Human-Environment Interactions 2

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Chapter 12
Sustaining Agricultural Systems in the Old and New Worlds: A Long-Term Socio-Ecological Comparison

Geoff Cunfer and Fridolin Krausmann

Abstract During the late nineteenth and early twentieth centuries, tens of millions of migrants left Europe for the Americas. Using case studies from Austria and Kansas, this chapter compares the socio-ecological structures of the agricultural communities immigrants left to those they created on the other side of the Atlantic. It employs material and energy flow accounting (MEFA) methods to examine the social metabolic similarities and differences between Old World and New World farm systems at either end of the migration chain. Nine indicators reveal significant differences in land use strategy, labour deployment and the role of livestock. Whereas Old World farms had abundant human and animal labour but a shortage of land, Great Plains farms had excess land and a shortage of labour and livestock. Austrian farmers returned 90% of extracted nitrogen to cropland, sustaining soils over many generations, but they produced little marketable surplus. A key difference was livestock density. Old World communities kept more animals than needed for food and labour to supply manure that maintained cropland fertility. Great Plains farmers used few animals to exploit rich grassland soils, returning less than half of the nitrogen they extracted each year. Relying on a stockpiled endowment of nitrogen, they produced stupendous surpluses for market export, but watched crop yields decline between 1880 and 1940. Austrian immigrants to Kansas saw their return on labour increase 20-fold. Both farm systems were efficient in their own way, one

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producing long-term stability, the other remarkable commercial exports. Kansas farmers faced a soil nutrient crisis by the 1940s, one that they solved in the second half of the twentieth century by importing fossil fuels. Austrian and Great Plains agriculture converged thereafter, with dramatically increased productivity based on oil, diesel fuel, petroleum-based pesticides and synthetic nitrogen fertilisers manufactured from natural gas.

Keywords Historical agro-ecosystems • Socio-Ecological metabolism • Agricultural frontier • Material and energy flow accounting • Agricultural land use • Biophysical economy • Soil sustainability • Austro-Hungarian agriculture • Great Plains sustainability • Grassland ecosystem

12.1 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 meet. 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 organised its western territory just 6 years earlier, including the Thirs' new home of Decatur County. 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 countries. The Thirs most likely immigrated from Gols, in what is now Austria, where most of their Kansas neighbours 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 travelled to Kansas. Within a few months of arrival he chose suitable farmland in Section 18 of Finley Township and, on 9 October 1884, filed a Homestead claim on 65 ha of grass (Decatur County Historical Book Committee 1983, 25–31; Homestead records from Kansas GenWeb 2009;

[1] This study is supported by U.S. National Institute of Child Health and Human Development grant nos. HD044889 and HD033554. An earlier version of this text appeared as Cunfer and Krausmann (2009).

[2] For details on the emigration from this region of the Austro-Hungarian Empire see Dujmovits (1992) and Antoni (1992).

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

Turning 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 neighbours. He had not really started farming his new land yet when the census-taker recorded his presence in the spring of 1885, but the next 10 years would see considerable progress on the Thir farm (Kansas State Board of Agriculture 1895 held at KSHS).

In 1888, when George Thir was 23 years old, he married Elizabeth Demmer, aged 20. Born in Gols in 1868, at the age of 13 she and her family had 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 migrants sought free agricultural land and an opportunity for economic improvement, while 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-Hungary to Kansas so that they could file a claim for him (*Decatur County, Kansas*, cit., 152, 204, 333–334, 351–2, 374, 425, 428–433).

George's new wife, Elizabeth Demmer, was also part of a multi-generational migration. She was one of five children born to Mathias 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 to the United States, where they found (and often intermarried with) former neighbours from Austria-Hungary. Families from Gols, Ragendorf, and Kaltenstein selected homesteads all around Finley Township, where George and Elizabeth Thir made their new farm (Fig. 12.1). 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 three horses, one milk cow, and one hog (*Decatur County, Kansas*, cit., 152, 184, 374, 430; *Standard Atlas of Decatur County, Kansas* (1905), held at KSHS, Kansas

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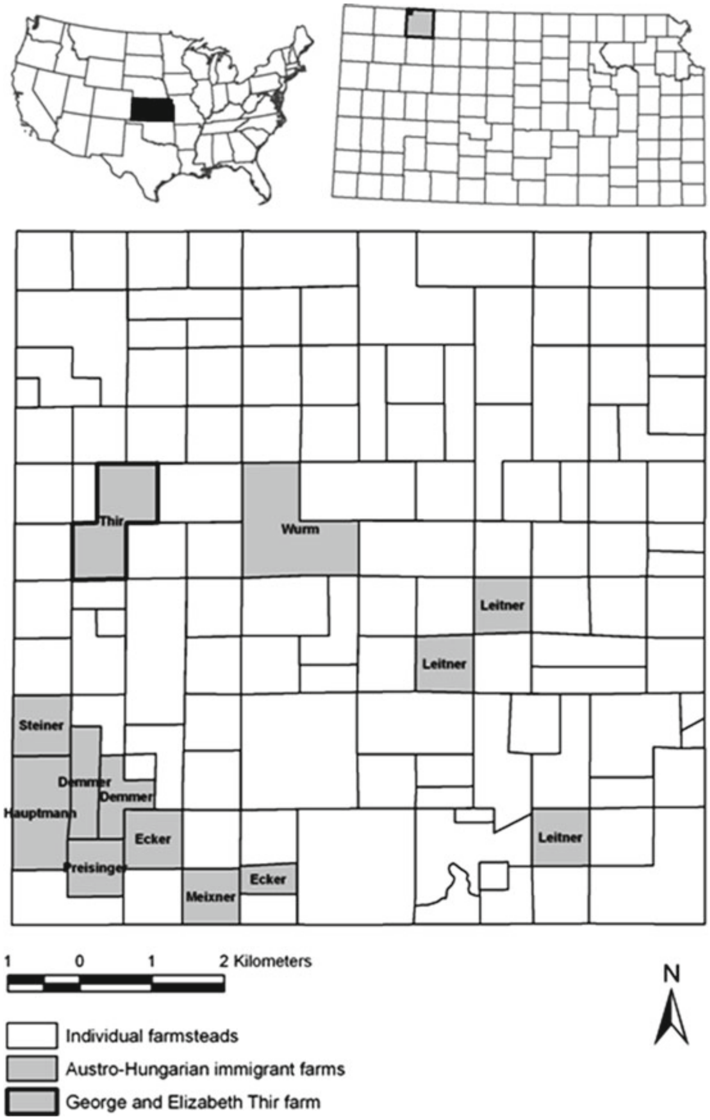

Fig. 12.1 Austro-Hungarian immigrant farms, including the Thir farm, situated within Finley Township. Small locator maps show the location of Kansas within the United States and of Decatur County and Finley Township within the state of Kansas

State Board of Agriculture 1905, held at KSHS; Kansas State Board of Agriculture, population and agricultural census manuscripts, Decatur County, Kansas, 1895).

Over the next few decades, as the Thir children grew up, the farm expanded. By 1905 it had doubled in size to 130 ha, with buildings, implements, a dozen milk cows, 10 beef cattle, 4 horses, 11 hogs, and a variety of cropland, hay land, and

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pasture, all together worth $2,000. Ten years later, the farm had doubled in size again to 259 ha—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 (Kansas State Board of Agriculture 1905, 1915, 1920, 1925, 1930, 1935, 1940; U.S. Population Census 1900, 1910, 1920, 1930; Herndon Union Cemetery records, Rawlins County, Kansas).

When George and Elizabeth Thir migrated across the ocean, they left behind an agro-ecological system in Central Europe where farmland supported high populations on smallholdings, where rainfall was reliable, where nutrients and energy flowed through tightly bound pathways linking soil, plants, animals and people into a complex and highly evolved system. For centuries, farmers 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-Hungary, land was scarce, labour (and hungry mouths) abundant. Livestock were a crucial component of the system, providing food and clothing, but also physical labour and manure to fertilise cropland (Krausmann 2004).

They arrived in an agro-ecological setting in Kansas that had immense potential but little existing structure. There fertile soil was abundant and cheap, labour 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 labour to bear: their own strong backs plus those of 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 organised a new farm system alongside neighbours 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.

In order to understand the environmental history of farming communities like those the Thirs inhabited, it is important to recognise that agriculture is a coupled human-environment system (Haberl et al. 2006; Liu et al. 2007). Borrowing methods from sustainability science, this chapter employs a long-term socio-ecological perspective to focus on biophysical relations between society and the natural environment (Ayres and Simonis 1994; Fischer-Kowalski 1998). Recognising that all economic activity is based on a throughput of materials and energy, social metabolism links socioeconomic activity to ecosystem processes. The corresponding set of methods—material and energy flow analysis (MEFA)—allows one to trace material and energy flows through socioeconomic systems and provides a quantitative picture of the physical exchanges between societies and their environment. This approach has been applied in historical studies of local rural systems to investigate the relationship between land, humans, livestock, and the flows of materials and energy related to production and reproduction in agricultural systems (Sieferle et al. 2006; Krausmann 2004; Cusso et al. 2006; Guzman Casado and Gonzalez de Molina 2009; Cunfer 2004; Marull et al. 2008). George and Elizabeth Thir were not just

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farming—they were also manipulating energy and nitrogen, shifting them across the landscape and directing them into and out of particular soils, biota, crops, and animals. MEFA methods take us beneath the surface to understand the ecological implications of socioeconomic activities.

12.2 Comparative 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 chapter uses a long-term socio-ecological approach to explore similarities and differences in land use at either end of the migration chain (Fischer-Kowalski and Haberl 2007).[3] It employs 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 pre-existing dataset makes it possible to model Theyern's land-use history in great detail. Although regional differences between farming systems in the nineteenth century are considerable, the basic socio-ecological characteristics of pre-industrial agriculture in Theyern and the Gols-Ragendorf-Kaltenstein region that fed Finley Township's nineteenth century population boom are comparable. Theyern was a typical lowland farming system with an area of 2.3 km^2 and a population of 102 in 1829. The village lay in the low, rolling countryside of northeastern Austria. 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 favourable climatic conditions for cereal production. The village has been cultivated for many centuries (Sonnlechner 2001). By the early nineteenth century, more than half of Theyern's area was cropland (Fig. 12.2a). Despite a rather large livestock herd, only 3% of the village was in 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 also provided grazing and litter for animal bedding (Krausmann 2004, cit. 735–773). Theyern, like Gols, was on the edge of a wine-growing region and, although there are no vineyards in Theyern itself, farmers had access to vines in neighbouring villages. Population density was high: 45 persons per km^2. In 1829, Theyern was home to 17 families who farmed an average of 8 ha each (Cadastral Schätzungs Elaborat der Steuergemeinde Theyern, held at Landesarchiv St. Pölten). However, three of the farms were larger (13–19 ha), while four had very small holdings of under 4 ha, probably producing barely enough for subsistence.

[3] For an early discussion of agro-ecology as a central subject for environmental history see Worster (1990).

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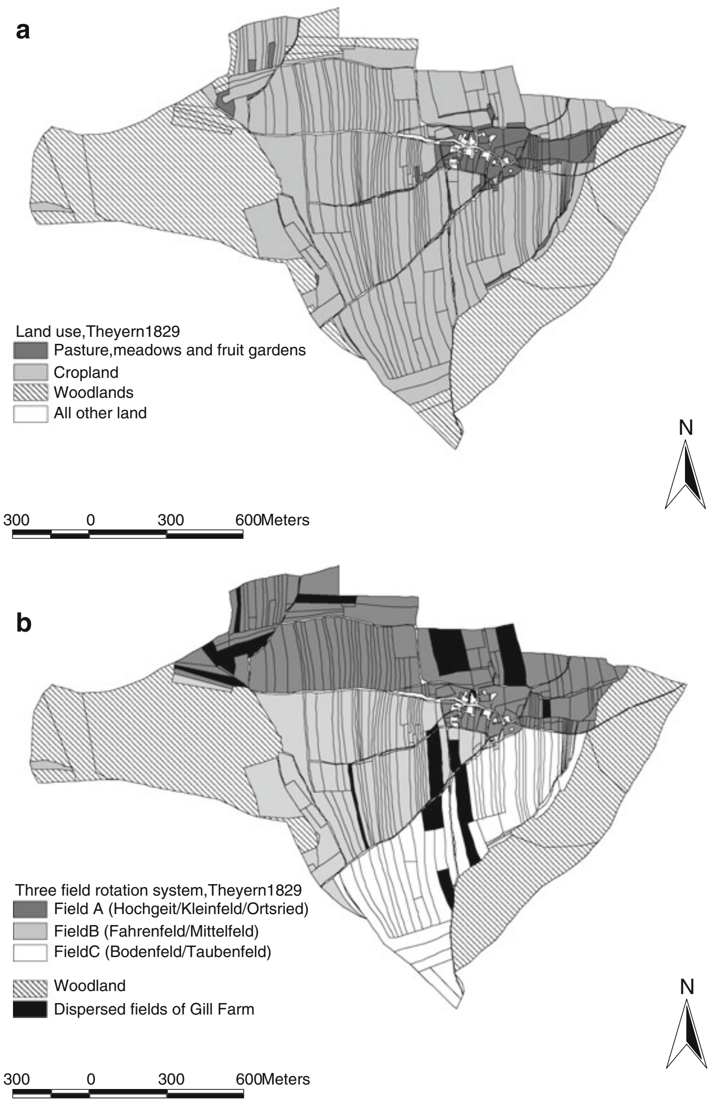

Fig. 12.2 Theyern land management; (**a**) Small meadows and orchards clustered closely around residential house lots, while cropland surrounded the village. On the outskirts of the community, woodlands prevailed on poor soils not suitable for cropping; (**b**) The cropland portion of the agro-ecosystem 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 larger holdings (ca. 13 ha farmland)

Until the mid-nineteenth 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 labour, or a

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share of agricultural produce). Beside the peasant families and the manor, the village 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 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 with respect to ploughing and harvesting of crops (Fig. 12.2b) (Cadastral Schätzungs Elaborat der Steuergemeinde Theyern, held at Landesarchiv St. Pölten).

The main source for the reconstruction of Theyern's land-use and farming systems is the Franciscan Cadastre (Franziszeischer or Stabiler Kataster; Moritsch 1972; Sandgruber 1979). This tax survey dates to the first half of the nineteenth century (1817–1856) and covered most of the territory of the Austro-Hungarian Empire, some 3,00,000 km^2. It included a geodetic survey of the territory, estimations of crop yields for all land-use classes and a report of monetary outputs (Lego 1968; Finanz-Ministerium 1858).

Up to 39 different land-use classes plus up to four distinct quality designators appear on the maps. The Cadastral Summary (Catastral Schätzungs Elaborat) is the basic data source for the reconstruction of land-use practice and biomass and nutrient flows. This handwritten text exists for each map and offers an extensive description of topography, demography and the farming system. It contains detailed information on land use and land cover, yields, population, livestock and farming practices, as well as livestock feeding practices, soil manuring standards, general information on the number of farms, wealth of the community, use of animals and markets. 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.[4] Furthermore, from previous research projects, published and unpublished data and analyses relating to the environmental history of the case study regions are available.[5]

Theyern's Cadastral survey dates to 1829. Rather than reflecting specific conditions during any single year, the cadastre reports long-term averages. A reconstruction of the agro-ecosystem on the basis of these data represents a valid average for the first half of the nineteenth century. While this restricts the direct comparability of the farming system that the Thirs left behind in Austria when they emigrated in the 1880s and their Kansas farm, the data still allows for a comparison of the general socio-ecological characteristics of different types of nineteenth century farming systems, which is the main goal of this chapter (Sandgruber 1978).

At the other end of the migration lay Decatur County, Kansas. George and Elizabeth ended their separate travels on the Great Plains, a flat to gently undulating grassland environment, slowly rising in elevation from east to west. Recently

[4] For a detailed description see Krausmann (2004, 2008).

[5] This material includes digitised versions of the original cadastral maps of the village, 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 (1997, 1999) and Winiwarter and Sonnlechner (2001).

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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 steppe (Fig. 12.1). Rainfall averaged 475 mm, and the dominant native vegetation was little bluestem, grama, and buffalo grasses. Trees were rare—less than 5% of ground cover—and appeared only in narrow bands along rivers and streams. Here soils were quite rich, but rainfall was unreliable, reeling between wet years with 800 mm or more and droughts when less than 250 mm fell.[6] To the Thirs and their neighbours the land promised a prosperous future.

The reconstruction of Decatur County's agro-ecosystem comes mainly from agricultural censuses compiled periodically by the State of Kansas and 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 nine snapshots describe land-use activity over 55 years, from the beginning of frontier farm-making to the establishment of a fully developed, modern agricultural system. Censuses report the acreage and yield of various crops on each farm, the number of livestock, the amount of irrigation, fencing, and agricultural implements owned. With these data we can follow the progress of the Thir homestead from raw prairie to integrated farm. Identical data exist 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 neighbourhood of the township, to the entire 230,000-ha county, and, indeed, for all 105 counties in the state of Kansas.

Population censuses reveal important elements of the social side of farm systems. Manuscript 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 (Sylvester et al. 2006).

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[6] Climate data come from two sources. The first is Karl, T.R., Williams, C.N. Jr., Quinlan, F.T., and Boden, T.A. (1990). United States Historical Climatology Network serial temperature and precipitation data. Environmental Science Division. Publication No. 3404. Oak Ridge, Tenn.; Carbon Dioxide Information and Analysis Center, Oak Ridge National Laboratory. The historical climatology data are stored as point data for weather stations at monthly intervals for 1,221 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. 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.

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12.3 A Long-Term Socio-Ecological Approach to Agricultural Systems

This chapter uses a simple conceptual model of agriculture as a coupled socioeconomic and natural system (Fig. 12.3). 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 (Boserup 1965, 1981). It is specific about the interactions of socioeconomic systems and ecosystems, allowing one to capture important technological developments related to the industrialisation 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, characterised by biogeographic conditions and land use types) and a socioeconomic system, consisting of a population subsystem (characterised by demographic attributes) and an economic production subsystem (including infrastructure, farm technology and livestock).[7] The model describes a farming unit (here a farm, township or village) as an agro-ecosystem managed by a local population investing labour 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 the flows into and out of the local environment. Such a systemic perspective allows one to analyse

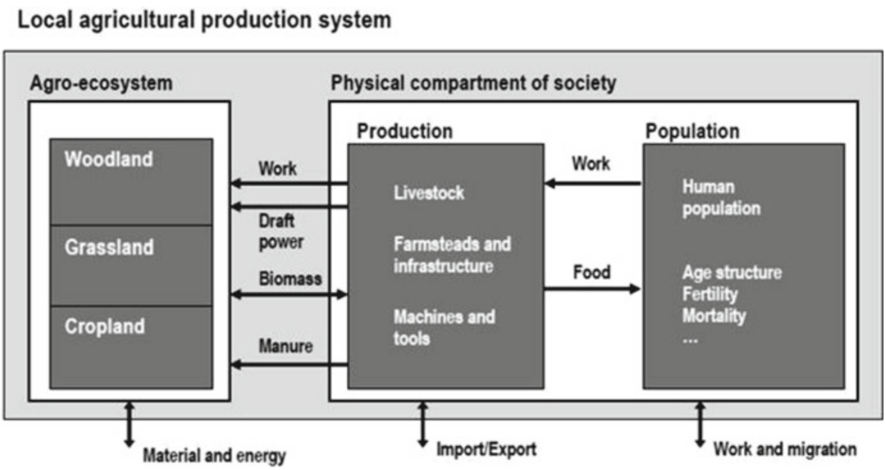

Fig. 12.3 A conceptual model of agriculture as a coupled socioeconomic and natural system (See text for explanation)

[7] This version of the model focuses on biophysical relations between society and nature and thus reduces the socioeconomic system to its physical components, i.e. the population and the production subsystem. See Fischer-Kowalski and Weisz (1999).

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all biomass and energy flows and their interrelations within the farming unit, and to link them to land use, ecosystem processes and the demographic system.

The Austrian cadastral records and the Kansas agricultural and population censuses can be used to quantify the flows of nutrients, materials and energy through the various subsystems described in this model. This technique allows one to cross-check the validity of historical data and to fill gaps in the data 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-specific feed demand make it possible to generate a picture of feed requirements compared to available supply.[8]

This study identifies nine key socio-ecological indicators that describe the physical stocks and flows of the two farm 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 Tables 12.1, 12.2, 12.3, 12.4, 12.5, and 12.6.

People and Space

- **population density**: census population divided by land area (people/km^2)
- **average farm size**: agricultural area[9] divided by number of farms (ha/farm)
- **land availability**: agricultural area divided by number of farm labourers reported in the Kansas census or estimated based on Theyern's age structure (ha/person)

Annual 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 available for export, converted into food energy and divided by agricultural area (GJ/ha)[10]
- **labour productivity**: plant and animal produce for human nutrition, including edible produce available for export, converted into food energy and divided by number of farm labourers reported in the Kansas census or estimated based on Theyern's age structure (GJ/person)[11]

[8] See, for example, Schüle (1989).

[9] 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 and woodlands. Uncultivated prairie in Kansas and woodlands in Theyern were integral components of both agricultural systems, as they were used for grazing or to extract bedding materials and also served as sources of biomass and plant nutrients transported to intensively used cropland (Cf. Krausmann 2004; Cunfer 2004).

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

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

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Table 12.1 Population, land use, livestock and crop production in Finley Township, 1895–1940

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	n.d.	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	n.d.
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	n.d.	663	314	319	117	263	106	299

Sources: See text

Table 12.2 Population, land use, livestock and crop production on the Thir farm, 1895–1940

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	n.d.
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

Sources: See text

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Table 12.3 Socio-ecological characteristics, Finley Township, 1895–1940

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 per farm	92	130	127	154	151	137	128	135
Land availability	ha per agric. labourer	36	45	47	58	69	59	55	58
Grain yield	kg/ha/year	1,141	1,687	1,244	1,351	736	1,278	370	378
Area productivity	GJ/ha/year	4.6	4.9	7.0	5.1	1.7	6.5	0.4	1.6
Labour productivity	GJ/labourer/year	168	220	327	293	114	385	19	92
Marketable crop production	% of total production	74%	53%	69%	66%	26%	72%	−14%	43%
Livestock density	animal per km²	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%

Sources: See text

Table 12.4 Socio-ecological characteristics, Thir farm, 1895–1940

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 per farm	65	130	259	162	162	162	227	227
Land availability	ha per agric. labourer	32	43	86	54	54	54	76	76
Grain yield	kg/ha/year	1,274	1,427	1,041	1,371	709	1,246	406	369
Area productivity	GJ/ha/year	4.9	4.8	3.1	3.7	1.3	5.4	0.5	0.7
Labour productivity	GJ/labourer/year	159	209	267	198	68	293	34	55
Marketable crop production	% of total production	75%	59%	59%	54%	23%	65%	6%	33%
Livestock density	animal per km²	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%

Sources: See text

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Table 12.5 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

Sources: See text

Table 12.6 Socio-ecological characteristics, Theyern municipality, 1829

Variable	Unit	1829
Population density	cap/km²	45.3
Farm size	ha per farm	13
Land availability	ha per agr. labourer	3
Grain yield	kg/ha/year	819
Area productivity	GJ/ha/year	4.4
Labour productivity	GJ/labourer/year	9
Marketable production	% of total production	25%
Livestock density	animal per km²	24
Nitrogen return on cropland	% of total extraction	92%

Sources: See text

- **marketable crop production**: cereal production minus grains required for feed, seed and subsistence (percentage of extracted biomass as tons dry matter)

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- **livestock density**: large animal units of 500 kg live weight divided by agricultural area (animals/km^2)[12]

[12] We converted livestock numbers into large animal units of 500 kg live weight by using species and region-specific data on average live weight in the observed period. See Krausmann (2004); 735–773 and Krausmann (2008), 56.

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- **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)[13]

12.4 People and Space

Theyern, Austria was typical of European agro-ecological systems. With episodic agricultural occupation dating at least as early as 1000 B.C., we know that population expansion during the late Middle Ages led to a gradual re-colonisation of the area for agriculture. By 1830, Theyern had existed as a discrete community for hundreds of 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 nearly at the subsistence level, producing as much food and supporting as many people as possible, given current cultivation practices, technology and energy availability. The fully populated land achieved its peak productive potential. Theyern's population density in 1830 was 45 people per km^2 (Fig. 12.4a). The average family farmed 13 ha of land, and there were 2 ha of agricultural land per person in the community (1 ha/cap if woodland is excluded; Fig. 12.4b, c). 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, travelling on foot over wide distances. Native agriculture expanded on the plains only after 1000 A.D. and only over a very small area. Occasional patches of maize, beans, and squash dotted the narrow river valleys

[13] 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 volatilisation 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 Krausmann (2004, 2008, 17–20) and Cunfer (2004). On soil nutrient balances more broadly, see Loomis (1978, 1984), Campbell and Overton (1991), Loomis and Connor (1992), and Shiel (2006a, b).

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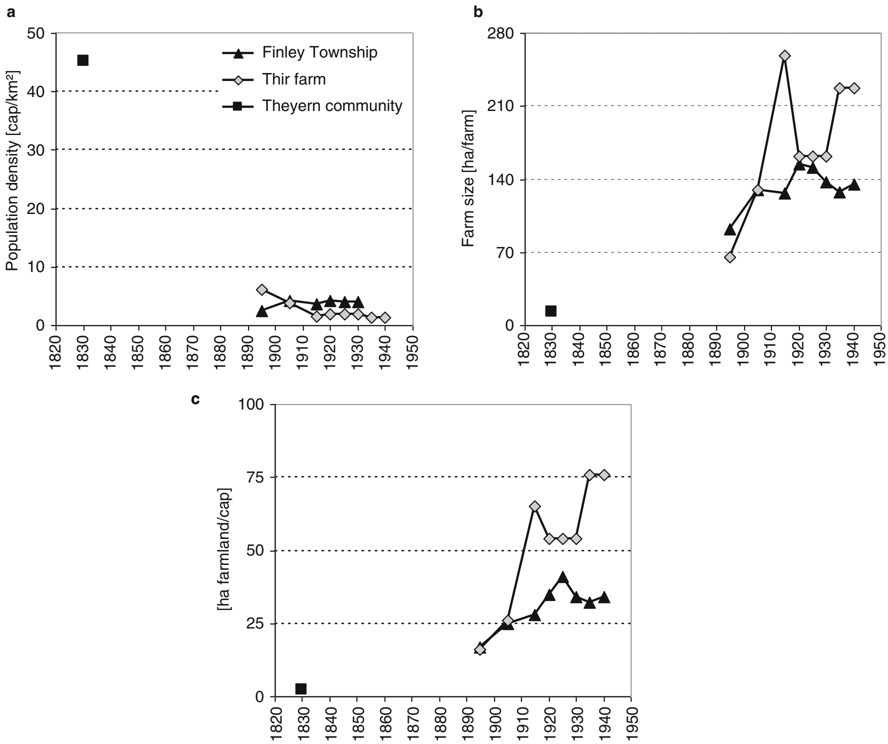

Fig. 12.4 People and space, Theyern, 1829 and Finley Township and Thir farm, 1895–1940; (**a**) population density; (**b**) average farm size; (**c**) land availability (Sources: see text)

winding through vast uncultivated upland grasslands.[14] At their greatest extent, Indian crop fields never reached even 1% of the area of the Great Plains. After the seventeenth century, many natives adopted horse-based hunting and gathering, and some moved in the direction of horse pastoralism.

European farmers who moved into the region in the late nineteenth century entered an agricultural vacuum. Importing livestock with them, and thus increasing their ability to work the soil by 100-fold, American, German, and Austro-Hungarian settlers began the enormous task of agricultural colonisation, plowing sod that had lain intact for thousands of years. The contrast with European agricultural villages

[14] 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. Indian farmers had no domesticated livestock. Women tilled the soil entirely through human labour. 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 Hurt (1987, 57–64) and Wedel (1978).

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could not have been greater. The population density in Finley Township, where George and Elizabeth Thir made their new farm, was only two people per km^2 in 1895, an order of magnitude lower than in Theyern. The average farm size was an incredible 92 ha, so large that for the first several decades, few farmers could make use of all of their land and a considerable fraction of the available land was used only for extensive grazing. There were 17 ha of land in the township for every man, woman, and child. The amount of land available to be worked per agricultural labourer 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 labour on this agricultural frontier, much of the land remained unused. On the Thir homestead, 65 ha 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 six people per km^2 and about 16 ha 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 moved toward an agricultural equilibrium. Population density in Finley Township increased during the initial period of homesteading and then stabilised at between 4 and 5 people per km^2. During the same period, average farm sizes rose rapidly, from 92 ha in 1895 to a peak at 154 ha in 1920, then dropped slightly to settle at around 130 ha for the next few decades. Land per person followed a similar curve, rising from 17 ha in 1895 to 35 in 1920, and thereafter floating between about 30 and 40 through the early twentieth 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 ha of land, a whopping 65 ha 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 intensively used land; If anything, they moved away from that model.

12.5 Annual 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. Theyern farms in 1830 produced 819 kg of grain per hectare, which, together with animal products, were enough to provide 9 GJ of nutritional energy for every farm labourer (Fig. 12.5a). Area productivity was 2.9 GJ of food per hectare (Fig. 12.5b). The highly integrated subsistence system supported a lot of people, but surplus above local demand was low and 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.

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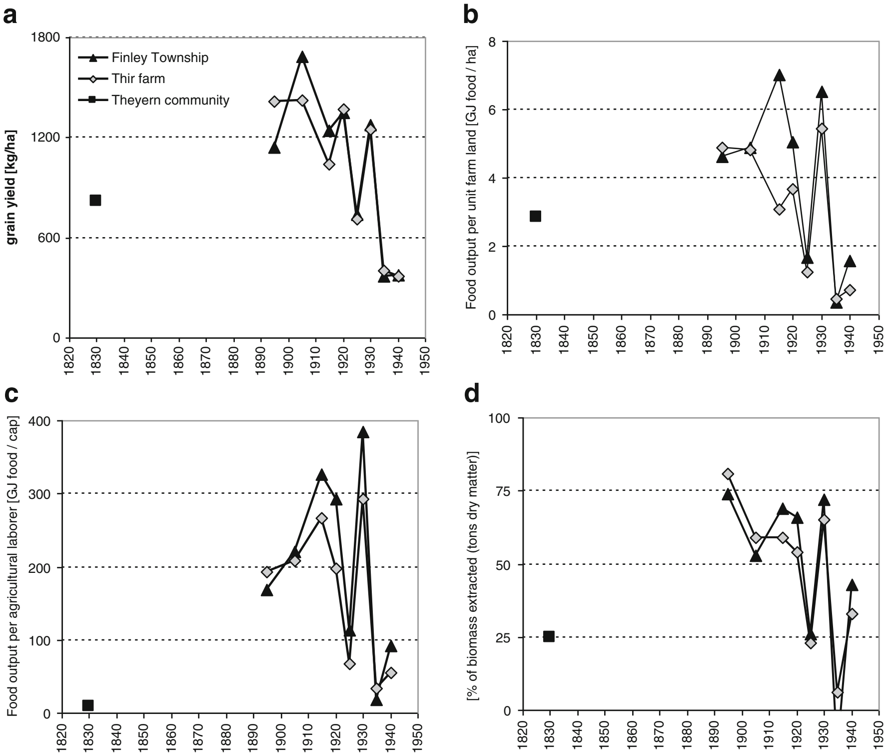

Fig. 12.5 Annual farm productivity, Theyern 1829 and Finley Township and Thir farm, 1895–1940; (**a**) grain yield; (**b**) area productivity; (**c**) labour productivity; (**d**) marketable crop production (Sources: see text)

Theyern exported from the local system no more than 25% of its agricultural produce through sales in nearby markets or rent paid to the landlord (Fig. 12.5d). This profile provides a long-term average of the community's typical productivity throughout the first half of the nineteenth century.

In western Kansas the freshly ploughed soils produced much higher yields in the first couple of decades. Taking advantage of 10,000 years of stockpiled soil nutrients, the Thir farm produced 1,274 kg of grain per hectare in 1895, 56% higher than Theyern's yield, while Finley Township as a whole averaged 1,141 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/ha, and because there were fewer people on the land in Kansas, nutritional energy production per farm labourer was 168 GJ in Finley Township (Fig. 12.5b, c). Such return on labour—nearly 20 times Theyern's rate—was stupendous. Whereas one Theyern farm labourer grew enough food to feed about 2.5 people, one agricultural labourer 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

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Great Plains was from the beginning oriented towards commercial production and was 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 grain elevators on the railroad line and shipped their produce east. Cities grew rapidly in the late nineteenth century as other immigrants poured in to take factory jobs in the United States' industrialising economy (Prickler 2003). Kansas wheat farmers fed not only themselves but those distant urban workers too.

The exploitation of stockpiled soil nutrients could not continue indefinitely. Through the early twentieth century, cereal yields in western Kansas fell, plummeting to less than a quarter of their peak levels. As farmers ploughed up fresh land in the first two decades of agricultural settlement, yields remained high, rising from 1,141 kg/ha in 1895 to 1,687 kg 10 years later. Thereafter, once most of the new land was already in production, yields began to fall, down to 1,244 kg in 1915 and 736 kg 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 during the 1930s drought. The Thir farm closely followed community-wide trends.

The decline in yields was unmistakably downward over half a century, but from year to year there were sharp upturns and downturns. For example, 1925 saw township-wide yields of only 736 kg/ha, but 1930 produced a bumper crop at 1,278 kg. Five years later, in 1935, production was down sharply again. Area productivity likewise varied widely, fluctuating between 4 and 7 GJ/ha, then dropping to less than 2 in 1925 and again in the 1930s. Crop yields in Kansas derived not only from soil fertility, but also from soil moisture. The extreme annual variation in rainfall at the centre 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 downward trend in yields over the long term reveals a combination of declining rainfall and 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 exploited the stockpiled soil fertility that had accumulated century by century under native grass.

None of the primary sources report actual exports of farm produce. Instead, we estimate marketable crop production by calculating how much of the harvest was needed for feeding the people and livestock in the community and for seeding next year's crop. Any surplus would have been available for sale on the market. The marketable production in excess of subsistence needs moved downward in Finley Township, 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 actually fell 14% below what was needed for bare subsistence, but was up again to more than 40% of total production just 5 years later.

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12.6 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 (Fig. 12.6a). The impact of livestock cannot be understated. Most obviously, farm animals provided food (beef, pork, poultry, milk, eggs, lard, butter) and clothing (leather, wool). They also provided labour for ploughing soil, cultivating weeds, harvesting crops and transporting farm produce over short and long distances.[15] More subtle, but no less significant, was the impact of 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. Livestock 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 manure to their crop fields, they essentially transported soil nutrients from untillable land to arable land, subsidising fertility in the infields with nutrients transported by livestock from the outfields. Theyern farmers maintained significantly more livestock than they needed for food and labour; they kept additional animals because of their manure production (Allen 2008; Frissel 1978; Cusso et al. 2006).

Every year, Theyern farmers returned to the soil more than 90% of the nitrogen that they extracted from it in crops (Fig. 12.6b). Much of that restored nitrogen flowed through livestock and their manure. Collecting, processing and properly applying manure was labour-intensive work. The whole system was intricately interrelated: Feeding a dense population required maintaining animals that produced manure, which in turn required a significant labour force and thus dense populations. 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 5–20 years as soil fertility declined.

[15] 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 labour (working fields and fallow areas) and transport (moving harvest from dispersed fields), fuelwood from the community forests, and manure back to the fields. Krausmann (2004) estimates that installed power amounted to 0.17 kW per ha of cropland. According to Schaschl (2007), who quantified the monthly supply of and demand for human and animal labour during the course of a year for individual farms in Theyern, the supply of animal labour exceeded demand even during peak seasons in March and April. 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 similar to that in Theyern.

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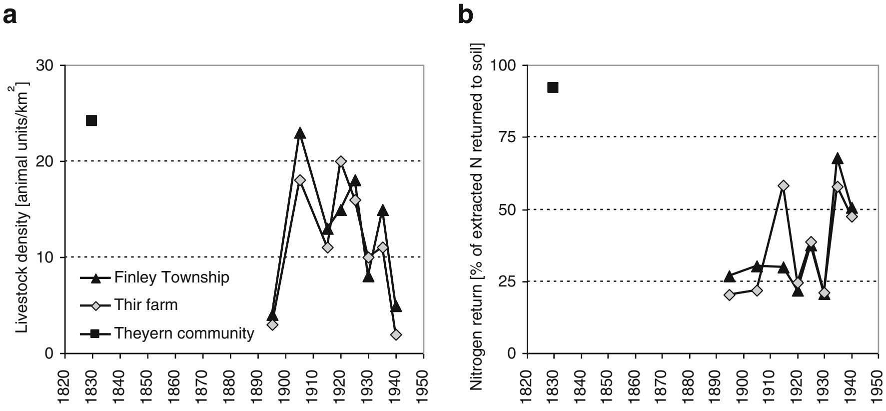

Fig. 12.6 Livestock and nutrient management, Theyern, 1829 and Finley Township and Thir farm, 1895–1940; (**a**) livestock density; (**b**) nitrogen return (Sources: see text)

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 a 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 ploughed into the soil. Mineralised 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 nineteenth century, Austrian farmers were only beginning to include nitrogen-fixing legume fodder crops such as clover or alfalfa fodder 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 plough-up accelerated the decomposition of accumulated organic matter and spiked nitrogen into the soil for the first several years (Parton et al. 2005). But ongoing ploughing and cultivation soon generated nitrogen declines through both chemical and biological processes (Hass et al. 1957). Exposure of soils to the atmosphere initiated ammonia volatilisation by which stored nitrogen escaped into the air. Tillage also encouraged bacterial denitrification, in which soil bacteria converted nitrate to nitrogen gases by means of digestion, returning soil nitrogen to the atmosphere. Ploughing could accelerate leaching of nitrogen via rainwater deep into the soil, plus additional losses from water and wind erosion (Stevenson 1982; Cunfer 2004; Burke et al. 2002). Thus it is not surprising that crop yields began at remarkably high levels, then dropped throughout the next 50 years after settlement.

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In addition to these natural nitrogen losses, Kansas farmers extracted more nitrogen from their soils than they returned each year, in large part because they put little manure back onto the fields. Finley Township had a low livestock density of only four large animals per hectare in 1895, far below Theyern's 24. That number rose to 23 animals per km^2 in 1905 (mostly beef cattle, horses, and milk cows), and then dropped steadily over the next 40 years, down to just five 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 that number remained below 40% through the 1920s. The 1930s saw an increase in nitrogen return to between 50 and 70% only because significant crop failures during drought years prevented farmers from extracting much nitrogen from their land.[16] 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 labour and used cattle and pigs for household food and to create added value to uncultivated prairie. But beyond that, they did not maintain additional animals simply for their soil fertility benefits, as in Theyern.

As George and Elizabeth Thir and their neighbours 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. The eventual solution came, not in adopting Old World-style farm management, but from the importation of fossil fuel energy. The decline in livestock density in Finley Township after 1905 went hand-in-hand with the advent of fossil fuel energy deployment. When farmers 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 applying synthetic fertiliser in place of the missing manure. Nitrogen fertiliser also represents a fossil fuel import, since its production requires large amounts of natural gas. Thus twentieth century farmers substituted fossil fuel-driven tractors for the labour function of livestock, and substituted 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.

[16] While the peaks in the rate of nitrogen return in Finley Township and at the Thir farm in the 1940s are due to harvest failures and consequent low nitrogen extraction rather than to increases in nitrogen input, leguminous crops contributed to the high return rate (above 50%) which can be observed for the George Thir farm in 1915. This was the only year when Thir planted a considerable fraction of his cropland with alfalfa.

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12.7 Conclusion

This chapter 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, the rural village of Theyern, serves as a reference point to contrast the Kansas farm system and 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 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, 1 ha of farmland in Theyern produced about 2.9 GJ of food; in 1895, 1 ha 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 at the same order of magnitude.

The same was not true for labour productivity. Theyern produced about 9 GJ of food per farm labourer while those in Decatur County produced 200 GJ, 20 times their cross-Atlantic counterparts. The Theyern farm system coaxed food from the soil through intensive applications of labour, 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 labour to produce large amounts of food. Consequently, population and livestock densities were lower, and declined between 1905 and 1940.

The two farm systems had different optimisation goals. The long history of subsistence farming, the tight social networks of village, manor and church in Theyern aimed not at peak production but at risk minimisation and long-term sustainability.[17] Theyern's greatest resource was a high labour supply, which it employed to maintain soil fertility. The tiny, scattered village fields, managed collectively, did not encourage peak production, but rather diversified holdings for all families and reduced the risk of catastrophic failures.

Finley Township, Kansas, followed a different strategy aimed at taking advantage of new commercial grain markets in the industrialising cities, new transportation opportunities as railroads spread across North America, and a rich endowment of fertile soils. Here were economies of scale with large, consolidated farms. Kansas was short of labour, 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

[17] For a discussion of risk minimisation strategies see McCloskey (1976).

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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 Austria and the Great Plains changed through the nineteenth and early twentieth centuries. In some ways their trajectories crossed paths. Austria as a whole moved steadily upward from relatively low yields and labour productivity in the early nineteenth century to higher production and increasing labour productivity by the century's end. Yields doubled over 75 years (Sieferle et al. 2006). Finley Township, for its part, began with high yields and labour productivity in 1895, and drifted downward over the decades, to a nadir in the 1930s. Kansas had reached a crisis of soil fertility by World War II. Thus through the nineteenth century and early twentieth century, the two farm systems moved in different directions.

After World War II, the application of fossil fuels to agricultural systems transformed both locations and began a transformation of productivity never seen before in the history of agriculture. The import of energy—diesel fuel for tractors, natural gas for nitrogen fertiliser, petroleum for pesticides, and gasoline and electricity for a multitude of farm machinery—presented a new solution to the ancient problem of maintaining soil fertility. With fossil fuels, Austrian farmers no longer needed to invest enormous amounts of labour in demanding livestock to provide power and manure. With fossil fuels, Kansas farmers could continue farming their depleted prairie soils by 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 converged, with each moving toward high output commercial farming. By the end of the twentieth century, average cereal yields in Austria and Kansas were at a similar level and ranged between 6.5 and 7.5 t/ha (Sieferle et al. 2006; Kansas State Board of Agriculture. *Biennial Reports*. Topeka, Kans.).

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 agro-ecosystems. 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. The application of fossil fuel energy saved the region for commercial agriculture, and allowed farmers to sustain their land-use practices for another 75 years.

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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 pressured backward and inefficient Old World people to improve agriculture (which some did) or to abandon it for industrialising cities (which most did) (Hayami and Ruttan 1985; Persson 1999; Williamson 2006; Van Zanden 1991; Koning 1994). This chapter points out an ecological component to the story that economists have missed or downplayed. One of the key reasons why 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 half a century, Great Plains farmers mined 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 fertilisers and other high energy inputs rescued farmers, as the developed world substituted oil for soil.

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