

SOCIAL METABOLISM OF CZECH AGRICULTURE IN THE PERIOD 1830–2010

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ABSTRACT

This article presents the concept of social metabolism and highlights its use for the analysis of the development of agriculture in Czechia. Similar to the general discipline of geography, social metabolism investigates the interactions between people and nature throughout time and space. In this article, we apply social metabolism methods, such as energy flow analysis (EFA), to investigate the transformation of Czech agriculture during the 1830–2010 period. The article is based on public data, as well as datasets compiled by the authors. The article documents the changes in Czechia's historical development and its effect on land use and agriculture through the observation of several metabolic key indicators within their historical context. It primarily concentrates on changes in crop and livestock production, land use, and associated demographic and societal developments. We conclude that the strategies of all political regimes in the 19th and most of the 20th century increased the socio-metabolic output of agriculture, despite a very different political and economic background. Only the collapse of the Eastern Block resulted in a restructuring of the agricultural sector that produced a visible change in agricultural energy flows trends.

Keywords: social metabolism, Czech agriculture, material and energy flow analysis (MEFA), land use, environmental history

1. Introduction

1.1 Social metabolism

This article investigates a period of hundred and eighty years of Czech agriculture from the perspective of social metabolism (Fischer-Kowalski, Weisz 1999; de Molina, Toledo 2014) or industrial metabolism (Ayres, Simonis 1994). This is a conceptual framework widely used in fields like ecological economics and industrial ecology. It treats human systems as analogous to living organisms. Like living organisms, societies exploit natural resources, require space, materials and energy and produce waste. This metabolism of socio-economic systems is the cause of a broad range of environmental and sustainability problems, and the concept has proven valuable to the study of interactions between society and its natural environment. With a set of methodological tools derived from the concept, it is possible to quantify relevant flows through socio-economic systems (usually in mass or energy units) and explore their relationship with other socio-economic characteristics, such as population or economic development.

Studies on social metabolism, particularly those focusing on biomass, have frequently also investigated land use changes and the processes which cause them (e.g. Fischer-Kowalski, Haberl 2007; Cusso et al. 2006; Krausmann et al. 2003). The agricultural system is placed at the intersection of natural and economic processes, and providing food in order to meet one principal biological human need serves as the nutritional basis for

societal development. For this reason, knowledge of its operation from a biophysical perspective and quantification of relevant processes in physical units (hectares and Joules in this instance) is of key importance in enhancing our understanding of the relationship between people and nature in a long-term perspective. Consequently a number of studies involved with the concept of social metabolism cross over to environmental history (see e.g. Jeleček 2000; Hoffman 2007; Siefertle 2011; Cunfer, Krausmann 2009).

This article attempts to combine a metabolic and an environmental history perspective to study the evolution of Czech agriculture. The study period of 1830–2010 brought a wealth of significant historical developments in Czechia: a transition from feudalism to capitalism, industrialization, system collapse brought by both world wars, transition to socialism, return to free market, and the integration into global market. We investigate this development through a quantification of selected metabolic indicators and discuss causes and conditions of the observed development, founded on an analysis of relevant historical context. This research complements studies focused on Czechia and long-term changes in its land use, agriculture, and social metabolism (Bičík et al. 2001; Bičík et al. 2010; Štych et al. 2005; Jeleček 1984; Kušková et al. 2008; Grešlová Kušková 2013). It contributes to long-term socioecological research, which concentrates on socioecological systems (Redman et al. 2004; Haberl et al. 2006). Furthermore, the article intends to continue a discussion in the field of industrial and social ecology, especially in relation to material and energy flows

accounting and biomass metabolism (Haberl 2002; Krausmann et al. 2003; Eurostat 2001; Cusso et al. 2006; Erb et al. 2007; Krausmann et al. 2008a; Fischer-Kowalski, Haberl 2007).

1.2 Czech agriculture throughout history

Until the end of the First World War (WWI), and the subsequent emergence of an independent Czechoslovakia, Czechia had for centuries been a part of the Habsburg Monarchy. Prior to WWI, agricultural productivity and intensity in Czechia was generally more advanced than was the case in other regions of the monarchy. Throughout the 19th century and the beginning of the 20th century, Czech agriculture was influenced by the agricultural and technological revolution in much the same way as agriculture of many other European countries.

The end of WWI ushered in two decades of democratic Czechoslovakia. Further intensification of agricultural production, fostered by the introduction of mineral fertilizers and tractors, proceeded successfully alongside the reparation of damages caused by the war. During WWII, Czechoslovakia came under the occupation of Nazi Germany. Dramatic changes took place during the communist era (1948–1989). Czech industrialization was significantly affected by the socialist system, which brought about the “nationalisation” (state control) of most industrial and agricultural production and the implementation of a rigid planned economy. Some authors describe this process as “socialist industrialisation” (Bičík et al. 2001). The sudden collapse of the communist system and its planned economy caused a radical transformation of agriculture and a general re-organization of production in terms of both quantity and structure (Bičík, Jančák 2005). The new era precipitated the need to integrate the economy into the wider global market structures, which was further accelerated by the accession to the EU in 2004.

The analysed time span could be divided into 6 principal periods reflecting historical events and the society’s technological level in terms of agricultural

production. An overview of the periodization proposed in this article is presented in Table 1. The selected historical stages could certainly be divided even further, which will be hinted at within the article, however, a more detailed investigation would go beyond the scope of this study. The 19th century saw the transition from three-field crop production including a fallow period towards more advanced forms of crop rotation, as well as significant social reforms, the most important of which was the abolishment of serfdom in 1848. These changes were associated with a gradual shift away from feudalism to capitalism. At the beginning of the observed time period, agricultural production was dominated by small scale farms under 20 ha (numerically, they represented 85% of all farms and took up almost 38% of all agricultural (and forested) land). However, while farms above 100 ha were the least numerous (0.3%), they occupied an identical share of cultivated land. The described state of affairs remained more or less unchanged until the inter-war period, except that the share of small scale farms declined to 64% of all farms, while large farms (now over 50 ha, representing 1%) occupied approximately 20% of land (Jeleček 1995). After WWII and the rise of socialism, Czech agriculture underwent a radical transformation. Collectivization, nationalization, and the consolidation of agricultural plots produced a monotonous structure of agricultural production, one which was dominated by large-scale farms taking up thousands of hectares.

After the Velvet Revolution of 1989, most land has been returned to its original owners and their families, who, however, rarely cultivate this land themselves but rent it out. Even though on paper there are approximately 2 million small-scale land holders, contemporary agricultural production is dominated by large enterprises, who, despite representing only 5% of all entities, cultivate over 75% of all agricultural land. Family farms take up only 13% of agricultural land and all farms together own roughly 12–13% of whole land. The rest is under long-term lease agreements (Doucha, Foltýn 2006).

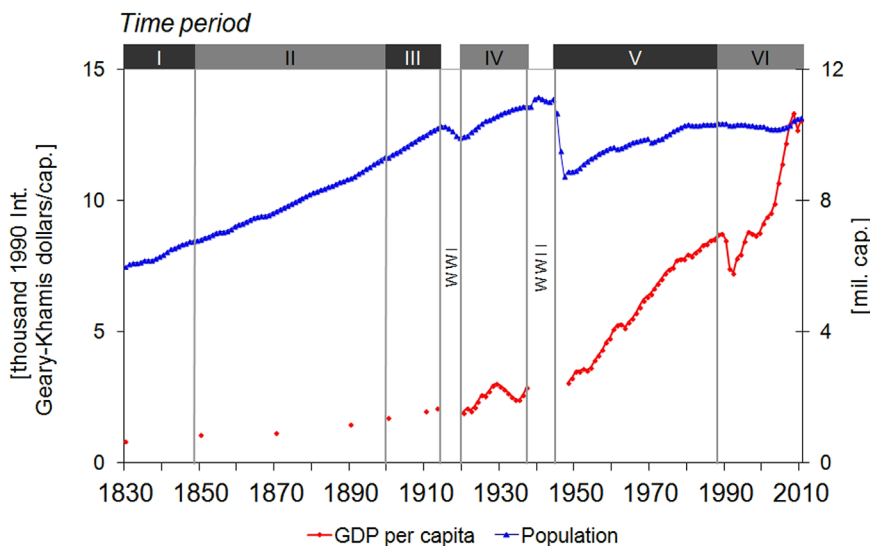


Fig. 1 Population and GDP per capita, 1830–2010.

Source: Bolt et al., 2013

Tab. 1 The overview of studied time periods and main characteristics of Czech agriculture. Periods are numbered in Roman numerals.

Period	I. 1830–1848	II. 1848–1900	III. 1900–1914	IV. 1918–1937	V. 1948–1989	VI. 1989–2010
State formation of which the examined territory (Czechia) was a part of	Austrian Empire (1804–1867)	Austrian Empire (1804–1867) Austro-Hungarian Empire (1867–1918)	Austro-Hungarian Empire (1867–1918)	Czechoslovak Republic (1918–1938)	Czechoslovak Socialist Republic (1948–1989)	Czech and Slovak Federative Republic (1990–1992) Czech Republic 1993 onward
Political arrangement	Feudalism	Capitalism	Capitalism	Capitalism	Socialism	Capitalism
Main historical trends and events influencing Czech agriculture	1827 invention of an improved wheeled plough called the “Ruchadlo” in Bohemia.	Abolition of serfdom in 1848. Transition from a three-field system to a crop rotation management system. Industrialization, beginning of use of artificial fertilizers. 1873 The Vienna stock market crash – agrarian crisis. (1870s–1890s) – The consequence was a shift from plant production to keeping livestock. Change in the structure of crop.	Beginnings of concentration of production and capital. Decrease in the numbers of agricultural workers, who at the beginning of the 19th century represented almost the entire population to only 37% (Beranová, Kubačák 2010).	Continuation of trends from the previous period (intensification). Land Reform Act – all agricultural holdings in excess of 150 ha and other land over 250 ha, was confiscated and divided among farmers.	Totalitarian regime, nationalization and collectivization, land consolidation, massive industrialization.	Transformation in the sense of transition from socialism to capitalism. Sharp decrease of agricultural production, alignment with foreign markets.
Structure of farms	Large manorial estates dominated and owned most of the land. serfdom, agricultural inhabitants in the country prevailed and had to pay tithes and taxes from the rented land.	Small farms under 20ha dominated (almost 85%) and occupied about 38% of land. Farms larger than 100 ha represented a 0.3% in terms of numbers but occupied the same share of land.		Small farms under 20 ha dominated (64%) but farms larger than 50 ha which represented only 1% in numbers occupied 1/5 of agricultural land.	Large farms over thousands of ha dominated.	5% of the largest farms occupy almost 75% of the land (but millions of small owners). Czech farms own only about 12–13% of the land, with the remaining land in lease. Family farms about 13% of agricultural land.

More detailed analysis of the development of Czech agriculture during the years 1989–1998 published Doucha and Sokol (1999).

Figure 1 illustrates the developments in population growth and income in Czechia. Population kept growing slowly but steadily throughout the observed period with only three exceptions: WWI and II caused a reduction in population numbers, particularly WWII when war losses and the displacement of mostly German-speaking inhabitants caused a population loss of over 2 million inhabitants. The third decline in population numbers, registered in the 1990s, occurred due to a fall in birth rates which followed the collapse of the Eastern Block. The economy grew only slowly during the first half of the 19th century but growth in income (GDP per capita) picked up speed over the course of industrialization. Growth significantly accelerated after WWII and further so after the transition from planned to market economy. The development in the values of the socioeconomic indicators in Figure 1 is

also consistent with the principal stages of the development of agriculture.

1.3 Data and methodology

The quantification of selected metabolic variables and indicators was performed on a database comprised of publicly accessible information, mostly from the Czech Statistical Office, FAOstat, and contemporary yearly reports of the Czechoslovak Republic and the Central Statistical Office of Austria-Hungary (for more information on data and methodology, see Kušková et al. 2008; Grešlová Kušková 2013). Data for Czechoslovakia have also been published at <http://lucc.ic.cz>, a website managed by the LUCC – Czechia research team, and at <http://www.uni-klu.ac.at/socec/inhalt/2608.htm>, a website maintained by the Institute of Social Ecology Vienna. Our article is mostly focused on the area of Czechia with the exception of data on international trade, which is not available for the

territory of the Czechia until 1993). We compiled these data to provide timelines reaching all the way to 2010. Table 2 lists the main indicators presented in this study.

Tab. 2 Overview of selected indicators.

Indicator	Definition	Unit
Domestic extraction of agricultural biomass (DE)	Harvest from agricultural areas plus grazed biomass	Joule
Physical trade balance	Physical trade balance = Imports – Exports	Joule
Livestock density	Livestock Units of 500 kg (LSU500) per total area	LSU/km ²
Yields	Harvest per area	Joule/km ²

We empirically evaluated long term changes in land use and social metabolism of Czech agriculture over the period of 1830–2010. We employed the method of Material and Energy Flow Analysis (MEFA; see e.g. Haberl 2002) and Energy Flow Analysis (EFA) in particular, because it enables a quantification of the interactions between people and nature and, for example, a comparison between the flows of biomass and fossil fuels by expressing them in identical units (Joules) (see Haberl 2001). For better illustration see the conversion factors and water content of main crops together with yields for specific periods in Table 3.

Statistical sources usually record the values of the observed indicators in units of mass or area size. For our purposes, data expressed in units of mass was recalculated into dry matter (DM) and further into gross calorific values (GCV upper heating value), as outlined in Haberl (1995). Density of livestock production was expressed in livestock units per area.

2. Results

2.1 Land Use

The extent of agricultural land is a key indicator of the production potential of the agricultural system. Changes in its extent, structure, and use reflect significant societal processes and historical developments. At the beginning

of the observed period, the extent of agricultural land (arable land incl. permanent crops, fallow, meadows and pastures) was slowly increasing in the period I (from an initial value of little over 51,000 km² in 1830 by approximately 2,000 km² by the mid-19th century, when it reached its peak in the observed period I). This was primarily caused by an increase in the size of areas devoted to the cultivation of new kinds of crops intended to feed livestock. Along with this, however, the use of the three-field continued. Fallow land remained an essential component of the cropping system well into the 1870s. In the second half of the 19th century (period II), the extent of agricultural land started to gradually decline. This trend was initially accompanied by a simultaneous decline in the extent of pastures and meadows and the gradual disappearance of fallow land. Since the end of the 19th century (during the periods III and IV), the size of agricultural land had stagnated up until WWII. The displacement of German inhabitants from border regions after the end of World War II also played a significant role in the decline of agricultural land (for more information, see Bičík et al. 2001). During the period V, the extent of agricultural land started to decline even more rapidly (from approximately 49,000 km² in the inter-war period to 41,000 km² recorded in the 1980s). This was brought about by the introduction of the so called “socialist economy” and the ongoing mechanization of agriculture, which enabled an increased concentration and specialization of agricultural production and the use of former agricultural land for other purposes (Bičík et al. 2001). Average annual growth in the size of agricultural land and arable land over the individual periods is recorded in Table 4. Cattle grazing virtually disappeared over the course of the 20th century, while the importance of fodder production increased, the roots of which go back to the end of the 19th century.

After the Velvet Revolution and the accession to the European Union (period VI), the reduction of agricultural land further accelerated. Moreover, agricultural land now also accommodated new cultivars grown as potential source of energy and fuel, whose share accounted for 15% of arable land in 2010 and 11% of agricultural land. Simultaneously, the extent of permanent grasslands increased again as a result of a general stagnation of agricultural

Tab. 3 Average yields in kg fresh weight/ha.

Period	Cereals	Roots and Tubers	Fodder Plants	Oil Plants	Permanent Crops
I. 1830–1848	805	3,717	7	–	–
II. 1848–1900	1,035	8,331	6	–	3,124
III. 1900–1914	1,518	16,357	175	–	27,823
IV. 1918–1937	1,059	17,898	3,393	169	29,069
V. 1945–1989	1,333	21,817	5,343	1,048	18,307
VI. 1989–2010	1,420	35,324	6,164	2,478	12,598
Water content (%)	14	88	14	12	98
Energy content MJ/kg (dry matter)	18.3	16.3	18.5	25.0	2.9

Tab. 4 Average annual growth rates of agricultural products and agricultural area in %.

Period	Average yield from arable land	Cereals	Roots and Tubers	Fodder Plants	Oil plants	Other Crops	Permanent Crops	Arable land	Agricultural land
I. 1830–1848	1.4	1.5	-0.6	-0.7	-	1.6	0.0	0.18	0.16
II. 1848–1900	0.6	0.3	2.1	2.7	-	0.4	0.0	0.03	-0.11
III. 1900–1914	2.6	4.2	2.3	-1.0	-	4.1	0.0	-0.02	-0.02
IV. 1918–1937	1.7	3.2	3.6	2.5	0.9	-	-	0.05	-0.10
V. 1948–1989	1.7	2.9	2.5	3.3	5.3	9.3	-0.6	-0.09	-0.21
VI. 1989–2010	-1.5	-0.3	2.3	-0.9	0.6	-4.2	-7.8	-1.26	-0.75

Source: own calculation. See the text. Note: "arable land" includes arable land and permanent cultures, while the "agricultural area" includes all arable land plus meadows and pastures.

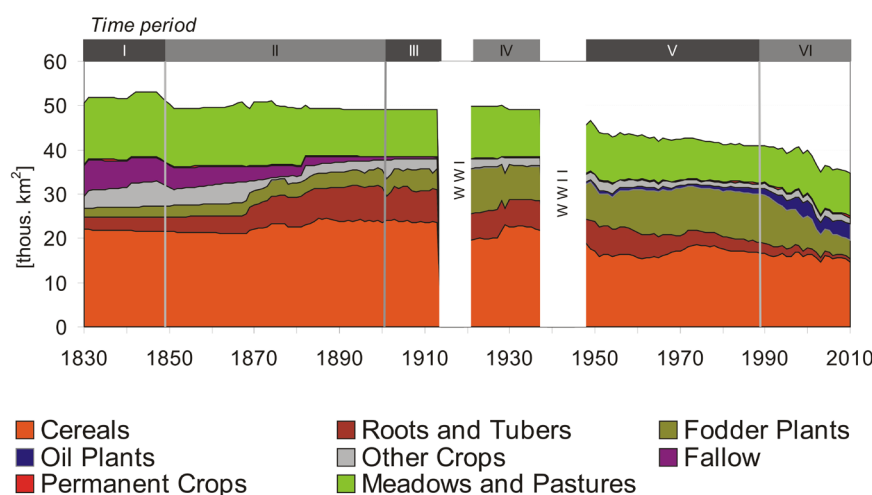
production and the elimination of subsidies on intensive agricultural production in naturally less favourable areas (Figure 2; Bičík, Jančák 2003; Bičík et al. 2001).

The size of land taken up by cereals proved to be the most stable at 40–50% of all agricultural land over the entire observed period, with a slight yet steady decline in its extent starting in the second and third decades of the 20th century and continuing until present day. In the 19th century (periods I–II), however, the size of agricultural land taken up by cereals was on the rise, along with the overall extent of arable land. This was associated with the aforementioned onset of industrialization and the transition towards more sophisticated forms of crop rotation with beets and forage replacing fallow. The end of the 19th century (period II) saw a rise in the importance of areas used for the production of animal fodder, forage crops, and root-crops. These areas had risen from roughly 10% at the beginning of the 19th century to approximately a quarter of all agricultural land by the beginning of the 20th century, after which it continued to grow until it reached over 30%. This share remained constant until 1989, when it started to decline rapidly in period VI until it has reached its current value of 14%. On the other hand, the share of oil plants has increased significantly during the latest stage (periods V–VI) and currently covers 11% of agricultural land. After cereals (over 40%) and permanent grasslands (approx. 1/3), oil

plants now take up the third most significant share in the agricultural land structure.

2.2 Agricultural production and livestock numbers

Agricultural production was primarily concentrated in more fertile areas throughout the time period and, with the exception of some brief periods, increased as a result of new technologies and improved agricultural techniques. The structure of agricultural production significantly shifted away from a predominantly crop oriented production towards an emphasis on livestock production, which was also reflected in the increasing production of fodder crops. The development of domestic extraction (DE) of biomass is recorded in Figure 3. We can observe a drop in production during an agricultural crisis in the sixth and the seventh decade of the 19th century, from a value over 210 PJ/yr by roughly 30 PJ/yr (period II). This is followed by a period of growth which lasted, with the exception of the duration of world wars, until the late 1980s, when it reached values between 450 PJ/yr and 488 PJ/yr (period V). In period VI, a massive drop in production brought these values down to around 350 PJ/yr. This drop was associated with a re-structuring of agriculture, scaling back of agricultural subsidies, and the collapse of markets previously secured by the COMECON (Bičík, Jančák 2003, 2001). Together with the application of artificial

**Fig. 2** Land use, 1830–2010.

Source: own calculation. See the text.

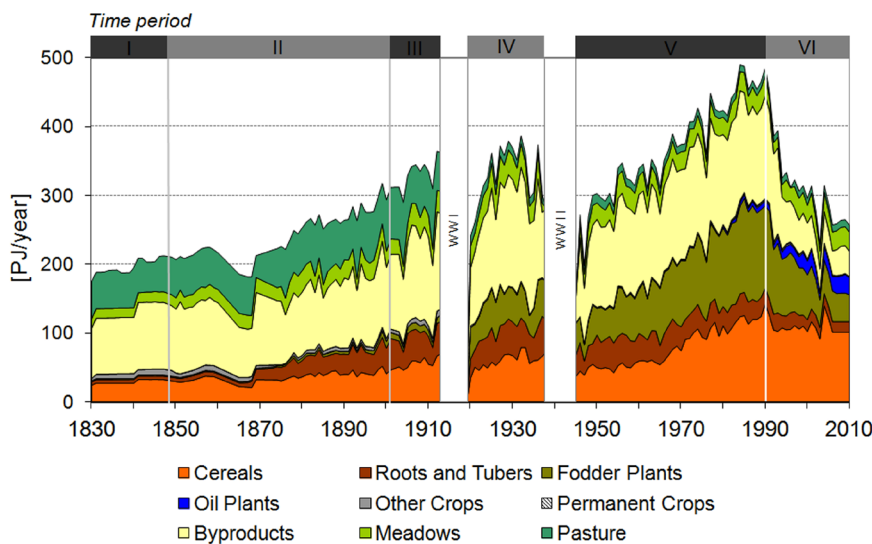


Fig. 3 Domestic extraction (DE) of agricultural biomass, 1830–2010. Source: own calculation. See the text.

fertilizers, whose use reached its peak in the 1980s, new approaches and technologies also facilitated an increase in the intensity of livestock husbandry (Figure 4).

Over the observed timeframe, cereals have undoubtedly been the most significant type of crop, which is demonstrated by the recorded volumes of their production (Figure 3). Cereal straw has subsequently represented a significant portion of agricultural by-products. Pasture played an important agricultural role in the 19th century, when it existed alongside the three-field agricultural system. However, by the 20th century, a significant portion of animal fodder was already produced in the form of crops. The production of roots and tubers reached significant volumes by the second half of the 19th century, despite the fact that their productive yield grew more slowly than was the case with fodder crops.

In the period I, cattle was primarily used to perform work or for milk production, while the production of meat was of secondary importance. This started to change during the period II, when the number of cattle, here expressed in livestock units per unit area (in

this case the area of Czechia) began to rise dramatically except for temporary declines. The transition towards livestock production was further facilitated by an agrarian crisis of the late 19th century and the competition with cheap American grain flooding the world market. This trend continued until the second half of the 1980s. With the rising yields and production, cereals and other crops were available to feed livestock. This was one of the preconditions for the observed surge in animal production. With the disintegration of the collectivized planned production units in the early 1990s (period VI) the production of most kinds of livestock downright collapsed. Pig husbandry was affected somewhat less significantly than was the case with beef-cattle (which returned to the values from the first half of the 19th century) and, even more strikingly, sheep and goats. On the other hand, the onset of industrial production contributed to a rise in poultry farming by the factor of 4 in the period V (originally mostly produced domestically and not accounted for statistically) all the way up to 4 LSU/km² in by the 1980s. However, even poultry farming experienced

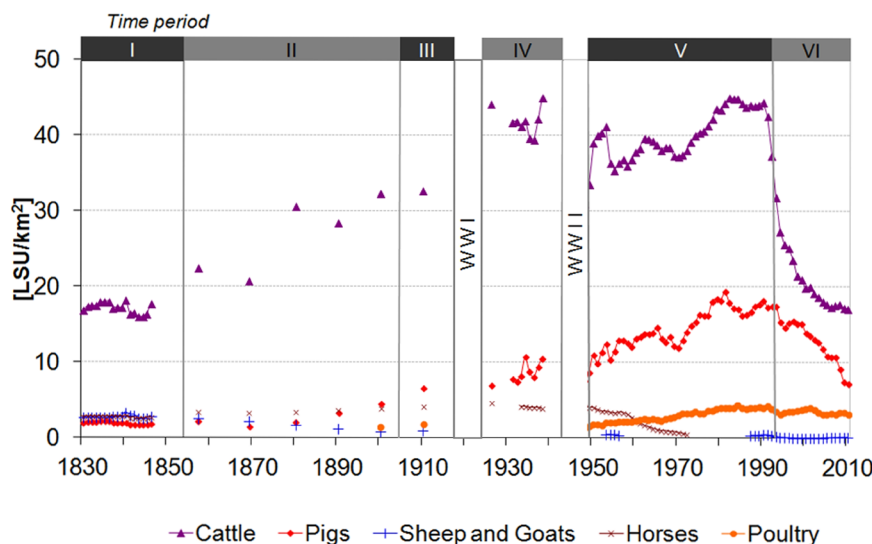


Fig. 4 Livestock density, 1830–2010. Source: own calculation. See the text.

a decline in the aftermath of 1989 (period VI) and currently stands at 3 LSU/km².

2.3 Yields

Yield, meaning the volume of production relative to the production area, is an important measure of the level of intensification and advancement of agricultural production. For example, before 1848, cereal yields were about only 0.5 t/ha and only approximately three times higher than the seed volumes (Beranová, Kubačák 2010). Until the second half of the 19th century, Czech agriculture was dominated by the three-field system typically combining two cereal crops with a year of fallow (or rotating field system), which was eventually replaced by more sophisticated forms of crop rotation and the use of artificial fertilizers. Agricultural yields kept growing throughout the entire observed period, except after 1989, when the overall decline in agricultural production also affected production per area (see Figure 5). Overall, during the observed timeframe, average crop yields have increased. While actual crop yields of cereals increased by a factor of 6, average biomass yield on agricultural land rose only by a factor not much higher than 3.

This value takes into account the drop in yields which occurred after 1989 and affected all plant yields with the exception of oil plants and root plants. Currently, average yield oscillates between 5 and 10 TJ/km².

The values of average yearly yield growth for individual plant types over the observed periods are presented in Table 4. On closer inspection, we can observe that different periods feature somewhat diverging trends. During the first half of the 19th century (period I), yield growth was relatively slow and primarily pertained to cereal crops (the average annual growth rate of their yields was 1.5%). New crops, especially fodder crops, gained significance during the second half of the 19th century (period II), during which their yields grew by 2.7% per year on average. Root vegetables reached a yield growth of 2.1% per year in the same time period. At the beginning

of the 20th century (period III), the growth in yields of all observed plants further accelerated (while the table seems to indicate a slower growth in the yields of fodder crops, some fodder plants are included in the category of “other crops”). In period III, cereal yields grew particularly fast, reaching an average growth rate of 4.2% per year. The IV experienced further increasing growth primarily thanks to increased mechanization or agriculture and the use of chemical fertilizers. This period also saw the introduction of larger quantities of oil plants, which were to rise in prominence later. Between 1918 and 1937 oil plant yields had increased by 0.9% every year on average. This growth continued by an average value of 5.3% per year during the post-war period (period V). The 1990s, period VI, represent a decisive turning point in regards to agricultural yields. Overall harvest yields have since declined by an average value of 1.5% per year. Only the yields of oil plants (0.6%) and roots and tubers (2.3%) have continued to experience growth.

Figure 6 shows changes in crop yields and in the use of artificial fertilizers over the observed time period. 1937 (shortly before the beginning of WWII) was chosen as the original reference year. At this point, agriculture was still primarily based on family farming and small scale land ownership, although cooperative farming and mechanization of production were already on the rise. Fertilizers have been in use since the mid-19th century. The application of fertilizers in Czechia particularly increased after the 1880s mainly alongside a growing production of sugar beet (Mayhofer 2014). However, reliable data on their application are only available since the third decade of the 20th century when mineral fertilizer started to be used on an important scale. If we consider the observed timeframe as a whole, like production, yields were growing continuously, except for limited intermissions cause by the world wars. However, the collapse of socialism in 1989 represented a decisive turning point, after which yields have declined by roughly a third of their maximum value from the 1980s. While the maximum yields achieved in the 1980s represented approximately a 100%

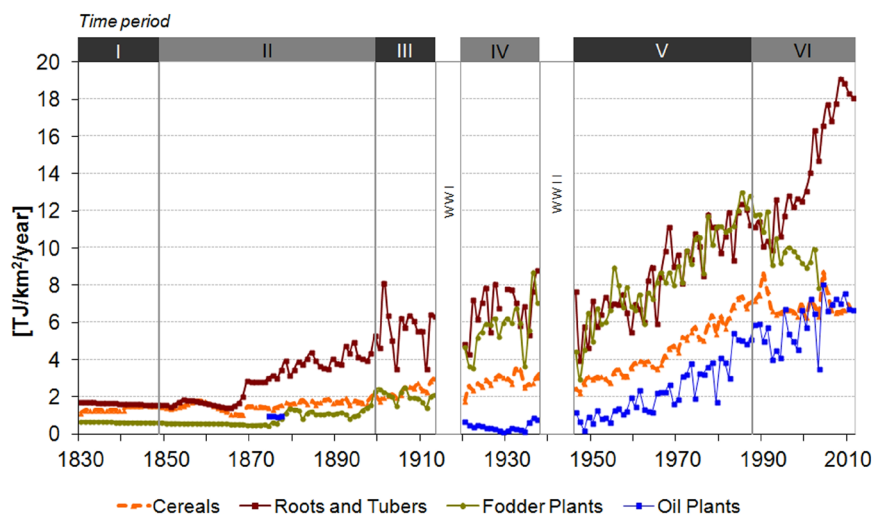


Fig. 5 Yields, 1830–2010.

Source: own calculation. See the text.

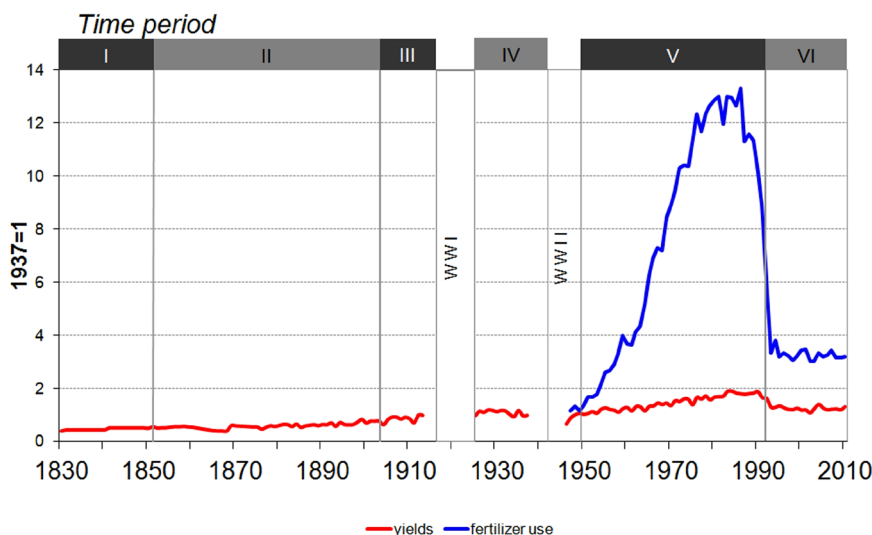


Fig. 6 Yields and fertilizer use, 1830–2010. Source: own calculation. See the text.

increase over maximum yield values recorded in the interwar period, the application of artificial fertilizers had increased much more in the same period: the use of artificial fertilisers had increased by a factor of 14 (period I–V), and by a factor of 13 during the first four post-war decades (period V). While the amount of biomass extraction per unit of artificial fertilizer application declined strongly in the first decades after WWII, it remained relatively stable between around 1970 and today at around one GJ per ton N applied.

2.4 International trade

Advances in agricultural production, such as increases in yields, produced volumes, or improvements in the storage, refinement or transportation of produce were accompanied by growing opportunities for agricultural trade. Since the mid-19th century, Czech agriculture started to integrate into, and thus to be influenced by, international trade structures. However, especially certain parts of Moravia had supplied neighbouring lands with various products even before (for example Vienna and other regions in the Habsburg Empire). Unfortunately international trade statistics only provide data pertaining to sovereign states, wherefore specific data for the territory of Czechia is only available for the period after the breakup of Czechoslovakia in 1992/3. Prior to the establishment of the Czechoslovakia (1918), Czechia conducted trade almost exclusively with other regions of the Habsburg Empire. We do, however, present net trade per person data for Czechoslovakia since 1920. All values until 1992 pertain to the former Czechoslovakia, while data since 1993 is recorded for the Czech Republic. While these data do provide some insight into long-term changes in the importance of foreign trade for Czechia's agricultural energy metabolism, we need to be aware of the caveats of shifting system boundaries: (1) the assumption that foreign trade with Czechoslovakia was distributed evenly between Czechia and Slovakia

may be flawed and thus average values may not be accurate for Czechia, and (2) before 1992, exchange processes between Czechia and Slovakia are by definition not considered foreign trade, but they are so thereafter. This may naturally increase values after 1993, even without actual changes in the transfer of biomass.

Figure 7 captures distinct differences between the individual historical periods and, to an extent, reflects the changes in agricultural structure described above. Prior to WWII, the primary focus seems to have been on the attainment of food self-sufficiency, with sugar, extracted from domestically grown sugar beet, being the only heavily exported commodity. The import of grain, predominantly during the 1920s, was caused by its falling prices at the world market. Grain, like meat, was primarily imported from the USA. Such imports have come to halt, however, with the economic crisis of the 1930s and the imposition of import tariffs. The post-war period (period V) brought along further intensification of production, an increase in the production of meat, and imports of feed (mostly in the form of cereal grains) from the Soviet Union. During the last 20 years (period VI), after the separation of Czechia and Slovakia, we have witnessed further integration into global market. While imports have still been mostly dominated by feed crops, they have also come to include fruits, vegetables, and meat, whereas cereals have increasingly become an export commodity, in all likelihood as result of changes in feeding practices and the overall decline of livestock production.

Figure 8 clearly captures the distinct character of the identified historical periods of the 20th century (period IV–VI). Throughout the second and third decade of the 20th century (period IV), both import and export were relatively balanced and never exceeded a level of 8% of Domestic Extraction (DE). After WWII (period V), the share of imports had risen sharply, reaching its peak at 10–12% in the 1970s–80s with the peak of industrial livestock production in the planned economy. At the same time, shares of agricultural exports on DE remained

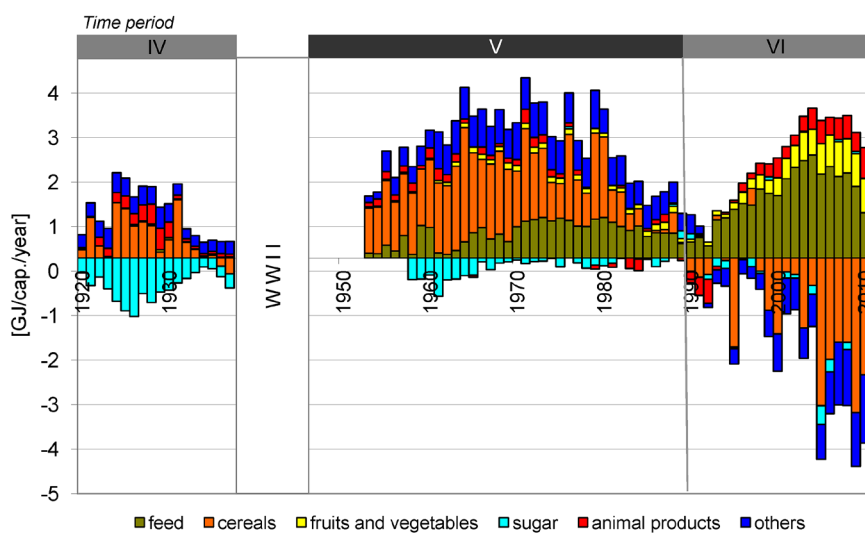


Fig. 7 Physical trade balance per capita per year, 1920–2010 (import is + and export –). Source: own calculation. See the text. Data until 1992 refer to Czechoslovakia, data from 1993 onwards refer to Czechia.

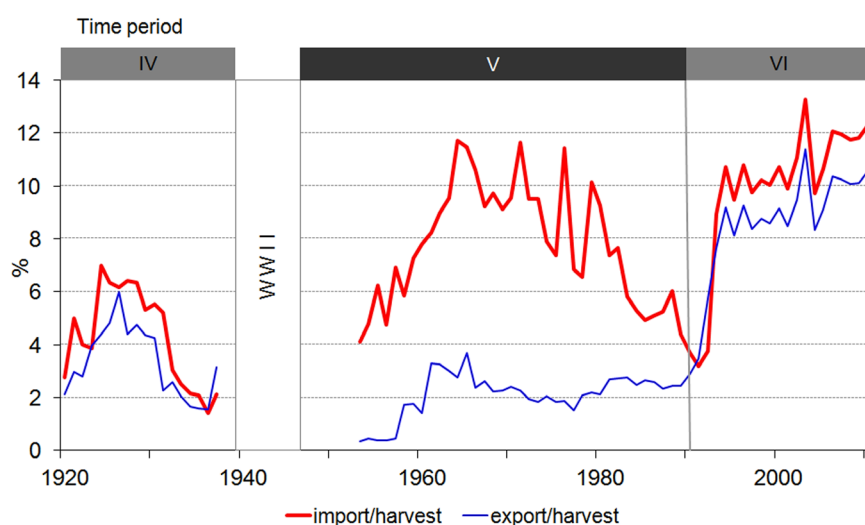


Fig. 8 The relation of import and export to harvest (DE), 1920–2010.

Source: own calculation. See the text. Data until 1992 refer to Czechoslovakia, data from 1993 onwards refer to Czechia.

below 4%. As is the case with most other indicators, also this trend changed significantly after 1989 (period VI). Since then, both shares have gone up and consistently exceed 10%. While this may be partly due to the inclusion of trade between the new Czechia and Slovakia in foreign trade after 1993, we argue that the increasing relative importance of foreign trade is also linked to the fact that Czech agriculture is significantly included in the European and global market. If, however, we take a closer look at the previous graph, it becomes apparent that Czechia exports resources and imports products with higher added value, with little benefits to both Czech agriculture and the Czech economy as a whole.

3. Summary and conclusions

The six phases of the development of Czech agriculture during the last almost 200 years summarized in Table 1 reflect fundamental societal changes in socio-economic and political organization and technological development. This study is premised on several principal research questions: How has the agricultural

system been affected, from a biophysical perspective, by large-scale economic, political or technological changes, such as the onset of industrialization in the 19th century, ongoing mechanization and changes in land ownership, collectivization in the aftermath of WWII, and the privatization of previously state controlled and collectivized assets after 1989.

In the period I, Czech agriculture was predominantly extensive in character. This began to change with the onset of industrialization by the mid-19th century, with changes in land ownership and the gradual expansion of the international market with agricultural products playing an important supporting role in the process. Imports of cheap grain from the USA were partially responsible for the outbreak of the agricultural crisis in the late 1870s. The agricultural system reacted by a shift towards livestock production and also more globally competitive crops, such as sugar beet or (in significantly smaller quantities) hop (*humulus sp.*) (period II). With the exception of drops caused by the two world wars, production volumes grew at varying speed throughout the entire observed timeframe. Agricultural mechanization was also accompanied by the implementation of chemical treatments,

which paved the way for unprecedented increases in crop yields during the post-war (V) period. During 35 years (1955–1990), crop yields had effectively doubled; however, this was largely due to massive application of artificial fertilizers and agrochemicals. Indeed, at the end of this period, the use of artificial fertilizers was thirteen times higher than it had been in 1955. The values of most observed indicators reached their maximums in the 1980s (period V), and experienced a sharp fall in the period VI after 1989. This decline and stagnation persists until present day (except for the production of oil plants). This trend also applies to harvest values (DE) and in particular to the numbers of livestock.

The analysed 180 years featured many socio-economic changes and particularly changes of political regimes, which profoundly affected the energy profile of the system's metabolism. This was perhaps best reflected in the excessive path of large scale agricultural industrialization and the associated environmental damages caused during the so-called "communist period" (Vavroušek 1994). The sudden change of the political system after 1945/48, which forced a reorganization of agriculture (in terms of both ownership and capital) and a general re-structuring of production, had a detrimental effect. For example, after WWII, it was not until the 1960s that agricultural production reached the same level it had in the 1930s, although the agricultural system had not been damaged by the war nearly as much as it had been in the neighbouring countries. Collectivization caused a number of negative phenomena, many of which endure into present day (impacts on landscape caused by the unification of parcels, melioration, and excessive use of chemical treatments, as well as social problems such as the collapse of traditional rural communities).

Over the observed period, the metabolism of Czech agriculture, shifted away from a form still partially dependent on a solar system bound to a production area (sustained by human labour and the work of biomass-fed animals) towards a form largely dependent on the inputs of fossil-based energy (for more information see Kušková et al. 2008; Kušková Grešlová 2013; see also Krausmann et al. 2008b). This new mode of organization of agricultural production can be characterized by open cycles of nutrient and biomass flows, whereas the land-bound mode was, with respect to materials largely closed (of course, this transition was allowed not only by the introduction of fossil-based energy inputs, but also by an expansion of agro-economic and agro-technological knowledge, as well as the spread of modern technologies). Czech agriculture is increasingly influenced by the world trade. This is, in fact, the case to such an extent that it could be argued that world trade currently plays a dominant role in its further development. The material and nutrient cycle is currently more open than it has historically ever been.

At the beginning of the 21st century, Czechia exports resources (especially cereals and oil plants) and imports

products with higher added value (meat products), which is detrimental to the agricultural system and all social structures immediately associated with it, as well as to the Czech economy as a whole. With the exception of the first two observed decades (period I), the decline in the extent of agricultural land (recently particularly intensified) serves as a unifying element of the entire analysed timeframe. The current acceleration of this process is due to a relaxation of laws which protected agricultural land, a drop in production volumes (brought about by subsidised imports from the EU and elsewhere), and lack of capital, which can (from the standpoint of economic logic) only be invested into the most fertile land. During these changes, agriculture lost large numbers of workers, who mostly went into industrial production (Jančák, Götz 1997). These workers did not, however, include only farmers, but also significant numbers of employees of dissolved "associated production cooperatives", which were often industrial in character. Despite massive industrialization, modernization, and regular increases in production, Czechia never achieved self-sufficiency in regards to the production of livestock feed. The production of large numbers of cattle during the post-war period was possible only on the basis of substantial imports of feed, especially cereal grains. Even though the number of cattle and pigs has since decreased by more than half, it is currently responsible, for example, for an increase in the import of protein feed (soy) from the USA and Latin America.

The 1970s and 1980s represented the most intensive period in regards to agricultural production and energy outputs. This was, however, accompanied by detrimental environmental effects including soil erosion, ground water pollution, loss of habitat for many plant and animal species. For current Czechia, which is tightly integrated into the European and global market, food self-sufficiency is not a political priority, wherefore the competitiveness of Czech agriculture is confronted with cheap and heavily subsidised imports. The overall extent of arable land continues to decline, especially in less fertile hillside territories, which, however, also carries a positive environmental impact (e.g. reforestation, extensification). The changing role of agriculture makes it increasingly possible to push ahead with construction development even on the most fertile agricultural land, which is, from a long term perspective, unsustainable. If we chose to argue that the flows of materials and nutrients are opening up and lose their attachment to the observed area, the reasonable conclusion would be that a similar case might apply to socio-economic cycles, workforce and capital flows, specifically. Currently, agricultural production is dominated by large profit-oriented enterprises which only represent 5% of all agricultural subjects, yet occupy over 75% of agricultural land. Czech agriculture is currently in historically the weakest position to fulfil its role as its country's principal source of food production.

On a more general level, the research presented in this article sheds light on the long-term interrelations

between political or institutional change on the one hand and changes in the biophysical functioning of agriculture on the other. We find that over long periods, changes in the political and institutional framework conditions followed a different temporal pattern than agricultural change. Some historical events like the crisis of the 1870s, the world wars and particularly the collapse of the planned economies of the Eastern Block obviously left their imprint on land use and particularly agricultural production. Yields were lower after wars, croplands abandoned, livestock numbers reduced. However, with the single exception of the collapse of the Soviet Union and the following disintegration of Czechoslovakia and the shift from a planned to a market economy, these events did not hamper long-term trends of increasing agricultural production and land-use intensification. After WWI, biomass extraction soon reached the levels of the Habsburg Monarchy. And, quite surprisingly, the political regime of state socialism actually produced agricultural industrialization patterns which were possibly less economically efficient and more ecologically harmful, but from a socio-metabolic perspective very similar to those observed in Western European countries in the postwar-period (e.g. Krausmann et al. 2012). Niedertschneider et al. (2014) who investigated the case of Western and Eastern Germany came to a similar conclusion. Maximizing agricultural output was an aim reached by ideologically very distinct political leaderships and fundamentally different economic regimes in similar ways. From the perspective of long-term socio-ecological research, technological and energetic constraints seemed to have a stronger effect on agricultural intensification than specific political measures or events.

The events after the Velvet Revolution (1989) might be the signs of an ongoing transition from the previous state of the system to a new one connected with global material and biomass flows. In many Eastern European countries, a similar break-down of the agricultural production system (and in particular the livestock sector) can be observed as well (e.g. Kolheb, Krausmann, Schaffartzik et al. 2014). While a general de-intensification can be observed also in other parts of Europe towards the turn of the millennia, the situation in Czechia points to a different issue: agriculture was completely restructured under the changing political-economic conditions. Livestock numbers as well as agricultural productivity reached levels which were one third or more below the values of just two decades earlier, and only one third higher than in the early 19th century. While Czechia did not suffer from long-term lack of food supply after the 1989, the change in agricultural production may have been connected to efficiency gains e.g. in the livestock sector, and was tightly linked to changes in foreign trade. The impact of the collapse of the Soviet Union on the global biomass supply countries exporting food to the former Eastern Block is an important issue for future research.

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RESUMÉ

Sociální metabolismus českého zemědělství (1830–2010)

Prezentovaný výzkum sleduje vývoj českého zemědělství v posledních téměř 200 letech. Objasňuje dlouhodobé vztahy mezi politickými a institucionálními změnami na jedné straně a změnami v biofyzikálním fungování zemědělství na straně druhé. Příspěvek se snaží odpovědět na výzkumné otázky, jak ovlivnily z biofyzikální perspektivy zemědělskou soustavu hlavní strukturální změny jako: počátek industrializace v 19. století, pokračující mechanizace a změny v držbě půdy, kolektivizace po 2. světové válce a transformace po roce 1989. Analýza vychází z konceptu

sociálního metabolismu a metod hodnocení materiálových a energetických toků. Kvantifikuje následující indikátory: vývoj využití území, domácí extrakce biomasy, výnosy zemědělských plodin, vývoj počtu hospodářských zvířat, fyzická bilance zahraničního obchodu. Výsledky jsou vyjádřeny v jednotkách energie (Jouly) a tzv. velkých dobytčích jednotkách na plochu. Jmenované ukazatele interpretujeme v širších socio-ekonomických souvislostech.

Na počátku sledovaného období mělo české zemědělství spíše extenzivní charakter. To se měnilo společně s nástupem industrializace v polovině 19. století, kterou výrazně urychlily změny v držbě půdy a postupný rozvoj mezinárodního obchodu se zemědělskými produkty. Dovoz levného obilí z USA byl jedním z faktorů, který zapříčinil nástup zemědělské krize. Reakcí zemědělského systému byl rozvoj živočišné výroby a postupné zavádění plodin, které byly světově konkurenceschopné (např. cukrová řepa, chmel). Až na propady během války lze sledovat trvalou rostoucí objem produkce i výnosů s různou rychlostí během studovaných period. Podobně jako v případě výsledků předchozích výzkumů dosahuje většina sledovaných indikátorů maximálních hodnot v 80. letech 20. století a po roce 1989 nastává jejich prudký pokles. Stejný trend se projevil i u sklizně zemědělských plodin a počtu chovaných zvířat. Ruku v ruce s mechanizací šla chemizace zemědělství, což umožnilo nevídaný růst výnosů v poválečném období. Během pětaticeti let (1955–1990) se výnosy plodin zdvojnásobily, což však bylo doprovázeno růstem používání průmyslových hnojiv přibližně třináctkrát větším než na počátku tohoto časového intervalu.

Metabolismus českého území a tím i českého zemědělství ve sledovaném období přešel z formy závislé na solárním systému a vázané na produktivní plochu (práce zvířat krmených biomasou)

do formy závislé na vstupech fosilní energie a zejména na vnějších vstupech a výstupech v podobě začleňování zemědělství do mezinárodního obchodu. Tato forma organizace zemědělské výroby může být charakterizována otevřenými cykly toků živin a biomasy, zatímco forma vázaná na plochu byla prakticky uzavřená. České zemědělství je stále více ovlivňováno zahraničním obchodem a lze tvrdit, že zahraniční obchod hraje v současnosti dominantní úlohu. Cyklus živin a materiálů je nyní otevřen nejvíce v historii. Na začátku 21. století vyváží Česko suroviny (zejména obilniny) a dováží produkty s vyšší přidanou hodnotou (masné výrobky), což má pro zemědělský systém (a na něj navazující sociální strukturu) minimální výhody, stejně jako pro celou českou ekonomiku.

S výjimkou zhruba prvních dvou sledovaných dekád je pro celé sledované období charakteristický pokles rozlohy zemědělské půdy, který je v současnosti ještě zesílen. Navzdory masivní industrializaci, modernizaci a růstu zemědělské produkce nebylo Česko v produkci krmiv pro hospodářská zvířata nikdy soběstačné. Udržování vysokých stavů dobytka v poválečném období záviselo na relativně vysokém objemu dovážených krmiv (zejm. obilovin). Dnes pak souvisí s růstem dovozu sóji, a to přesto, že jsou v Česku dnes stavy skotu a prasat poloviční.

V současnosti není prioritou české politiky zajistit spotřebu potravin co nejvíce z vlastní produkce. Proto je konkurenceschopnost zemědělství vystavena více dotovaným a tím levnějším produktům z dovozu. Tvrdíme-li, že se toky materiálů a živin otevírají a odpoutávají od zkoumaného území, docházíme k závěru, že stejně je to i s cykly socio-ekonomickými (pracovní síla, toky financí). Role českého zemědělství jako hlavního základny produkce potravin je tak v současnosti nejslabší v historii.

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