. Lotze-Campen, M. Mirtl, C.A. Redman, A. Reenberg, A.D. Wardell, B. Warr, and H. Zechmeister, "From LTER to LTSER: Conceptualizing the Socioeconomic Dimension of Long-term Socioecological Research", in *Ecology and Society*, 11, 2006, http://www.ecologyandsociety.org/vol11/iss2/art13/-. J.G. Liu, T. Dietz, S.R. Carpenter, C. Folke, M. Alberti, C.L. Redman, S.H. Schneider, E. Ostrom, A.N. Pell, J. Lubchenco, W.W. Taylor, Z.Y. Ouyang, P. Deadman, T. Kratz, and W. Provencher, "Coupled Human and Natural Systems", in *Ambio*, 36, 2007.

vironment, using a social metabolism approach to investigate the structure and functioning of agricultural production systems. The concept of social metabolism appears widely in sustainability science.[10] Recognizing that all economic activity is based on a throughput of materials and energy, it links socioeconomic activity to ecosystem analysis. The corresponding set of methods – material and energy flow analysis, or MEFA – allows one to trace material and energy flows through socioeconomic systems and provides a quantitative picture of the physical exchange processes between societies and their environment. This approach has also been applied in historical studies and in particular to explore society-nature interactions in local rural systems and to investigate the relationship between land, humans, livestock, and the flows of materials and energy related to production and reproduction in agricultural systems.[11]

Old World and New World farm systems

How did the farm system that immigrants left behind compare with that which they found (and created) on the Great Plains frontier? This study uses a socio-ecological approach to explore similarities and differences in land use at either end of the migration chain.[12] It employs

[10] R.U. Ayres and U.E. Simonis, *Industrial Metabolism: Restructuring for Sustainable Development*, United Nations University Press, New York 1994. M. Fischer-Kowalski, "Society's Metabolism. The Intellectual History of Material Flow Analysis, Part I: 1860-1970", in *Journal of Industrial Ecology*, 2, 1998.

[11] R.P. Sieferle, F. Krausmann, H. Schandl, and V. Winiwarter, *Das Ende der Fläche. Zum Sozialen Metabolismus der Industrialisierung*, Böhlau, Köln 2006. Krausmann, *Milk, Manure* cit.. X. Cusso, R. Garrabou, and E. Tello, "Social Metabolism in an Agrarian Region of Catalonia (Spain) in 1860 to 1870: Flows, Energy Balance and Land Use", in *Ecological Economics*, 58, 2006. G.I. Guzman Casado and M. Gonzalez de Molina, "Preindustrial Agriculture versus Organic Agriculture: The Land Cost of Sustainability", in *Land Use Policy*, 26, 2009. G. Cunfer, "Manure Matters on the Great Plains Frontier", in *Journal of Interdisciplinary History*, 34, 2004. J. Marull, J. Pino, and E. Tello, "The Loss of Landscape Efficiency: An Ecological Analysis of Land Use Changes in Western Mediterranean Agriculture (Vallès County, Catalonia, 1853-2004)", in *Global Environment*, 2, 2008.

two community case studies, one in Austria and the other in Kansas, to compare the ways that people turned the raw materials of soil, climate, and biota into the finished products of food, field, and culture.

Theyern, Austria, as it existed around 1830, serves as the first case study. Theyern is about 100 km northwest of Gols. A considerable preexisting dataset makes it possible to model Theyern's land use history in great detail, and the agricultural system there matches, in broad outline, that of the Gols-Ragendorf-Kaltenstein region that fed Finley Township's nineteenth century population boom. Theyern was a typical lowland farming system with an area of 2.3 km² and a population of 102 in 1829.[13] The village lies in the low, rolling countryside of northeastern Austria. Here a loess soil over conglomerate rock with a high lime content provides good conditions for cultivation. With an average annual temperature of 10° C and 521 mm of precipitation, Theyern has favorable climatic conditions for cropland farming and cereal production. The village has been cultivated for many centuries; it is possible to trace individual farmsteads to the early 15th century.[14] By the early nineteenth century more than half of Theyern's area was cropland (Fig. 2a). Despite a rather large livestock herd, only 3% of the village was grassland, but woodland commons provided additional grazing. Woodlands covered roughly one third of the territory, but only prevailed on soils unsuitable for cultivation. They served not only as a source for fuel and timber but were also grazed and provided litter for animal bedding.[15] Theyern, like Gols, was on the edge of a wine-growing region and, although there

[12] M. Fischer-Kowalski and H. Haberl (eds), *Socioecological Transitions and Global Change: Trajectories of Social Metabolism and Land Use*, Edward Elgar Publishing, Cheltenham, Gloucestershire, UK 2007. For an early discussion of agroecology as a central subject for environmental history, see D. Worster, "Transformations of the Earth: Toward an Agroecological Perspective in History", in *Journal of American History*, 76, 4, 1990.

[13] More detailed information on population, livestock and land use in Theyern is provided in Supporting Table S5.

[14] C. Sonnlechner, "Umweltgeschichte und Siedlungsgesc. Methodische Anmerkungen zu Hans Krawariks 'Frühe Siedlungsprozesse im Waldviertel'", in *Das Waldviertel*, 50, 2001.

[15] Krausmann, *Milk, Manure* cit.

are no vineyards in Theyern itself, farmers had access to vineyards in neighboring villages. Population density was high: at 45 persons per km^2 it was somewhat above the Austrian average of 42 persons per km^2. In 1829 Theyern was home to 17 farm families who cultivated an average of 8 ha each. [16] However, 3 of the farms were larger (approximately 13-19 ha), while 4 had very small holdings of under 4 ha, probably producing barely enough for subsistence.[17]

Until the mid 19th century, land did not belong to the peasants but to the local manor, which assigned it to particular families. In the case of Theyern, the nearby Benedictine monastery of Göttweig served this function, and also collected tithes and taxes (in the form of money, compulsory human and animal labor, or a share of agricultural produce). Besides the peasant families and the manor, the village community itself was an important institution of land-use decision-making. The village managed its woodlands collectively as commons. Also, the village as a whole determined the temporal rhythm of cropland cultivation and crop choice. Each family tended numerous small plots of land scattered across the municipality. A three-field rotation system necessitated joint decisions and efforts regarding plowing and harvesting of crops (Fig. 2b).[18]

The main source for the reconstruction of Theyern's land use and farming systems is the Franciscean Cadastre (Franziszeischer or Stabiler Kataster). [19] This tax survey was conducted during the first half of the 19th century (1817-1856) and covered most of the territory

[16] Cadstral Schätzungs Elaborat der Steuergemeinde Theyern, held at Landesarchiv St. Pölten.

[17] The small size and low output of some of the farms is assumed to be one of the main reasons for the comparatively frequent turnover in farm holders observed in Theyern between 1500 and 1800 (see Projektgruppe Umweltgeschichte, *Historische und ökologische Prozesse in einer Kulturlandschaft*, Wien 1997).

[18] Cadastral Schätzungs Elaborat der Steuergemeinde Theyern.

[19] A. Moritsch, "Der Franziszeische Grundsteuerkataster. Quelle für die Wirtschaftsgeschichte und historische Volkskunde", in *East European Quarterly*, 3, 1972. R. Sandgruber, "Der Franziszeische Kataster und die dazugehörigen Steuerschätzungsoperate als wirtschafts- und sozialhistorische Quellen", in *Mitteilungen aus dem niederösterreichischen Landesarchiv*, 3, 1979.

Figure 2. Theyern land management

(2a) Small meadows and orchards clustered closely around residential house lots, while cropland surrounded the village. On the outskirts of the community, woodlands prevailed on poor soils not suitable for cropping. (2b) The cropland portion of the agroecosystem rotated annually through a three-field sequence. Family farms consisted of scattered plots distributed across all parts of the village, as illustrated here for the Gill family, one of the three larger holdings (ca. 13 ha of farmland)

of the Austro-Hungarian Empire, some 300,000 km². It includes a geodetic land survey, estimations of crop yields for all land use classes, and a report of monetary outputs.[20] The Franciscean Cadastre comprises several different types of documents:

— A 1:2,880 scale cadastral map of each Cadastral Municipality (Katastral Gemeinde) with information on land use and cover for individual parcels. Up to 39 different land use classes plus up to 4 distinct quality designators appear on the maps.

— Survey Protocols (Parzellen Protokoll) indicating ownership plus size and land use type for each parcel or building.

— Cadastral Summaries (Catastral Schätzungs Elaborat), the main data source for the reconstruction of land use practice and biomass and nutrient flows. These are handwritten texts, one for each map, offering extensive descriptions of topography, demography, and the farming system. They contain detailed information on land use and land cover, yields, population, livestock, and farming practices, as well as production, livestock feeding practices, soil manuring standards, general information on the number of farms, community wealth, use of animals, and markets.

— Estimates of Expenses and Monetary Yield (Darstellung des Kulturaufwandes und des Reinertrages), giving aggregate information on factor costs and estimated monetary gross and net yields based on local prices in 1824, for each land-use category in a cadastral unit. In combination with the Survey Protocol, this document was the basis for tax calculation.

In addition to the data provided by the cadastre, we used a wide variety of sources and literature about local, regional, and general aspects of the structure and functioning of pre-industrial farming systems.[21] Furthermore, published and unpublished data and analyses relating to the environmental history of the case study regions

[20] K. Lego, "Geschichte des österreichischen Grundkatasters", Bundesamt für Eich - und Vermessungswesen, Wien, 1968. K.K. Finanz-Ministerium (ed.), Tafeln zur Statistik des Steuerwesens im österreichischen Kaiserstaate mit besonderer Berücksichtigung der directen Steuern und des Grundsteuerkatasters, Wien, 1858.

[21] See Krausmann, *Milk, Manure* cit. Id., "Land Use and Socio-economic Me-

were available from previous research projects.[22]

The Cadastral survey for Theyern dates to 1829. Rather than reflecting specific conditions during any single year, it reports long-term averages. A reconstruction of the agroecosystem on the basis of these data represents a valid average for much of the first half of the 19th century. Only later in the 19th century did the farming system begin to change slowly as innovations associated with the first agricultural revolution and the land reform of 1848 spread in Austria.[23]

At the other end of the migration lay Decatur County, Kansas. George and Elizabeth ended their separate travels in the grasslands of the Great Plains, a flat to gently undulating steppe environment slowly rising in elevation from east to west. Recently buffalo range controlled by Cheyenne, Pawnee, and Arapaho horse cultures, Decatur County sat at the transition zone between dry mixed-grass prairie and very dry short-grass plains (Fig. 1). Rainfall averaged 475 mm, and the dominant native vegetation was little bluestem, grama, and buffalo grasses. Trees were very rare – less than 5 percent of ground cover – and appeared only in narrow bands along rivers and streams. Here soils were quite rich, but rainfall was unreliable, reeling between very wet years with 800 mm or more and severe

tabolism in Pre-industrial Agricultural Systems: Four Nineteenth-century Villages in Comparison", in *Social Ecology working paper* n. 72, Institute of Social Ecology, Vienna 2008 for a detailed description.

[22] This material includes digitised versions of the original cadastral maps of the villages, specific evaluations of parcel protocols (e.g., the quantification of the extent of external land use, land use data, and factor costs at the farm level). See Projektgruppe Umweltgeschichte, *Historische und ökologische Prozesse* cit. Projektgruppe Umweltgeschichte, *Kulturlandschaftsforschung: Historische Entwicklung von Wechselwirkungen zwischen Gesellschaft und Natu*r, CD-ROM, Bundesministerium für Wissenschaft und Verkehr, Wien 1999. V. Winiwarter and C. Sonnlechner, *Der soziale Metabolismus der vorindustriellen Landwirtschaft in Europa*, Breuninger Stiftung, Stuttgart 2001.

[23] R. Sandgruber, "Die Agrarrevolution in Österreich. Ertragssteigerung und Kommerzialisierung der landwirtschaftlichen Produktion im 18. und 19. Jahrhundert", in *Österreich-Ungarn als Agrarstaat. Wirtschaftliches Wachstum und Agrarverhältnisse in Österreich im 19. Jahrhundert*, A. Hoffmann (ed.), Verlag für Geschichte und Politik, Wien, 1978.

droughts when less than 250 mm fell. To the Thirs and their neighbors the land promised a prosperous future.[24]

The reconstruction of Decatur County's agro-ecosystem comes mainly from agricultural census data compiled periodically by the State of Kansas and by the U.S. federal government. Census descriptions for individual farms in this part of Kansas are available for 1885, 1895, 1905, 1915, 1920, 1925, 1930, 1935, and 1940. These 9 snapshots describe land use activity over a period of 55 years, from the beginning of frontier farm-making through the establishment of a fully developed, modern agricultural system. Censuses report the acreage and yields of various crops on each farm, the number of livestock, the amount of irrigation, fencing, and agricultural implements owned, and many other things. With these data we can follow the progress of the Thir homestead from raw prairie to integrated farm. Identical data exist for the same years for every farm in Finley Township, allowing a comparison between the Thir farm and the several dozen that surrounded it. Aggregated county level data are more readily available, existing for each year between 1880 and 1940. Thus it is possible to study the land use history of the region at nested scales, from the individual farm to the rural neighborhood of the township, to the entire 230,000-hectare county, and, indeed, for all 105 counties in the state of Kansas.

But land, crops, and livestock are not all that make up a farm. Population censuses reveal the social side of farm systems. Manu-

[24] Climate data come from two sources. The first is T.R. Karl, C.N. Williams, Jr., F. T. Quinlan, and T. A. Boden, *United States Historical Climatology Network (HCN) Serial Temperature and Precipitation Data, Environmental Science Division*, Publication n. 3404, Carbon Dioxide Information and Analysis Center, Oak Ridge National Laboratory, Oak Ridge, Tennessee (the historical climatology data are stored as point data for weather stations at monthly intervals for 1221 stations in the United States). The second source is National Climatic Data Center, Arizona State University, and Oak Ridge National Laboratory, Global Historical Climatology Network (GHCN) (this data set includes comprehensive monthly global surface baseline climate data). The Great Plains Population and Environment Project (www.icpsr.umich.edu/plains) interpolated data from 394 weather stations in the Great Plains to counties for each month between 1895 and 1993.

script population schedules are available for 1885, 1895, 1900, 1905, 1910, 1915, 1920, 1925, and 1930. These data reveal the life cycles of families, as couples married and had children, as children grew up and left home, as people aged and died. Again, we can observe these changes at various scales, from individual people and families to aggregated townships and counties. Together, the population and agricultural censuses provide basic data about the social metabolism of Kansas farmsteads.[25]

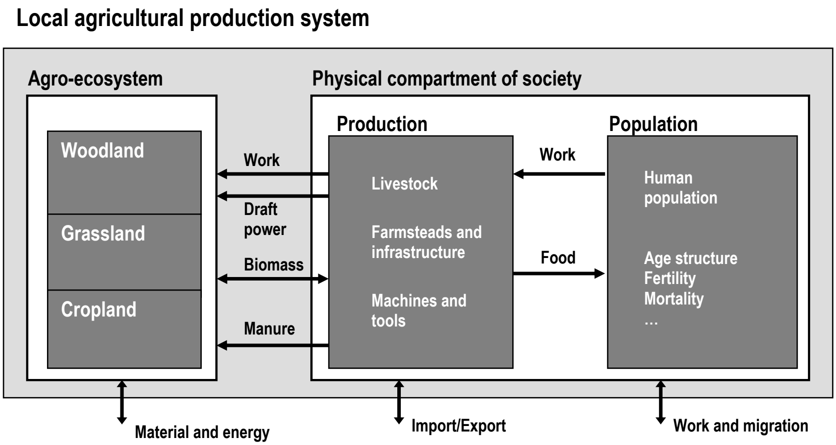
A socio-ecological approach to agricultural systems

Figure 3 presents a simple conceptual model of agriculture as a coupled socioeconomic and natural system. It builds on basic assumptions about the relation of population, land use, and agricultural production formulated by Ester Boserup, but extends this perspective by explicitly including flows of material and energy.[26] It is specific about the interactions of socio-economic systems and ecosystems, allowing one to capture important technological developments related to the industrialization of agriculture. In its most general form, the model defines the main biophysical relations in terms of flows of energy and materials between (and within) a natural system (i.e. the agro-ecosystem, characterized by biogeographic conditions and land use types) and a socio-economic system, consisting of two subsystems, namely the population subsystem (characterized by demographic attributes) and the economic production subsystem (including all infrastructure, farming technology and

[25] K.M. Sylvester, S. Hautaniemi Leonard, M.P. Gutmann, and G. Cunfer, "Demography and Environment in Grassland Settlement: Using Linked Longitudinal and Cross-Sectional Data to Explore Household and Agricultural Systems", in *History and Computing*, 14, 2006.

[26] E. Boserup, *The Conditions of Agricultural Growth: The Economics of Agrarian Change Under Population Pressure*, Aldine/Earthscan, Chicago 1965. E. Boserup, *Population and Technological Change - A Study of Long-Term Trends*, University of Chicago Press, Chicago 1981.

Figure 3. Conceptual model of material and energy flows in local agricultural production systems. See text for explanation



livestock).[27] The model describes an agricultural production system (here a farm or a village) as an agro-ecosystem managed by a local population investing labor and energy, applying a certain mix of technology, and generating a certain return of agricultural produce. It maintains exchange processes with other demographic, socioeconomic, and ecological systems. On a more detailed level, the model specifies the relation of land use and land cover with the extraction of biomass, different types of conversion and consumption processes within the local production system, and land use practices and the flows into and out of the local system. Such a systemic perspective allows one to analyze all biomass and energy flows and their interrelations within the agricultural production system, and to link them

[27] This version of the model focuses on biophysical relations between society and nature and thus reduces the socio-economic system to its physical components, i.e., the population and the production subsystem. See M. Fischer-Kowalski and H. Weisz, "Society as Hybrid Between Material and Symbolic Realms: Toward a Theoretical Framework of Society-Nature Interaction", in *Advances in Human Ecology*, 8, 1999.

to land use, ecosystem processes and the demographic system.

Historical sources such as the Austrian cadastral records or the Kansas agricultural and population censuses provide a basic set of quantitative and qualitative data that can be used to quantify the flows of nutrients, materials, and energy into, within, and out of the various subsystems described in this model. This systemic perspective allows one to cross-check the validity of historical data and to fill gaps in the data consistently when omissions or flaws occur in the original sources. For example, even though only fragmentary quantitative data on feed supply and livestock may be available from the cadastral record, knowledge about the reproductive patterns of livestock as well as species- and production-specific feed demand make it possible to generate a picture of feed demand in relation to available supply.[28]

Following the model presented in Figure 3, this study identifies nine key socioecological indicators that describe the physical stocks and flows of the two agricultural production systems. Those indicators fit into three categories: people and space, farm productivity and livestock, and nutrient management. This text includes graphic figures to represent the most important indicators; the complete data behind those figures are available in the Appendix as Supporting Tables S1-S6.

People and Space

population density: census population divided by land area (people/km^2)
average farm size: agricultural area[29] divided by number of farms (ha/farm)
land availability: agricultural area divided by number of farm laborers reported in the Kansas census or estimated based on Theyern's age structure (ha/person)

[28] See for example H. Schüle, *Raum-zeitliche Modelle - ein neuer methodischer Ansatz in der Agrargeschichte: Das Beispiel der bernischen Viehwirtschaft als Träger und Indikator der Agrarmodernisierung 1790 – 1915*, Lizensiatsarbeit, Historisches Institut der Universität Bern, Bern 1989.

[29] Throughout the paper we define "agricultural area" as not only cultivated and intensively used land such as cropland, meadows or fruit gardens, but also uncultivated prairie in farms (Kansas) and woodlands (Theyern). Uncultivated prairie and woodlands have to be considered integral components of the agricultural production systems in Theyern and Kansas as they are used to graze animals or to extract

Farm Productivity

grain yield: cereal production (including grain returned as seed) divided by total area planted, excluding fallow (kg/ha)

area productivity: plant and animal produce for human nutrition, including edible produce for export, converted into food energy and divided by agricultural area (GJ/ha)[30]

labor productivity: plant and animal produce for human nutrition, including edible produce for export, converted into food energy and divided by number of farm laborers reported in the Kansas census or estimated based on Theyern's age structure (GJ/person)[31]

marketable crop production: cereal production minus on-farm use of cereals (on-farm use includes the use of cereals as feed, seed, and for meeting subsistence needs (percentage of extracted biomass as tons of dry matter)

Livestock and Nutrient Management

livestock density: large animal units of 500 kg live weight divided by agricultural area (animals/km²)[32]

nitrogen return: N inputs from natural deposition, free fixation, manure, and leguminous crops divided by N contained in harvested biomass (percentage of extracted N returned to soil)[33]

bedding materials and served as sources for biomass and plant nutrients for more intensively used fields (Krausmann, *Milk, Manure* cit. Cunfer, *Manure Matters* cit.).

[30] One Giga Joule (GJ) corresponds to 10^9 Joule or 239 Mega calories (Mcal). Food output is measured in Joules of nutritional value (according to standard nutrition tables).

[31] We use "area productivity" and "labor productivity" in conformity with their usage in socio-ecological literature. Readers should be aware that economists have different definitions for these terms.

[32] We converted livestock numbers into large animal units at 500 kg live weight by using species and region-specific data on average live weight in the observed period (Krausmann, *Milk, Manure* cit. Id., *Land Use* cit., p.56).

[33] This estimate of nitrogen return to soils is only approximate. This analysis does not include a full soil nutrient balance. For one thing, it does not consider N losses due to volatilization and leaching. Furthermore, a comprehensive assessment of soil fertility would need to include phosphorus, potassium, and organic matter, plus the structural properties of soils. Given the limitations of historical data, this paper focuses on those N inputs and extractions that farmers control most directly. For further details concerning the procedure used to estimate nitrogen flows see id., *Milk, Manure* cit.; id., *Land Use* cit., pp. 17-20. Cunfer, *Manure Matters* cit. On soil nutrient balances more in general, see R.S. Loomis, "Ecological Dimensions of Medieval Agrarian Systems: An Ecologist Responds", in *Agricultural History*, 52, 4, 1978. Id., "Traditional Agriculture in America," in

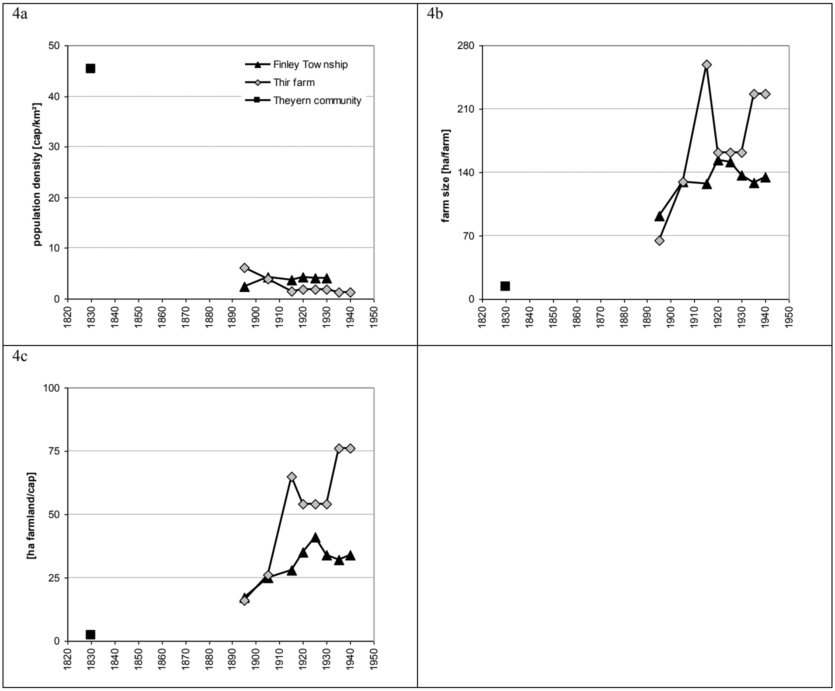
People and Space

The village of Theyern in Austria had a typically European agro-ecological system. Population expansion during the late Middle Ages led to a gradual colonization of new land for agriculture. By 1830 Theyern had existed as a discrete community for several hundred years and its cropland, hay meadows, grazing commons, and surrounding forests had been producing food, feed, and shelter, year in and year out, for a very long time. Most members of the community lived little above subsistence level, producing as much food and supporting as many people as possible, given current cultivation practices, technology, and energy regimes. The fully populated land eventually achieved its peak productive potential. Theyern's population density in 1830 was 45 people per square kilometer. The average family farmed 13 hectares of land, and there were 2 hectare of agricultural land per person in the community (1 ha/cap if woodland is excluded). Over centuries, the people of Theyern had learned how to use their land intensively, supporting the highest number of people possible, and sustaining those populations for multiple generations.

The situation in Decatur County, Kansas, when Elizabeth Demmer, George Thir, and their compatriots arrived, was just the opposite. Here was land that had never known widespread agricultural use. For 10,000 years since the end of the last ice age the Great Plains had been steppe grassland, home to wild grazers – bison – and browsers – pronghorn – but few other large animals. The indigenous people were mobile hunters and gatherers, traveling on foot over wide distances. Native agriculture expanded on the plains only after

Annual Review of Ecological Systems, 15, 1984. B.M.S. Campbell and M. Overton (eds), *Land, Labour, and Livestock: Historical Studies in European Agricultural Productivity*, Manchester University Press, Manchester, NY, 1991. R.S. Loomis and D.J. Conner, *Crop Ecology: Productivity and Management in Agricultural Systems*, Cambridge University Press, New York, 1992. R. Shiel, "An Introduction to Soil Nutrient Flows", in *Soils and Societies: Perspectives from Environmental History*, J.R. McNeill and V. Winiwarter (eds), White Horse Press, Isle of Harris, UK 2006. R. Shiel, "Nutrient Flows in Pre-Modern Agriculture in Europe," in McNeill and Winiwarter (eds), *Soils and Societies* cit.

Figure 4. People and Space, Theyern, 1829; Finley Township and Thir farm, 1895 to 1940: (4a) population density; (4b) average farm size; (4c) land availability



1000 A.D. Occasional patches of maize, beans, and squash dotted the narrow river valleys winding through vast upland grasslands.[34] At their greatest extent, Indian crop fields never reached even 1 percent of the area of the Great Plains. After the 17th century, many natives adopted horse-based hunting and gathering, and some moved in the direction of horse pastoralism.

[34] Farming Indians maintained soil fertility by swidden, moving their villages wholesale every 5-10 years when soil nutrients failed and crop yields declined. The most notable difference between New World and Old World agriculture was the presence of domesticated animals in the latter. Livestock—oxen, milk cows, hogs and pigs, poultry, and dozens of other domesticated animals—were ubiquitous on

Thus European farmers who moved into the region in the late nineteenth century entered an agricultural vacuum. Importing their livestock with them, and thus increasing their ability to work the soil 100-fold, American, German, and Austro-Hungarian settlers began the enormous task of agricultural colonization, plowing sod that had lain intact for thousands of years. The contrast with European agricultural villages could not have been greater. The population density in Finley Township, where George and Elizabeth Thir made their new farm, was only 2 people per square kilometer in 1895, about one order of magnitude lower than in Theyern. The average farm size was an incredible 92 hectares, so large that for the first several decades few farmers could practically make use of all of their land and a considerable fraction of the available land was used for extensive grazing. There were 17 hectares of land in the township for every man, woman, and child. The amount of land available to be worked per agricultural laborer was huge and increased from 36 ha in 1895 to almost 70 ha in 1925, when the first tractors appeared in the township. Given the shortage of labor on this agricultural frontier, much of the land remained unused. On the Thir homestead, 65 hectares supported and employed two adults and three children. Compared to the community as a whole, the Thir farm was nearly representative, with a population density of 6 people per square kilometer and about 16 hectares of land per person.

The pioneer era in Decatur County lasted about 50 years, from 1870 to 1920. During that time farmers filled the land, adjusted their farming practices to fit local soils, climate, and topography, and slowly moved toward an agricultural equilibrium. Population density in Finley Township increased during the initial period of homesteading then stabilized at between 4 and 5 people per square kilometer. During the same period average farm sizes rose rapidly, from 92

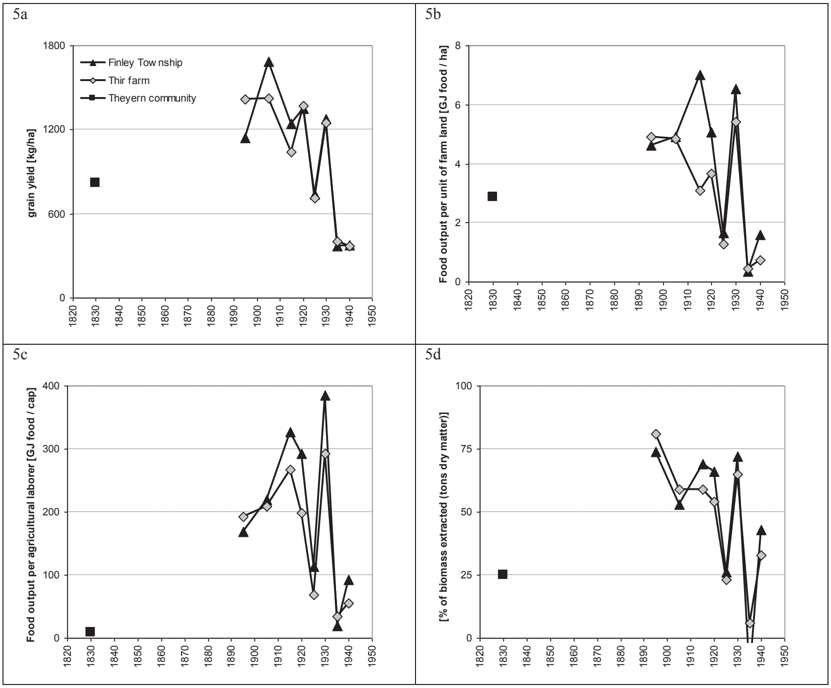
European farms and crucial to their function and success. Indian farmers had no domesticated animals. Women tilled the soil entirely through human labor. Thus Indian agriculturalists never farmed the widespread uplands of the Great Plains. Both population densities and the area of arable land remained very low. See R.D. Hurt, *Indian Agriculture in America: Prehistory to the Present*, University Press of Kansas, Lawrence 1987, pp. 57-64; W.R. Wedel, "The Prehistoric Plains," in *Ancient Native Americans*, J.D. Jennings (ed.), W.H. Freeman and Company, San Francisco 1978.

hectares in 1895 to a peak at 154 hectares in 1920, then dropped slightly to settle at around 130 hectares for the next few decades. Land per person followed a similar curve, rising from 17 hectares in 1895 to 35 in 1920, and thereafter floating between about 30 and 40 through the early 20th century. On the Thir farm, rapid acquisition of additional land pushed these numbers higher for the family. In 1915, 30 years after immigration from Austria, the Thirs owned 259 hectares of land, a whopping 65 hectares for each person in the family. While farmers on the Kansas frontier went through a period of adaptation and adjustment, they did not move toward an Old World style farm system of high population densities on intensely used land. If anything, they moved away from that model.

Farm productivity

Theyern farmers maximized their grain yields, but within the bounds of long-term sustainability. They grew as much food as possible without undermining the ability of the land to support people for indefinite generations into the future. In 1830 Theyern farms produced 819 kg of grain per hectare, which, together with animal products, were enough to provide 9 GJ of nutritional energy for every farm laborer. Area productivity was about 2.9 GJ of food per hectare. The highly integrated subsistence system supported a lot of people, but surplus above local demand was comparatively low and, particularly for the smaller farms, production accomplished bare survival only. Here farmers had been re-using soils over centuries for agricultural production. The population density matched agricultural production, given local climate and available technology. The largest share of farm output went toward local consumption. The community exported little of its farm produce; our data suggest that Theyern exported from the local system no more 25% of its agricultural produce through sales in nearby markets or rent paid to the landlord. While the Franciscean Cadastre dates to 1829 in Theyern, the land use information it provides does not represent only one year, but rather a long-term average for the community that fairly represents the village's typical productivity throughout the first half of the 19th century.

Figure 5. Farm Productivity, Theyern 1829; Finley Township and Thir farm, 1895 to 1940: (5a) grain yield; (5b) area productivity; (5c) labor productivity; (5d) marketable crop production



In western Kansas, the freshly plowed grassland soils produced much higher grain yields in the first couple of decades. Taking advantage of 10,000 years of stockpiled soil nutrients, the Thir farm produced 1274 kg of grain per hectare in 1895, 56% higher than Theyern's yield, while Finley Township as a whole averaged 1141 kg, a 39% surplus over the Austrian case. The township's area productivity in 1895 was significantly higher than in Theyern, at 4.6 GJ per hectare, and because there were many fewer people on the land in Kansas, nutritional energy production per farm laborer was 168 GJ in Finley Township. Such return on labor – nearly 20 times Theyern's rate – was stupendous. Whereas one Theyern farm laborer grew enough food to feed about 2.5 people, one agricultural laborer in Finley Township could feed nearly 50. No person could reasonably consume so much food. Rather, the excess production beyond subsistence needs went into market exports. Agriculture in the Great Plains was from the very beginning oriented towards commercial production and was heavily reliant on the expanding railroad network to transport grain to urban markets. Three quarters of the grain grown in Finley Township was in excess of local food and feed needs, and instead found national and international markets. At harvest farmers bagged their wheat, hauled it to nearby grain elevators on the railroad line, and shipped their produce east. American cities grew rapidly in the late nineteenth century as other immigrants poured in to take factory jobs in the United States' rapidly industrializing economy. Kansas wheat farmers fed not only themselves but those distant urban workers too.

The rapid exploitation of stockpiled soil nutrients could not continue indefinitely. Through the early twentieth century, cereal yields in western Kansas fell, plummeting to less than 1/4 their peak levels. As recently arrived farmers plowed up fresh Finley Township land in the first two decades of agricultural settlement, yields remained high, rising from 1141 kg per hectare in 1895 to 1687 ten years later. Then, once most of the new land was already in production, yields began to fall, down to 1244 kg in 1915 and 736 in 1925. By the 1920s, in the fourth decade of agricultural settlement, grain yields dropped to levels similar to those Theyern farmers had produced a century earlier. Still, yields continued to fall, to below 400 kg in the late 1930s. The Thir farm closely followed community-wide trends in its first 40 years.

The decline in crop yields was unmistakably downward over half a century, but from year to year there were sharp ups and downs. For example, 1925 saw township-wide yields of only 736 kg per hectare, but 1930 produced a bumper crop at 1278 kg. Five years later, in 1935, production was down sharply again. Area productivity likewise varied widely, fluctuating between 4 and 7 GJ per hectare, then dropping to less than 2 in 1925 and again in the 1930s. Crop yields in Kansas were determined not only by soil fertility, but also by soil moisture. The extreme annual variation in rainfall at the center of the continent hovered just above or just below the minimum precipitation necessary to sustain wheat, corn, and other cereals. Unlike in Theyern, rainfall controlled yields as much as soil quality did. Thus, the extremely low yields in 1935 and 1940 resulted more from the deep drought of those years than from depleted soils.

The marketable production in excess of subsistence needs moved downward along with yields, from 74% in 1895 to just 26% in 1925. It bounced back with strong rainfall in 1930, to 72%, but then fell with the arrival of drought in the 1930s. By 1935, cereal production had actually fallen 14% below what was needed for bare subsistence, but was up above 40% just five years later.

Rainfall did not decline steadily between 1870 and 1940, but rather moved up and down around the average. The steep downward trend in yields over the long term reveals massive soil mining in western Kansas during the pioneer era. Newly arrived farmers produced stupendous food excesses and sold those crops into the cash market. In the process they rapidly exploited the stockpiled soil fertility that had accumulated century by century under native grass sod.

Livestock and nutrient management

In addition to high human population density, Old World farm systems had high densities of livestock. The menagerie of European agriculture included oxen, beef cattle, milk cows, draft horses, mules, donkeys, hogs and pigs, goats, and an array of birds, including chickens, ducks, and geese. Theyern, for example, had 24 large animals (500 kg equivalent) per km^2 around 1830. The importance of livestock cannot be overstated. Most obviously, farm animals provided food (beef, pork, poultry, milk, eggs, lard, butter) and clothing (leather, wool). Also of crucial importance, they provided labor for plowing soil, cultivating weeds, harvesting crops, and transporting farm produce over short and long distances.[35] A more subtle contri-

[35] The most common draft animals used in Theyern around 1830 were oxen. Only the larger farms kept horses, while in small holdings cows were also used for labor (working fields and fallow areas) and transport (moving harvest from

bution, but no less significant, came from the manure produced by livestock. Rich in nitrogen, organic carbon, and other soil nutrients, livestock manure was a vector by which people could redirect nutrients from biomass that humans cannot digest (grass, brush, stubble, litter) to agricultural crops. Manure also functioned as a means to move fertility from place to place across the landscape. For example, cattle grazing grass or brush growing on steep hillsides, in forests, or over non-arable soils, accumulated nutrients that they brought back to the farm yard and deposited on the ground. When farmers applied that manure onto their crop fields they were essentially transporting soil nutrients from untillable land to arable land, subsidizing fertility in the infields with nutrients transported by livestock from the outfields. Theyern farmers maintained significantly more livestock than they needed for food and labor; they kept additional animals, we surmise, for their manure production.[36]

Every year, Theyern farmers returned to the soil more than 90% of the nitrogen they had extracted from it in crops. Much of that restored nitrogen flowed through livestock and their manure. Collecting, processing, and properly applying manure was labor-intensive work. The whole system was intricately interrelated: Feeding a dense population required maintaining animals that produced manure,

dispersed fields, fuel wood from the community forests, and manure back to the fields). Krausmann estimates that installed power amounted to 0.17 kilo Watts (kW) per ha of cropland (Krausmann, *Milk, Manure* cit.). According to Schaschl, who has quantified the monthly supply of and demand for human and animal labor during the course of a year per individual farms in Theyern, the supply of animal labour exceeded demand even during peak seasons in March and April (E. Schaschl, *Rekonstruktion der Arbeitszeit in der Landwirtschaft im 19. Jahrhundert am Beispiel von Theyern in Niederösterreich*, Social Ecology working paper n. 96, Wien 2007). In Finley Township, horses were the only animals used to provide work until the first tractors appeared in the 1920s. According to our estimate, installed power per unit of cropland was about the same as in Theyern (see Supporting Table S3 and S6).

[36] R.C. Allen, "The Nitrogen Hypothesis and the English Agricultural Revolution. A Biological Analysis", in *Journal of Economic History*, 68, 2008. M.J. Frissel (ed.), *Cycling of Mineral Nutrients in Agricultural Ecosystems*, Elsevier, Amsterdam 1978. Cusso et al., *Social Metabolism* cit.

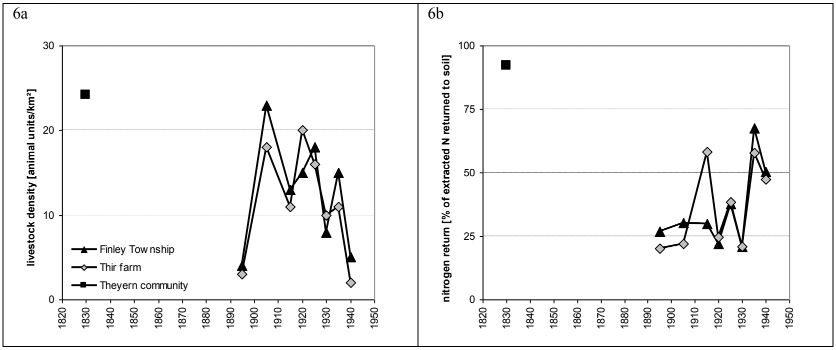
which in their turn required significant labor input and hence a dense population. Domesticated animals enabled the soil restoration necessary for continuous cropping into the indefinite future. The presence of these animals distinguished Old World farming from that of Native Americans. In the Americas, natives had no livestock, and managed soil fertility by moving to new farm fields every 5 to 20 years as soil fertility declined.

Another mechanism for the maintenance of soil nitrogen in the European system was fallow rotation. In 1829, cropland in Theyern was still cultivated in the traditional three-field rotation. A crop of winter cereal in the first year and one of summer cereal in the second year was followed by a year of fallow. During the fallow period, the land was manured and vegetation regrowth was plowed into the soil. Mineralized nutrients from organic matter accumulated for the benefit of crops in subsequent years. Natural ecosystem processes also provided additions of soil nitrogen, including free fixation by soil microorganisms and nitrogen deposited from the atmosphere in rain, snow, or dust. At the turn of the 19th century, Austrian farmers were only beginning to include nitrogen-fixing legume fodder crops such as clover or alfalfa into their crop rotations, but in the coming decades legumes gradually replaced fallow in the crop rotation system, emerging as a crucial element in the management of soil fertility. In Theyern in 1829, roughly one fifth of the fallow field was planted with clover, already providing a considerable contribution to soil nitrogen stocks. Thus, by a combination of means Theyern farmers were essentially in balance, replacing about as much soil nitrogen as they extracted each year.

Finley Township, for its part, was decidedly out of balance with the nitrogen system. The initial plow-up accelerated the decomposition of accumulated organic matter and spiked nitrogen into the soil for the first several years.[37] But ongoing plowing and cultivation soon generated nitrogen declines through both chemical and

[37] W.J. Parton, M.P. Gutmann, S.A. Williams, M. Easter, and D. Ojima, "Ecological Impact of Historical Land-Use Patterns in the Great Plains: A Methodological Assessment", in *Ecological Applications*, 15, 2005.

Figure 6. Livestock and Nutrient Management, Theyern, 1829; Finley Township and Thir farm, 1895 to 1940: (6a) livestock density; (6b) nitrogen return



biological processes.[38] Exposure of soils to the atmosphere initiated ammonia volatilization by which stored nitrogen escaped into the air. Tillage also encouraged bacterial denitrification, in which soil bacteria converted nitrate to nitrogen gasses by means of digestion, returning soil nitrogen to the atmosphere. Plowing could accelerate leaching of nitrogen via rainwater deep into the soil, plus additional losses from water and wind erosion.[39] Thus it is not surprising that crop yields began at remarkably high levels, then dropped throughout the next fifty years after settlement.

In addition to these natural nitrogen losses, Kansas farmers extracted more nitrogen from their soils than they returned each year, largely because they put little manure back onto the fields. Finley Township had a low livestock density of only 4 large animals per

[38] H.J. Hass, C.E. Evans, and E.F. Miles, *Nitrogen and Carbon Changes in Great Plains Soils as Influenced by Cropping and Soil Treatments*, U.S.D.A. Technical Bulletin n. 1164, Government Printing Office, Washington 1957.

[39] F.J. Stevenson (ed.), *Nitrogen in Agricultural Soils*, Agronomy Series n. 22, American Society of Agronomy, Crop Science Society of American, and Soil Science Society of America, Madison, Wisconsin 1982. Cunfer, *Manure Matters* cit.. I.C. Burke, W.K. Lauenroth, G. Cunfer, J.E. Barrett, A. Mosier, and P. Lowe, "Nitrogen in the Central Grasslands Region of the United States", in *BioScience*, 52, 2002.

hectare in 1895, far below Theyern's 24. That number rose to 23 animals per km² in 1905 (mostly beef cattle, horses, and milk cows), and then dropped steadily over the next forty years, down to just 5 again by 1940. The relative shortage of livestock on Kansas farms meant that farmers had correspondingly less manure with which to return nitrogen to cropland soils. Farmers there returned only 27% of the nitrogen they extracted in 1895, and the percentage remained below 40% through the 1920s. The 1930s saw an increase in nitrogen return to between 50 and 70 percent only because significant crop failures during drought years prevented farmers from extracting much nitrogen from their land.[40] With natural soil fertility that far exceeded subsistence needs and that produced large, exportable surpluses for two decades, farmers did not feel the need to husband large numbers of livestock for the purpose of manure accumulation. They needed horses for labor, and used cattle and pigs for household food and to add value to yet uncultivated prairie or pasture; but, beyond that, they did not maintain additional animals simply for their soil fertility benefits, as appears to have been the case in Theyern.

As George and Elizabeth Thir and their neighbors took more nitrogen than they returned every year, crop yields fell. It took a couple of generations before crisis loomed, and in the 1930s several regional problems converged. Low and declining soil fertility began to pressure farms just as a 9-year drought devastated the region and a world-wide economic depression further challenged farm sustainability in the Great Plains. The eventual solution came, not in adopting Old World style farm management, but from the importation of fossil fuel energy from outside the system. The decline in livestock density in Finley Township after 1905 went hand-in-hand with the advent of fossil fuel energy deployment on farms. When farmers

[40] While the peaks in the rate of nitrogen return in Finley Township and at the Thir farm in the 1930s are due to harvest failures and consequent low nitrogen extraction rather than to increases in nitrogen input, leguminous crops contribute to the high return rate (above 50%) which can be observed for the George Thir farm in 1915. This was the only year when George Thir planted a considerable fraction of his cropland with alfalfa.

adopted tractors, trucks, and other internal combustion engines in the early twentieth century they decreased their horse populations, simultaneously decreasing their manure supply. After World War II farmers addressed their soil fertility problem by increasing applications of synthetic fertilizer in place of the missing manure. Nitrogen fertilizer also represents a fossil fuel import, since its production requires large amounts of natural gas. Thus, 20th century farmers substituted fossil-fuel driven tractors for the labor function of livestock, and fossil-fuel derived fertilizers for the manure function of livestock. In multiple ways, fossil fuels provided substitutes for the missing livestock in the Kansas farm system.

Old World and New World yields: a long-term comparison

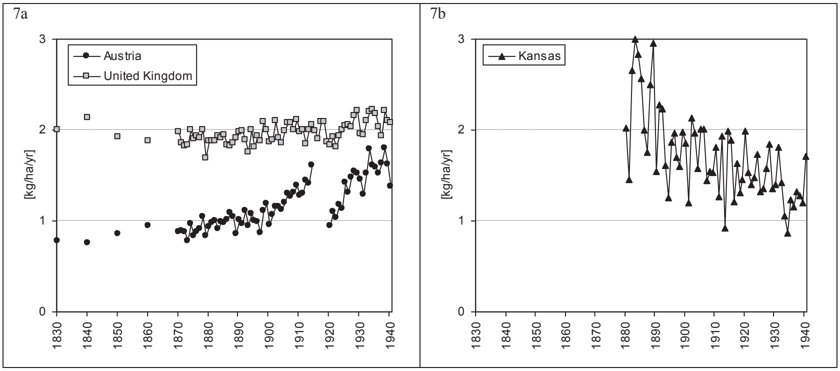
By comparison to modern farm systems, the Old World agricultural system may appear "sustainable", but it was by no means stable, permanent, or stagnant. Old World agriculture evolved steadily over centuries, responding to both natural and cultural change. One way to measure this change is through yields of cereal crops, the staple subsistence food in nearly all temperate agricultural regions on earth.

Figure 7 puts this story in a broader context, presenting cereal yields in the Old and New Worlds between 1830 and 1940.[41] The figure complements data for Kansas and Austria with cereal yields for the United Kingdom (UK), where agricultural innovations that increased European crop yields first emerged in the 19th century.

At the beginning of the period under consideration here, Austrian farmers devoted 1/3 of their arable land to unproductive fallow every

[41] Yield data in Figure 7 were derived from Sieferle, *Das Ende* cit., p. 259. R. Sandgruber, *Österreichische Agrarstatistik 1750-1918*, Verlag für Geschichte und Politik, Wien 1978 (U.K. and Austria) and Kansas State Board of Agriculture, Annual and Biennial Reports, Topeka, Kansas, 1877-1940 (Kansas). See S.J. Decanio, W.N. Parker, and J. Trojanowski, *Adjustments to Resource Depletion: The Case of American Agriculture. Kansas, 1874-1936*, ICPSR data set n. 7594 for Kansas yield data before 1937.

Figure 7. Cereal yields in the Old World and the New World, 1830 to 1940: (7a)Austria and the United Kingdom; (7b) Kansas



year, and the average cereal yield was low at around 800 kilograms per hectare. Through the 19th century farmers optimized the traditional low input agricultural system, increasing yields and population in tandem. A variety of innovations boosted yields, including new crops, new rotations, and the incorporation of yet more livestock, which required more fodder and produced more manure.[42] Cultural and institutional changes also supported slowly increasing productivity. These changes included the abolition of serfdom, the development of agricultural cooperatives and integration with distant markets. Together, this century-long process represents Austria's participation in what European scholars have designated as the "first agricultural revolution."[43] This process should be considered an optimization of the traditional low-input agricultural system. It centered on biological innovations and did not depend on external, off-farm inputs (with the exception

[42] Sieferle, *Das Ende* cit., p. 216. Krausmann, *Milk, Manure* cit.

[43] M. Overton, *Agricultural Revolution in England*, Cambridge University Press, Cambridge 1996. M. Mazoyer, L. Roudart, and J.H. Membrez, *A History of World Agriculture: From the Neolithic Age to the Current Crisis*, Earthscan, London 2006.

of coal-based iron manufacturing and the expanding railroad system). By 1914, Austrian yields had doubled from their 1830 levels.

In the United Kingdom a similar optimization process had started much earlier. Significant yield increases were evident throughout the 18th century, moving from yields of about 1000 kilograms per hectare in 1700 to double that by the early 19th century, after which they remained stable for over 100 years. By 1830 the potential for further optimization of low input agriculture was largely exhausted in the UK, when it was just beginning to climb in Austria.[44] Over the centuries, Old World farmers not only managed to stabilize agricultural yields, but to increase them steadily. The shift from production systems based on short fallow to livestock-intensive farming and crop rotation including leguminous crops led to increasing nitrogen stocks in the soil. This rise in soil nutrients contributed significantly to the rising yields observed first in England and a century later in continental Europe.[45]

In contrast to these two European examples, yields in Kansas started at the astonishingly high level of as much as 3000 kilograms per hectare when settlers began to plow the prairie in the 1870s. Kansas's continental location is evident in the extreme annual variability of yields. At the center of North America, far from the ocean, and shielded from Pacific weather systems by the high Rocky Mountains to the west, variable annual rainfall drove annual yields more than did soil fertility. Wet years produced bumper crops, while droughts brought crop failure and low yields. Kansas yields were very high by any European standard—even the dry years doubled Austrian yields—but output was also erratic compared to Austria and the UK, where annual rainfall was relatively consistent. But despite annual variations caused by weather, a clear downward trend in yields is evident. By the end of the 19th century Kansas' yields were below those of the UK, and by the early 20th they had dropped below the steadily increasing Austrian level. As late as the 1930s, Kansas'

[44] F. Krausmann, H. Schandl, and R.P. Sieferle, "Socio-ecological Regime Transitions in Austria and the United Kingdom", in *Ecological Economics*, 65, 2008.

[45] Allen, *Nitrogen* cit.

agricultural production continued its decline as farmers took more nitrogen from the soil than they returned, year after year.

Conclusion

This study presents a detailed picture of the social ecology and metabolic characteristics of farming systems in Decatur County, Kansas, and their development over time. The Austrian case—that of the rural village of Theyern—serves as a term of comparison, providing a contrast to the Kansas farming system and helping to highlight defining socio-ecological characteristics. Even though direct comparability may be hampered by differences in time period, environmental context, and institutional settings, some conclusions about the factors that determine the socio-ecological characteristics of farming systems and their development over time are possible.

In some respects, the two farm systems were similar. Both were mixed farming communities that integrated cereal production with domesticated livestock. Area productivity - the amount of food produced per area of farmland - was similar. In 1830, one hectare of farmland in Theyern produced about 2.9 GJ of food; in 1895, one hectare in Finley Township, Kansas produced 4.6 GJ. Area productivity fluctuated with rainfall in Kansas, between highs of 7 GJ and lows of less than 1, but both farm systems were within the same order of magnitude.

The same was not true for labor productivity. Austrian farmers produced about 9 GJ of food per farm laborer, while those in Kansas produced 200, 20 times their cross-Atlantic cousins. Here the contrast could not be greater. The Theyern farm system coaxed food from the soil through intensive applications of labor, both human and animal. Maintaining area productivity meant high population densities of both people and livestock to sustain soil fertility. In Kansas, farmers needed (or invested) very little labor to produce large amounts of food. Consequently, population and livestock densities were lower, and declining between 1905 and 1940.

The two farm systems had different goals for optimization. The long history of subsistence farming, the tight social networks of village, manor, and church, and the structures of village agriculture in Theyern aimed not at peak production but at risk minimization and long-term sustainability.[46] Theyern was not stagnant; during the nineteenth century the community aimed first of all at long-term food security and risk minimization, but nevertheless slowly intensified production and raised yields. Theyern's greatest resource was a high labor supply, which it employed to maintain soil fertility. The tiny, scattered village fields, managed collectively, did not encourage peak production, but rather ensured that all families would have diversified holdings, reducing the risk of catastrophic failure.

Finley Township, Kansas, followed a different strategy aimed at taking advantage of new commercial grain markets in the industrializing cities, new transportation opportunities as railroads spread across North America, and a rich endowment of fertile soils. Here economies of scale mattered, with large, consolidated farms. Kansas was short of labor, but instead exploited its chief resource: abundant soil nitrogen and organic carbon, accumulated through millennia and mined in the first 50 years after settlement. The two systems were both efficient in their own way. Theyern supported the most people possible over long periods of time, usually producing enough food to keep them alive but rarely enough to make them wealthy. Finley Township maximized productivity, dramatically raising the standard of living for immigrants and their descendents. The nine socio-ecological indicators discussed in this study define and frame the two strategies.

But agricultural systems never remain static, and the social metabolic systems in both Theyern and Finley Township changed through the nineteenth and early twentieth centuries. In some ways their trajectories crossed paths. Theyern moved steadily upward from relatively low yields and labor productivity in the early nineteenth century to higher production and increasing labor productivity by its end. Yields doubled over 75 years. Finley Township, for its part, began with high yields and labor productivity in 1895, and drifted

[46] For a discussion of risk minimization strategies see D. McCloskey, "English Open Fields as Behavior Toward Risk," in *Research in Economic History*, 1, 1976.

downward over the decades, to a nadir in the 1930s. Variable rainfall in Kansas affected these results, but it is clear that the state had reached a crisis of soil fertility by World War II. Thus, through the nineteenth century and early twentieth the two farm systems diverged, each moving in different directions.

After World War II the application of fossil fuels to agricultural systems transformed both locations, and started a convergence toward productivity levels never seen in the history of agriculture. The import of energy—diesel fuel for tractors, natural gas for nitrogen fertilizer, petroleum for pesticides, and gasoline and electricity for a multitude of farm machinery—solved the ancient problem of soil fertility. With fossil fuels, Theyern farmers no longer needed to invest enormous amounts of labor in livestock to provide power and manure that could sustain soil fertility in their crop fields. With fossil fuels, Kansas farmers could continue farming their depleted prairie soils by simply applying synthetic nitrogen every year as they watched crop yields rebound, match pioneer-era levels, and then exceed any previous production levels. It was not clear at the time, but the solution to the age-old problem of agricultural sustainability—soil maintenance—created a different one: unsustainable external energy inputs. But in the gap between the soil crisis and the oil crisis, Austrian and Kansas agricultural metabolism began to converge again, with each moving toward high output commercial farming. By the end of the 20th century, average cereal yields in the UK, Austria and Kansas were at a similar level, ranging between 6.5 and 7.5 t/ha.

Pioneer farms are rarely in equilibrium with their environment. By definition settlers undertake the task of transforming their environment and inevitably undergo an adaptation process as they learn the limits of their new home, its climates, soils, plants, animals, and microorganisms. The Thir family liberated themselves from conservative Old World institutions and constrained Old World agroecosystems. But the farm they built on the Kansas frontier was unsustainable. The soil mining enterprise played out over several generations, between 1880 and 1930, but by then a soil fertility crisis loomed. It is no coincidence that the 1930s stand out in American memory as a time of rural crisis, population turmoil, and transformation in government agricultural policy. The drought, dust storms, and global economic depression certainly contributed, but frontier farming in the Great Plains would have faced a dramatic change even without those forces. It was the application of fossil fuel energy that saved the region for commercial agriculture, allowing farmers to sustain their land use practices for another 75 years.

In a broader global context, the stories of Old World and New World agriculture are intimately connected. Even as nitrogen flowed through local human, livestock, and cropland systems, broader flows across the Atlantic tethered these places to one another. The New World agricultural frontier provided novel opportunities for European farmers escaping subsistence lifestyles, and millions followed the Thirs and Demmers across the ocean. The grain and beef they produced flowed the other way, flooding Europe with cheap American food that undermined farm villages across the continent. It was that economic pressure on traditional European agriculture that forced innovation and led to Austria's steadily increasing yields in the late nineteenth century. Economists have argued that highly efficient New World farmers thus pressured backward and inefficient Old World people to improve agriculture (which some did) or to abandon it for industrializing cities (which most did).[47] This study points out an ecological component to the story that economists have missed or downplayed. One of the key reasons New World farmers were so efficient and able to produce such stupendous crop surpluses for export between 1870 and 1930 was their endowment of stockpiled soil nutrients. For over half a century Great Plains farmers mined

[47] Y. Hayami and V.W. Ruttan, *Agricultural Development: An International Perspective*, Johns Hopkins University Press, Baltimore 1985. K.G. Persson, *Grain Markets in Europe, 1500-1900: Integration and Deregulation*, CUP, Cambridge 1999. J.G. Williamson, *Globalization and the Poor Periphery before 1950*, MIT Press, Cambridge, Massachusetts 2006. J.L. Van Zanden, "The First Green Revolution: The Growth of Production and Productivity in European Agriculture, 1870-1914", *Economic History Review*, 44, 2, 1991. N. Koning, *The Failure of Agrarian Capitalism: Agrarian Politics in the UK, Germany, Netherlands, and the USA, 1846-1919*, Routledge, New York 1994.

their rich soils and dumped those nutrients on the world market, disrupting risk-averse, long-lasting agricultural systems across the ocean. New World farming could not be sustained over the long term yet it undermined Old World systems that had been in place for centuries. Then, as the mid twentieth century soil depletion crisis loomed, fossil fuel fertilizers and other high energy inputs rescued farmers, as the developed world substituted oil for soil.

Appendix: Supporting Tables*

Table S1: Population, land use, livestock and crop production in Finley Township, 1895 to 1940

Variable	Unit	1895	1905	1915	1920	1925	1930	1935	1940
Population	persons	227	389	341	392	373	379	n,d,	n,d,
Agricultural population	persons	169	332	260	286	230	255	287	259
Farms	number	32	64	58	65	63	64	72	65
Total area (land in farms)	ha	2,939	8,320	7,376	10,006	9,487	8,792	9,233	8,761
Cropland	ha	1,341	3,545	5,048	4,643	5,344	4,780	4,938	5,142
Corn	ha	830	1,095	1,079	783	1,778	1,571	1,784	1,383
Wheat	ha	291	1,509	3,148	3,186	2,957	2,738	2,116	1,416
Barley	ha	-	373	177	212	128	181	219	639
All other crops	ha	220	568	645	462	482	290	819	1,704
Grassland	ha	1,598	4,775	2,328	5,364	4,142	4,012	4,295	3,619
All other land	ha	44	125	111	150	142	132	139	131
Cattle	head	161	1,541	557	1,035	1,244	432	1,548	701
Horses (and mules)	head	136	435	497	656	556	299	257	-
Pigs	head	167	1,749	531	335	1,114	344	222	30
Corn (harvest)	t	1,173	2,580	2,203	1,476	1,676	3,085	420	565
Wheat (harvest)	t	117	1,825	2,961	3,853	1,788	2,392	995	447
Barley (harvest)	t	-	663	314	319	117	263	106	299

Table S2: Population, land use, livestock and crop production on Thir farm, 1895 to 1940

Variable	Unit	1895	1905	1915	1920	1925	1930	1935	1940
Population	persons	4	5	4	3	3	3	3	3
Agricultural population	persons	4	5	4	3	3	3	3	3
Farms	number	1	1	1	1	1	1	1	1
Total area	ha	65	130	259	162	162	162	227	227
Cropland	ha	25	52	118	59	75	80	88	134
Corn	ha	20	8	8	12	16	26	24	28
Wheat	ha	3	32	81	40	49	51	57	34
Barley	ha	0	5	0	2	6	0	4	0
All other crops	ha	1	7	29	4	4	3	3	71
Grassland	ha	40	77	141	103	87	82	138	93
All other land	ha	1	2	4	2	2	2	3	3
Cattle	head	1	22	26	30	21	11	25	4
Horses (and mules)	head	3	5	8	9	9	8	5	-
Pigs	head	1	11	5	7	10	3	1	9
Corn (harvest)	t	29	19	17	23	15	52	6	12
Wheat (harvest)	t	1	39	76	49	29	44	27	11
Barley (harvest)	t	0	9	0	3	6	0	2	0

Table S3: Socio-ecological characteristics, Finley Township, 1895 to 1940

Variable	Unit	1895	1905	1915	1920	1925	1930	1935	1940
Population density	cap/km²	2.5	4.2	3.7	4.2	4.0	4.1	n.d.	n.d.
Farm size	ha of agricultural area per farm	92	130	127	154	151	137	128	135
Land availability	ha of agricultural area per capita	17	25	28	35	41	34	32	34
Land availability	ha of agricultural area per agric. laborer	36	45	47	58	69	59	55	58
Grain yield	kg/ha/yr	1,141	1,687	1,244	1,351	736	1,278	370	378
Area productivity	GJ/ha/yr	4.6	4.9	7.0	5.1	1.7	6.5	0.4	1.6
Labor productivity	GJ/laborer/yr	168	220	327	293	114	385	19	92
Marketable crop production	% of total production	74%	53%	69%	66%	26%	72%	-14%	43%
Livestock density	Large animal units (500 kg live weight) per km² agric. area	4.2	22.9	13.2	14.5	17.8	7.5	14.9	4.9
Nitrogen return on cropland	% of total extraction	27%	30%	30%	22%	38%	21%	68%	51%
Installed power	kW per ha of cropland	0.15	0.18	0.14	0.22	0.18	0.16	0.15	n.d.

Table S4: Socio-ecological characteristics, Thir farm, 1895 to 1940

Variable	Unit	1895	1905	1915	1920	1925	1930	1935	1940
Population density	cap/km²	6.2	3.9	1.5	1.9	1.9	1.9	1.3	1.3
Farm size	ha of agricultural area per farm	65	130	259	162	162	162	227	227
Land availability	ha of agricultural area per capita	16	26	65	54	54	54	76	76
Land availability	ha of agricultural area per agric. laborer	32	43	86	54	54	54	76	76
Grain yield	kg/ha/yr	1,274	1,427	1,041	1,371	709	1,246	406	369
Area productivity	GJ/ha/yr	4.9	4.8	3.1	3.7	1.3	5.4	0.5	0.7
Labor productivity	GJ/laborer/yr	159	209	267	198	68	293	34	55
Marketable crop production	% of total production	75%	59%	59%	54%	23%	65%	6%	33%
Livestock density	Large animal units (500 kg live weight) per km² agric. area	4.2	17.7	10.5	20.0	16.3	10.1	11.1	2.1
Nitrogen return on cropland	% of total extraction	20%	22%	58%	25%	39%	21%	58%	47%
Installed power	kW per ha of cropland	0.18	0.14	0.10	0.22	0.18	0.15	0.30	n.d.

* Sources: see the text. These tables can be downloaded from the data portal of the web page: http://www.uni-klu.ac.at/socec/inhalt/1088.htm

Table S5: Population, land use, livestock and crop production in Theyern municipality, 1829

Variable	Unit	1829
Population	persons	102
Agricultural population	persons	102
Farms	number	17
Total area	ha	225
Cropland	ha	135
Rye	ha	41
Cereal mix	ha	41
All other crops	ha	13
Fallow	ha	28
Grassland	ha	7
Woodland	ha	79
All other land	ha	4
Cattle	head	85
Horses and mules	head	5
Pigs	head	42
Sheep	head	77
Rye (harvest)	t	35
Cereal mix (*Linsgetreide*) (harvest)	t	32

Table S6: Socio-ecological characteristics, Theyern municipality, 1829

Variable	Unit	1829
Population density	cap/km²	45.3
Farm size	ha of agricultural area per farm	13
Land availability	ha of agricultural area per capita	2
Land availability	ha of agricultural area per agr. laborer	3
Grain yield	kg/ha/yr	819
Area productivity	GJ/ha/yr	4.4
Labor productivity	GJ/laborer/yr	9
Marketable production	% of total production	25%
Livestock density	Large animal units (500 kg live weight) per km² agric. area	24
Nitrogen return on cropland	% of total extraction	92%
Installed power	kW per ha of cropland	0.17