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THE IMPACT OF THE LITTLE ICE AGE ON WINTER WHEAT YIELDS IN THE CARPATHIAN BASIN IN THE FIRST HALF OF THE 19TH CENTURY

UTJECAJ KLIMATSKIH PROMJENA MALOG LEDENOG DOBA NA PRINOSE OZIME PŠENICE U PANONSKOM BAZENU U PRVOM DIJELU 19. STOLJEĆA

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Summary

The main focus of this study is to understand how weather and climate changes of the Little Ice Age in the first half of the 19th century affected the yields of winter wheat, the most important food crop in Hungary at that time and the country's main export item. In the Carpathian Basin, the impacts of the Little Ice Age were regionally specific. The research is based on a detailed analysis of the interactions between climate change and the phenological cycle of wheat in different regions. The study area is the territory of the Carpathian Basin, which includes Transdanubia, the Highlands, Transylvania, and the Great Hungarian Plain. Agriculture had a crucial role in traditional societies to allow subsistence, generate marketable surplus and contribute to political stability. Results highlight the vulnerability of agriculture to climatic and environmental changes. The presentation of risks posed by weather to winter-wheat farming in the Carpathian Basin revealed that cold and wet weather in October, cold March weather, and unfavourable conditions in May (dry, late frost, hail) and summer months (June: dry-hot, wet; July and August: wet) were the most decisive factors resulting in poor wheat harvests. Macroregional analyses shows that in the first half of the 19th century, wheat farming was riskier in the mountainous fringes of the Danube Basin, the Highlands, and Transylvania than in the Great Hungarian Plain. Three periods of countrywide wheat production crises were identified in the Carpathian Basin, with the most severe crisis occurring from 1811 to 1816, attributed to the Tambora volcano eruption in 1815. The interval from mid-1820s to early 1830s was the second period when wheat yields were predominately low. The wheat production crisis of 1845 and 1846 was particularly notable due to the accumulation of successive years of poor harvests. The temporal proximity of this food *crisis to the 1848 revolution is emphasized. In conclusion, the Little Ice Age had significant impacts on agriculture in the Carpathian Basin. Still, various weather factors influenced the macroregional and countrywide wheat production crises. Understanding the historical climate and weather patterns can provide insights into the vulnerability of agricultural systems.*

Keywords: climate history, environmental history, agricultural history, Hungarian reform era, subsistence crises, Carpathian Basin

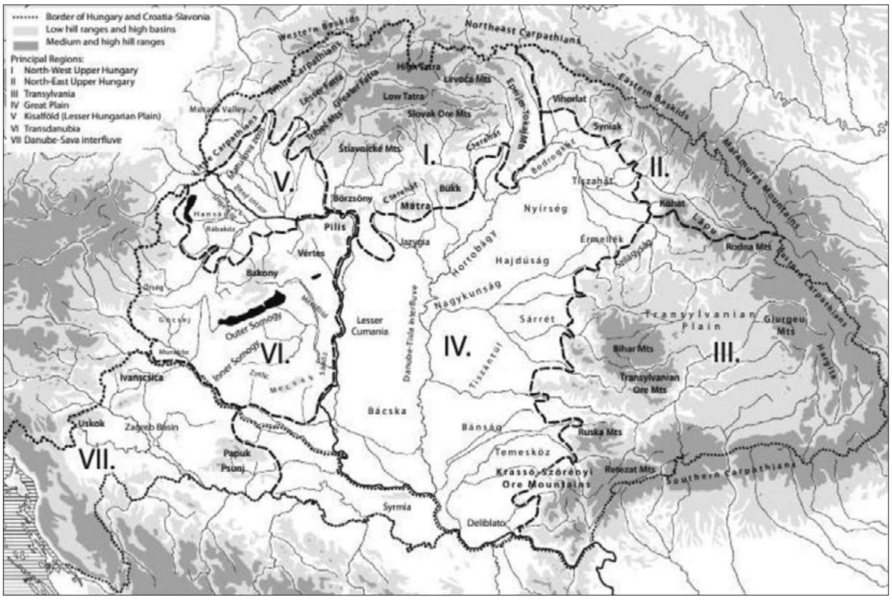
Ključne riječi: povijest klime, povijest okoliša, povijest poljoprivrede, mađarsko reformno doba, egzistencijalne krize, Panonska nizina

INTRODUCTION

I have been studying the climatic history of the Little Ice Age (14th–19th centuries) for more than three decades, but only in the last few years has my interest turned towards the impact assessment of climate change on agricultural production. Recently, I published my first century-scale overview of climate and environmental history (Rácz 2020), in which I examined the results of grain, hay and grape production in the Carpathian Basin from the 16th to the mid-19th centuries from the perspective of the Braudelian "longue durée" (Braudel 1969). During the course of my research, I arrived at the unexpected finding that the global cooling of the Little Ice Age in the Carpathian Basin not only did not, in general, cause severe agricultural damage, but the regional characteristics of climate change had a rather positive impact on agricultural production in some places. The main reason for this may have been that cooling in winter – or the winter half-year is of lesser importance as for the vegetation but the significant winter snow cover mostly protected the vegetation from freezing. The most important regional characteristic of the Little Ice Age was the increase in precipitation, which, for example, in Transdanubia and some areas of the Great Hungarian Plain, definitely improved the conditions for agriculture of the region (Rácz 1999, 2001). My surprising findings, drove me to the realisation that in order to explore and understand the interactions between the climate system and agricultural economy, it is necessary to do some "deep drilling" in environmental history. In this paper, I present the results of such an analysis, in which I examine Hungary in the first half of the 19th century. I conducted my analysis from the perspective of climate and environmental history in terms of Braudel's middle-term perspective (temps de conjoncture), paying special attention to the decades of the Hungarian reform era (1825–1848), which was of great importance for social and economic modernisation.

The principal question of my research is how weather and climate changes in the first half of the 19th century affected the yields of winter wheat, which was the most important and the best documented main food crop in Hungary during these decades, and the main export item of Hungary. However, I do not intend to analyse the impact of climate change on the Hungarian economy and society in this paper. In order to avoid meaningless generalisations, we must first clarify how the key crop produced by agriculture, which has been, to this day, the most vulnerable to the effects of climate change, responded to weather changes in different places in the study area and at different times, and how the interactions between climate change and the phenological cycle of wheat can be described. If this is not done, we can but remain at the level of cursory statements such as "the climate cooling of the Little Ice Age caused a decline in agricultural yields".

The region I examine is the territory of the Kingdom of Hungary, which I also refer to as Hungary orhistorical Hungary. In climate and environmental history, we distinguish between four macro-regions of the Carpathian Basin, namely Transdanubia [Hungarian name: Dunántúl], the Highlands [Felvidék], Transylvania [Erdély] and the Great Hungarian Plain [Alföld] (Map 1). The counties of the Kingdom of Hungary also appear in the analysis. Map 2 shows the administrative division (counties) in the first half of the 19th century.



Map 1. *Historical geography regions of the Carpathian Basin. Four macro-regions: Transdanubia (VI), the Highlands (I, II, V), Transylvania (III), the Great Hungarian Plain (IV) (Rácz 2013: 29).*

Map 2. *Counties of the Kingdom of Hungary in the 19th century (Source: https://hu.wikipedia.org/wiki/Magyar_Kir%C3%A1lys%C3%A1g#/media/F%C3%A1jl:Kingdom_of_Hungary_counties.svg; 24 April 2023).*

CLIMATE CHANGE AND AGRICULTURE

In the agricultural societies of the Ancien Régime, agriculture played a key role in sustaining social and political stability (Federico 2008; Van Cruyningen–Thoen eds. 2012). Depending on social-history context, consecutive years of poor harvests could often easily interfere with other social, economic and political crises, putting the affected rural area, region or country at risk of a great subsistence and political crisis (Alfani 2010; Campbell 2010; Pfister 2010; Dybdahl 2012; Gerrard–Petley 2013; Collet–Schuh eds. 2017.; Pfister–Wanner 2021). Weather patterns are crucial to the success of farming, and it is important to note that despite technological modernisation, the widespread use of fertilisers and pesticides, and the results of plant breeding, agriculture is considerably vulnerable to climatic and environmental changes even in the 21st century (Brázdil et al. 2019). There is no doubt that – with the limited technology, transport and storage facilities available in Ancien Régime – extreme weather and seriousclimate change that was unfavourable for agriculture posed a serious challenge to farmers in areas affected by poor harvests, and to the local society in general. Moreover, climate change does not only affect the development cycle of crops, but, due to the transmissions in agricultural economy, also other key fac-

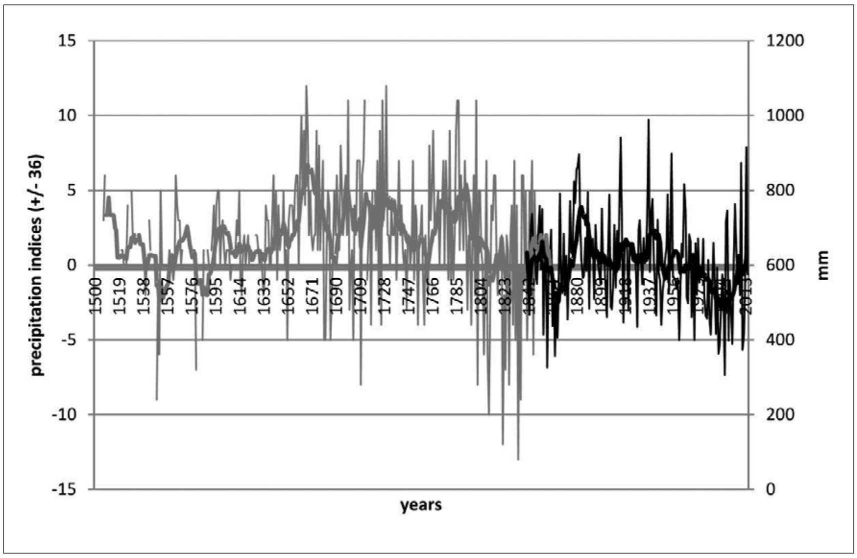


Figure 1. *Yearly precipitation time series of the Carpathian Basin from 1500 to 1850 based on documentary sources (grey line, scale of the left) and the instrumental time series of Budapest (black line), and its ten-year moving average (bold line, scale on the right). The yearly climate history indices are derived from monthly indices that may range from +3 (very wet) to -3 (very dry), and the yearly indices may change between +36 and -36. The indices of the time series are the author's research results. Note that the indices on the left axis do not correspond with mm on the right axis.*

tors such as the availability of animal power and human labour (Halstead–O'Shea eds. 1989; Ellis 2003; Vanhaute et al. eds. 2011). In the first half of the 19th century, however, farmers in the Carpathian Basin already had a number of solutions at their disposal to mitigate production risks. The spread of maize and potato from the mid-18th century onwards greatly diversified the structure of food crop production. Mixed sowing of wheat and rye mitigated the scale of harvest failure as they were not equally affected in many situations.

As Christian Pfister's and Heinz Wanner's findings suggest, the cooling in the Little Ice Age in Europe had four main peaks: around 1460, 1600, 1690 and 1825 (Pfister–Wanner 2021). According to the Swiss researchers, the cooling in much of the first half of the 19th century was partly caused by two volcanic eruptions of global significance (an unspecified eruption in 1809 and the eruption of the Tambora volcano in Indonesia in 1815) and by the Dalton sunspot minimum (1790–1830), which indicated a decrease in the Sun's radiant energy. The first half of the 19th century was one of the most extreme periods of the Little Ice Age both globally and in the Carpathian Basin. As extreme weather events, in particular droughts and periods of very high precipitation, were becoming more and more frequent, the risk to agricultural production also increased throughout Europe. In the Carpathian Basin, however, the global cooling of the Little Ice Age had a few important characteristics that were regional (Rácz 1999; Rácz 2020). Perhaps the most important of them was that the climate of the Carpathian Basin responds to global climate change primarily by a change in the amount and annual distribution of precipitation, with precipitation often increasing in times of cooling and decreasing in the periods of warming (Figure 1). Another important regional characteristic of the Little Ice Age was that the impact of global cooling manifested itself mostly in the winters and in the temperature variation in the winter half-year (Figure 2). Freeze damage, however, was prevented by the increased precipitation which manifested itself in the winters as well: the thick snow cover provided adequate protection for most crops, including winter wheat. Finally, the third important regional characteristic of global climate change in the Carpathian Basin was the change in the structure of seasons. The most striking sign of this was that March became more and more of a winter month during the Little Ice Age cooling (Figure 3), with ice covering the Danube at the end of the month at times, as it happened in the famous year of 1830 (Rácz 2014).

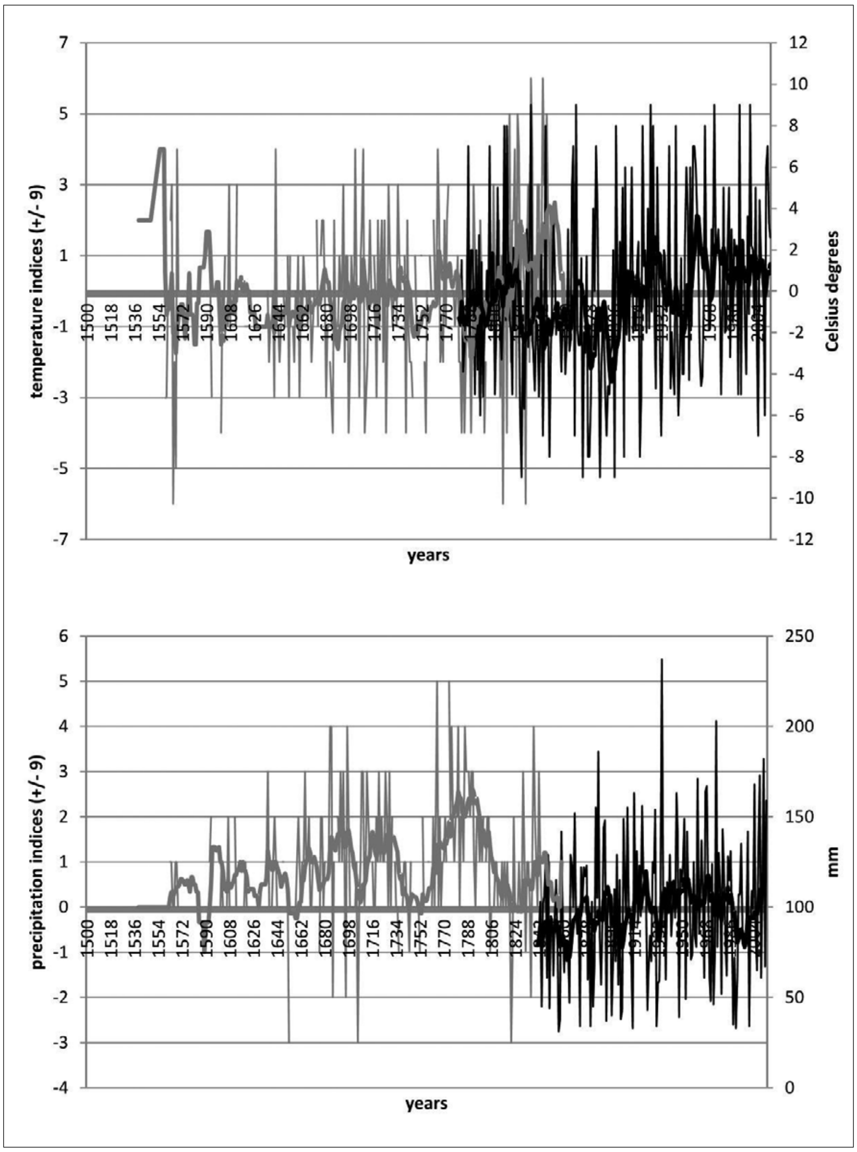


Figure 2. *Winter temperature and precipitation time series of the Carpathian Basin from 1500 to 1850 based on documentary sources (grey line, scale of the left) and the instrumental time series of Budapest (black line, scale on the right), and its ten-year moving average (bold line). The yearly climate history indices are derived from monthly indices that may range from +3 (very wet) to -3 (very dry), and the yearly indices may change between +36 and -36. The indices of the time series are the author's research results. Note that the indices on the left axis do not correspond with degrees Celsius on the right axis.*

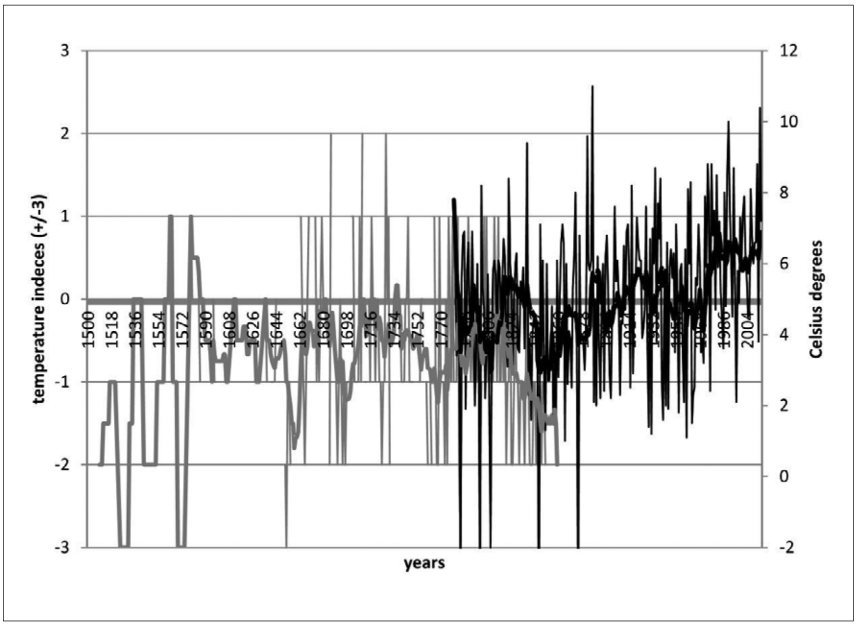


Figure 3. *March temperature time series of the Carpathian Basin from 1500 to 1850 based on documentary sources (grey line) and the instrumental time series of Budapest (black line), and its ten-year moving average (bold line). The indices of the time series are the author's research results. Note that the indices on the left axis do not correspond with mm on the right axis.*

PRODUCING WINTER WHEAT IN THE CARPATHIAN BASIN

The domestication of wheat took place in the Middle East sometime in the 6th millennium BC, and it is no coincidence that its bred varieties have become one of the most successful cereal crops of global significance in human history. One of the factors influencing on the success of wheat is its good storability and transportability, and another is its high nutritional value. Wheat bread contains almost all the essential chemical elements and most of the necessary vitamins, and people can survive on bread and water alone for long periods without serious damage to their health (Antal–Jolánkai eds. 2005: 165).

Wheat cultivation was first introduced to the Carpathian Basin before the Middle Ages. However, it is more likely that the occupying Hungarians cultivated barley and millet, as archaeological evidence suggests. It was only after the settlement and the emergence of the feudal system that wheat became the dominant cereal in the Carpathian Basin; the first record of wheat exports dates back to the era of Zsigmond (Sigismund von Luxemburg, 1387–1437). Most of the soils in the Carpathian Basin are suitable for wheat production, but the best yields are obtained on medium-textured grassland soils. During the Turkish wars (1526–1699), cereal production in the central Carpathian Basin decreased significantly and was replaced by extensive livestock farming, which was more suitable in times of low agricultural density and a marked market demand for cattle. At the time of the Treaty of Szatmár (1711), in a specific demographic situation a decade after the ferocities of the Great Turkish War and just after the end of a civil war in Hungary (1703–1711), Tamás Faragó estimates the population of the Kingdom of Hungary to be slightly under 4 million (Faragó 2013). According to the 1787 census, the combined population of Hungary, Croatia, Slavonia and the Military Frontier was 7.82 million, and 9.46 million with Transylvania included. By 1851, the total population of the Kingdom of Hungary would grow to 13.19 million (Glósz 2014: 36). As there were no fundamental innovations in farm management and technology in the first half of the 19th century to transform the country's agriculture, agricultural production, applying the three-field system, could most easily grow by increasing the area under cultivation. In the first half of the 19th century, cropland increased by only 3–5.5% in the mountainous areas, however, growth in the Great Hungarian Plain was much more dynamic, with the area of arable land increasing by one-third (31.4%) in Pest County and by two-thirds (71.6%) in Heves and Szolnok Counties. Zoltán Kaposi estimates the increase in arable land to be 35–40% over half a century for the country as a whole (Kaposi 2000: 100). Throughout the 19th century, it was cereals, among agricultural crops, that were grown in the largest area, regardless of changes over time. While tobacco and wine were mainly grown on peasant farms and wool was largely produced by large estates, cereals were grown on the parcels where the yields belonged to all kinds of social strata. Wheat was in growing demand both in Hungary and in other countries, as a foodstuff, animal feed and industrial raw material (Glósz 2014: 15).

In the first half of the 19th century, the word cereal was used in a very broad sense by contemporaries, who considered any crop that was consumed as a staple food in a given region to be a cereal. In this sense, corn and sometimes even potato were also considered as cereals in addition to winter and spring wheat, rye, barley and oats (Fónagy 1998: 48). Imre Wellmann estimates that, around 1780, wheat and rye accounted for 55% of the total cereal production (Wellmann 1989: 955). According to data from 1828, István Orosz put the share of cereal grains at 43% of the total production (Orosz 1996: 121), which, according to József Glósz, did not exceed 44% even in the mid-19th century (Glósz 2014: 35). In the agriculture of the time, there was a certain hierarchy of cereals, with noblemen, citizens and wealthy peasants eating daily bread made from wheat, the average peasant from wheat–rye maslin, while those in the poorer regions from rye. Wheat was produced for commerce, while wheat–rye maslin and rye were grown exclusively for local and home consumption. The most important wheat-growing areas were the Little Hungarian Plain [Kisalföld], the Transdanubian region near the Danube, the Bácska and the Bánát, and the Central Tisza region. It was not only their soil conditions that made these areas particularly suited to wheat production, but local farmers also took it into account that the proximity of navigable rivers provided favourable conditions for the commercialisation of wheat. In this way, the possibility of selling wheat on the market greatly influenced the expansion and extension of the area under wheat. According to József Glósz, the growth of cereal production in general, and wheat production in particular, was stimulated mainly by the expansion of the internal market in the first half of the 19th century (Glósz 2014: 32).

CLIMATE AND ENVIRONMENTAL CONDITIONS OF WINTER WHEAT

Concerning the weather and environmental conditions of wheat cultivation, we can draw on both contemporary historical records and the research findings of modern agronomy (Rácz 2019, 2020). In their diary entries and correspondence, farmers in the traditional world often discussed the weather and environmental conditions that hindered or supported cereal production. It was a common belief among contemporaries that the greatest hazard threatening soil preparation, ploughing and harrowing in October was wet weather. Especially if we consider that in the Carpathian Basin there were approximately 25,000–26,000 km^2 of permanently or temporarily flooded land, mostly in the Great Hungarian Plain. These areas were also regarded as unfit for commercial traffic, which was a major incentive for the Tisza Valley landowners to support water regulation plans (Pinke 2015). But returning to contemporary records, the cold March weather hampered the development of all forms of vegetation, reducing the prospects for cereal and, in particular, wheat yield. Dry weather in May could also hamper the development of cereals, while frost and hail could cause serious damage to sowings. Both the quantity and quality of the ripening cereals were affected by extremely hot and dry weather or by rainy weather in June. However, at harvest time, in July and August, it was only rainy weather that could have had a negative impact on the yield. It is apparent in the historical records that the role of the distribution, absence or excess of precipitation was much more important for cereal yields in the Carpathian Basin than temperature variation (Table 1).

Critical months	Harmful weather for winter wheat
October	wet
March	cold
May	dry, late frost, hail
June	dry-hot, wet
July	wet
Augusts	wet

Table 1. *Fundamental impacts of weather in critical months of the vegetation period on winter wheat in the Carpathian Basin.*

Let us also examine what views modern agronomy holds about optimal yield prospects for winter wheat (Antal–Jolánkai eds. 2005: 172). In most of the Carpathian Basin, the climate is suitable for winter wheat, which can safely survive in temperatures ranging from –20 to +40 °C. As for precipitation, it requires a minimum of 300–350 mm of rainfall, but needs 500–600 mm for optimal growth. In winter, temperatures below –20°C can be critical, and without snow cover, not even highly frost-tolerant varieties can survive without damage. Plant mortality can also be caused by heavy frosts in late winter and early spring, and by prolonged winter weather. Moderate warm spring weather is ideal for the development of winter wheat, while dry, warm weather after flowering can greatly facilitate the development of a good quality grain yield; heatwaves in June, however, can cause grain shrivelling. The amount and timing of precipitation during the growing period largely determine the quantity and quality of the wheat harvest. Dry autumn weather can lead to uneven and slow germination and early development problems, which can adversely affect wheat overwintering. Dry spring weather and especially poor rainfall in May have a negative impact on yields. Winter wheat requires a good water supply from its shooting to the period of grain development, but the period of ripening and harvesting is most favourable if there is no rainfall. The rainy period immediately preceding harvest causes the grain to re-wet.

SOURCES FOR CLIMATE AND AGRICULTURAL HISTORY OF THE FIRST HALF OF THE 19TH CENTURY

The first half of the 19th century, due to widespread literacy and the growth of journalism, provides a wealth of information on climate, environmental and agricultural history compared to the early modern centuries; not only were more sources produced in the 19th century, but also more sources have been preserved. As a starting point, I used the most important source collections of Hungarian climate and environmental history research, the three-volume book series entitled *Weather Events and Natural Disasters in Hungary*, edited by Antal Réthly (Réthly 1962; Réthly 1970; Réthly 1998). The manuscripts of the first two volumes were finalised by Réthly, but due to his passing, the third volume, covering the 19th century, was upgraded by Antal Simon working at the National Meteorological Service. Archival research for these volumes took place in the 1950s and 1960s; it was a systematic activity of a working group of priests and monks dismissed by the communist regime at the turn from 1940s to 1950s, for whom Antal Réthly, as the president of the Catholic St. Stephen's Society [Szent István Társulat], was able to provide at least a temporary livelihood this way. Only Réthly's most important collaborator, the Jesuit monk and archivist Flórián Holovics, appears by name in the volumes, however, it is important to note that the source research was carried out by a philologically and linguistically well-trained staff. Antal Réthly was also involved in the archival research, but his most important activity was the meteorological interpretation and editing of the volume manuscript. These source collections are important starting databases for climate and environmental history research in the Carpathian Basin; however, opinions on their use and usability in Hungarian climate history research are divided (Kiss 2009; Vadas 2020). I have been working with these collections of sources for more than three decades and have re-read and analysed the nearly two and a half thousand pages of the text on several occasions. My research has led me to the conclusion that the reliability of the sources published in the Réthly collections should always be examined individually and in detail, and, as far as possible, compared with the original texts. The key to the review process is to prove the authenticity of the source and the credibility of the climate-environmental information described. Nonetheless, so far I have not found any published source in the Réthly collections with respect to the modern period, which I examine, that did not stand the test of comparison with the original source text. During the analysis of the sources, it was more of a problem for me that Antal Réthly was driven by his meteorological-geographical interest in the compilation of the source collections; in addition, as an editor he had to comply with the limitations of the volume, so many sources were heavily truncated in this edition (Rácz 2001).

Focusing on climate and agricultural history sources not included in Réthly's collection but studied in this paper, the most useful were the newspapers usually published twice a week, which, through their national network of correspondents, gave an overview of the weather–environmental–agricultural conditions of large areas. They were mostly published in Hungarian and German, reflecting the multicultural character of the Hungarian Kingdom and the Habsburg Empire. However, due to the interest of the reporters or the whims of the editors, information of value for the reconstruction of agricultural history appears in the columns of newspapers rather randomly. One of the most important newspapers for research on regional climate and agricultural history is the *Pressburger Zeitung (Pressburg, Pozsony, Bratislava, Slovakia now)*, which was continuously published between 1764 and 1929, and thus it is the longest-lived newspaper in the history of the Carpathian Basin press. The *Magyar Kurír* [*Hungarian Courier*], published between 1788 and 1834, was the most important Hungarian-language newspaper in Vienna. The first Pest-Buda newspapers appeared at the turn of the 18th and 19th centuries. The *Vereinigte Ofner und Pester Zeitung* was first released in 1798 and was published continuously until 1845. The most important Hungarian-language newspaper in Pest-Buda was the newspaper *Hazai Tudósítások* [*Home Reports*], first published in 1806, since 1808 entitled *Hazai és Külföldi Tudósítások* [*Home and Foreign Reports*], since and from 1840 *Nemzeti* Újság [*National Newspaper*] until its closure in 1848. The newspaper *Erdélyi Híradó* [*Transylvanian News*] was published in Kolozsvár (Cluj-Napoca, Romania now) between 1828 and 1848; since 1848 it was entitled *Kolozsvári Híradó* [*Kolozsvár News*].

The research of periodicals is greatly facilitated by the searchable digitised database of 19th-century press available in the Arcanum Digital Library (arcanum.hu).

Another highly important and very useful source of information on climate and agricultural history is personal diaries kept more or less regularly, which was actually a very fashionable activity during the reform era. One of the most interesting manuscripts of this kind is the diary of József Jókay (1781–1837), in which the author describes his experiences in Komárom (Komárno) and during his travels in other parts of the country, especially in the Highlands, in a precise and objective manner, if not with literary ambition. László Zlinszky (1801–1862), the chief engineer and director general of roads of Pest County, started to write his diary, rich in weather records, in 1821 and kept it continuously until his death in 1862. Comprehensive monthly and seasonal assessments are characteristic of most of the weather records in his diary, while entries with daily records were more likely to be found only in connection with unusual weather events. Interestingly, Reformed pastors living in villages were very productive authors of climate history notices. Mihály Király, the Reformed pastor of Egerbegy (Agărbiciu) in Torda (Turda) County, kept a diary between 1823 and 1848, which is a very valuable source for historical climatology of Transylvania. He entered both daily records and end-of-month weather summaries in his diary. The diary of the Reformed pastor István Pap Debretzeni (?–1841) dealt with weather changes in varying detail: the majority of his diaries was a general assessment of the year, and only few daily data were included. He started to keep his diary in 1807 as a pastor of Tiszaug in Szolnok County, then in 1815 he became the head of the parish of Kenderes, where he worked and kept his diary until his death in 1841. Similarly to his fellow pastors in Egerbegy and Kenderes, Gábor Ecsedi, the Reformed pastor of Gyula in Békés County also kept a detailed diary of the weather of the passing days. It is his diary volumes covering the period between 1834 and 1852 that have been preserved. Another chronicle writer to include was Gottlieb Bruckner (1818–1894), who, having been inspired by German-language chronicles of Sopron, which he had collected, started writing a city chronicle himself from 1840 on. In 1894, the year of his death, the chronicle already had 489 densely filled pages (Réthly 1998).

QUANTIFYING DESCRIPTIVE CLIMATE AND AGRICULTURAL HISTORY SOURCES

From the point of view of scientific analysis, an important weakness of descriptive historical sources is that the data they provide are largely non-homogeneous, non-continuous and non-quantitative. To solve this challenge, Christian Pfister and Hannes Schüle developed a multi-stage method of analysis, sorting and "information cleansing" (Schüle–Pfister 1992). As a first step, information provided by the sources needs to be arranged in space and time, and simultaneously sorted according to whether they provide direct (e.g. snowfall) or indirect (e.g. freezing of a river; phenological information, e.g. ripening of wheat) weather–environmental data. Based on the descriptive sources of the first half of the 19th century, it is possible to make climate and agricultural history analyses with monthly precision and specific to four macro-regions of the Carpathian Basin (Transdanubia, the Highlands, Transylvania and the Great Hungarian Plain).

There are several scales available for quantifying information extracted and sorted from descriptive historical sources, such as the Brooks, Easton or Lamb scales (Rácz 1999, 2001), but the most useful of them all is the seven-point scale developed by Christian Pfister and referred to as the "Pfister index" by Franz Mauelshagen (Table 2) (Mauelshagen 2010). The weather event or crop outcome described by the sources is placed on a scale of +/–3, where 0 is the average, +3 means extremely high and –3 very low tem-

+3	extremely warm/wet/good
+2	very warm/wet/good
+1	warm/wet/good
0	normal
-1	cold/dry/bad
-2	very cold/dry/bad
-3	extremely cold/dry/bad

Table 2. *The seven-step index was introduced by Christian Pfister for quantifying descriptive documentary source information, which can be used to quantify temperature, precipitation, or crop yields.*

perature, precipitation or crop outcome. It is important to note that the process of creating index values cannot be formalised mathematically, as many factors have to be taken into account when assigning the appropriate value(s). The most important aspect of "weighing" is of course the reliability of the source, however, the interpretability and context of the description must also be taken into account (Pfister 1999). In the course of my research, I produced temperature and precipitation time series for the macro-regions of the Carpathian Basin (Transdanubia, Highlands, Transylvania and the Great Hungarian Plain), as well as agricultural time series on the quantity of grain and hay, and the quantity and quality of grape production. The annual agricultural production indices for the Carpathian Basin as a whole were created by summing the values of the macro-regions, so that they could vary between +/–12 as end-points (Rácz 2020).

IMPACT OF THE LITTLE ICE AGE CLIMATE CHANGES ON WINTER WHEAT YIELDS IN THE MACRO-REGIONS OF THE CARPATHIAN BASIN IN THE FIRST HALF OF THE 19TH CENTURY

Based on our database, we can provide a monthly and macro-regional analysis of weather patterns and winter wheat yields in the Carpathian Basin in the first half of the 19th century, paying special attention to the Hungarian reform era (1825–1848), when profound social and economic reforms were initiated. To provide a basis for the agro-meteorological synthesis of the Carpathian Basin, the climate and agricultural history data and time series of the four macro-regions of Transdanubia, the Highlands, Transylvania and the Great Hungarian Plain are examined.

WHEAT YIELDS IN THE TRANSDANUBIAN REGION IN THE FIRST HALF OF THE 19TH CENTURY

Bounded by the foothills of the Alps to the west, the Danube to the north and east, and the Drava to the south, Transdanubia cannot be considered a homogeneous region in any sense. Diversity of environmental conditions co-impacted on different agricultural orientations within Transddanubia, as found byJózsef Glósz (Glósz 2014: 52–53). The proximity of Austria made the export of cereals, especially wheat, an obvious option for farmers in Transdanubia, aided greatly by the fact that Fejér, Moson and Somogy Counties harvested significant exportable surpluses year after year.

Based on studied historical sources, there are no records of extremely cold and wet October weather in the first half of the 19th century (Figure 4). There are only two years in which we have records of unfavourable weather: a very cold October in 1825 and a particularly dry October in 1827. It is noteworthy that there was only one year in the whole time series, 1817, when the weather was cool and relatively wet in Transdanubia during the ploughing and sowing season. However, there were four years (1819, 1822, 1839 and 1846) when contemporaries considered October to be warm, and one (1841) when it was extremely warm. It was only in one year, 1825, that the October weather was really bad, cold and wet.

In the first half of the 19th century, the weather in March was considered by contemporaries to be distinctly cold in Transdanubia (Figure 5). March was very cold in eleven years (1818, 1825, 1830, 1834, 1838, 1839, 1840, 1842, 1843, 1845 and 1847) and extremely cold in one (1824). It is noteworthy that a cold March, the prolongation of the winter weather and the shortening of the growing season were important features of the decades of the reform era.

Weather in May in the first half of the 19th century was often considered by contemporaries to be cool (Figure 6). Only one particularly warm May (1841) was recorded in studied sources, while during the eight years between 1835 and 1842 data suggest that there were four years when May was particularly cold (1835, 1836, 1839 and 1842). May precipitation was much more balanced than temperature in the first half of the 19th century. Although there was an exceptional drought in 1808, mildly rainy climate became dominant during the reform era. There were three years during the reform era that were extreme

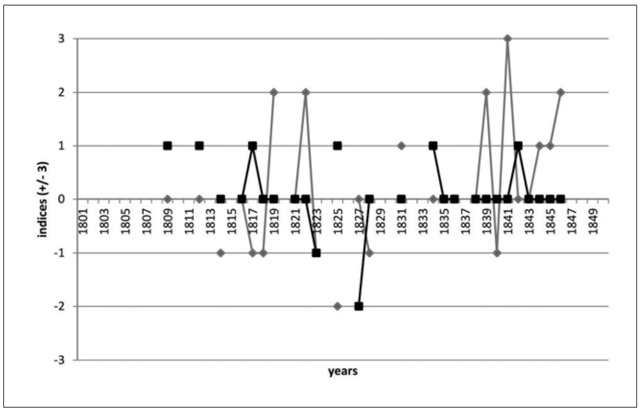


Figure 4. *Temperature (grey line) and precipitation (black line) indices of October in Transdanubia in the first half of the 19th century. The indices of the time series are the author's research results.*

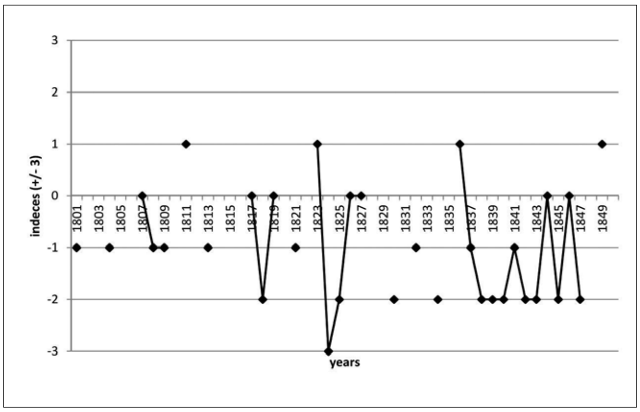


Figure 5. *Temperature indices of March in Transdanubia in the first half of the 19th century. The indices of the time series are the author's research results.*

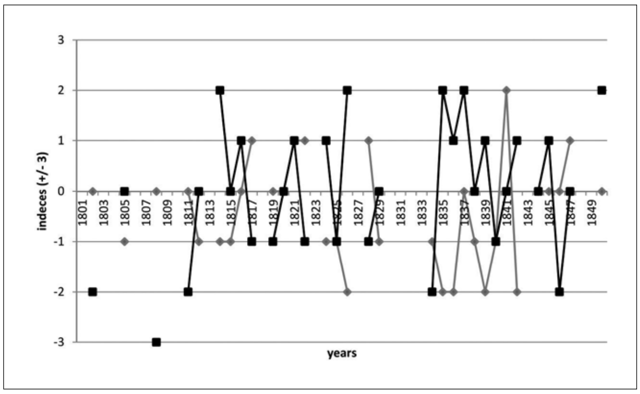


Figure 6. *Temperature (grey line) and precipitation (black line) indices of May in Transdanubia in the first half of the 19th century. The indices of the time series are the author's research results.*

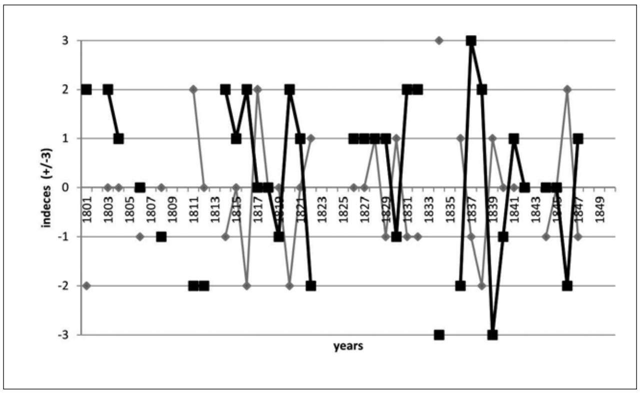


Figure 7. *Temperature (grey line) and precipitation (black line) indices of June in Transdanubia in the first half of the 19th century. The indices of the time series are the author's research results.*

in terms of both temperature and rainfall. In 1826, May was very cold and extremely wet, and 1835 and 1836 were two consecutive years with extreme weather in May.

Temperature and precipitation patterns in June were highly variable but relatively balanced in the long run (Figure 7). There was, however, a high number of years when the weather profile in June was unfavourable for the balanced ripening of winter wheat. June was very cold and rainy in 1801, hot and dry in 1811, very cold and rainy again in 1816 and 1820, there was a warm and very dry early summer in 1822. In the 1830s, there were hardly any years when June could be regarded as average or normal. In 1831 and 1832, June was cool and very rainy, and then in 1834, it was the hottest and driest June ever recorded in modern times. But the unusually varied weather in June followed later on as well, with a warm and very dry June in 1836, a cool–cold and very wet June in 1837 and 1838, and another warm and extremely dry early summer in 1839. In the 1840s, studied records report only one June weather anomaly: in 1846 the weather was hot and very dry.

In the first half of the 19th century, July and August in were characterised by dry weather favourable for wheat ripening and harvesting (Figure 8) in many years. Within the time series, only the summer of 1801 had truly rainy weather, while the summers of 1810, 1811, 1822 and 1824 were particularly dry,

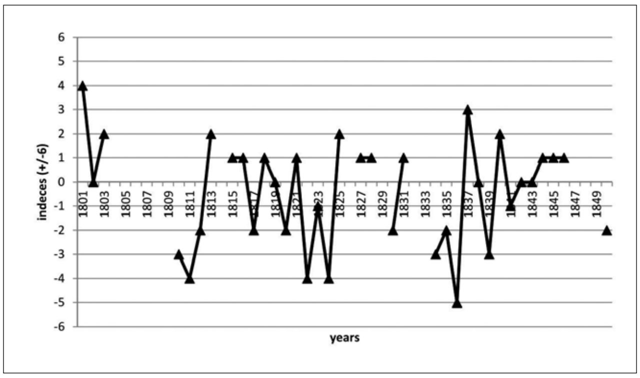


Figure 8. *Precipitation indices of July and August in Transdanubia in the first half of the 19th century. The indices of the time series are the author's research results.*

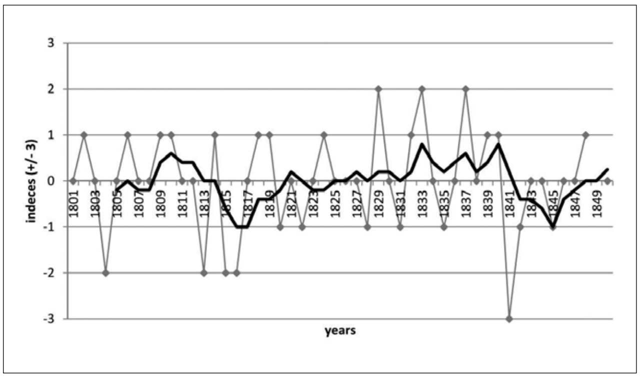


Figure 9. *Wheat harvest yields in Transdanubia in the first half of the 19th century (grey line) and the five-year moving average of the time series (black line). The indeces of the time series are the author's research results.*

and in 1836 the drought was devastating in the Transdanubian region. Not by any great extent, but in the mid-1840s the harvest season turned slightly rainy.

Apart from the disastrous wheat harvest of 1841, exceptionally poor grain harvests were only recorded in the first quarter of the 19th century (1804, 1813, 1815 and 1816). During most of the reform era, the wheat harvest was considered rather favourable by contemporaries, and the 1829, 1833 and 1837 harvests were particularly satisfactory (Figure 9). For all the poor grain harvests, June and July were extremely wet, and in three cases a cold March may have hindered the start of vegetation (1804, 1813 and 1841). A common characteristic of good grain years was excess rainfall in May, but, strangely enough, early summer rainfall did not worsen crop prospects in years of good yields. It is worth to pay special attention to the weather profile of 1841 with its disastrously poor harvests. October in 1840 was cold with average rainfall, the cold March weather delayed the start of vegetation, May was particularly warm and moderately dry, and June was particularly wet.

WHEAT YIELDS IN THE HIGHLANDS IN THE FIRST HALF OF THE 19TH CENTURY

In terms of wheat production needs, the Highlands can be divided into two zones, a mountainous zone and the northern fringes of Transdanubia and north of the Great Hungarian Plain. In the mountainous counties (Árva, Túróc, Liptó, Zólyom, Szepes, Máramaros, Sáros, Trencsén and the northern part of Bars) the conditions were mostly unfavourable for the production of winter wheat, and therefore, it was rye and barley that were mostly grown in these areas. The southern counties of the Highlands (Ung, Bereg, Ugocsa, Gömör, Nógrád, Abaúj, Borsod) were suitable for wheat to grow, and it was possible to engage in the grain trade, for which the industry of the Highland towns provided the basis of exchange. It is important to note that grain was exported from the south-western counties of the Highlands to Austria already in the early modern period, so there were well-established routes and institutions for agricultural trade quite early in those regions (Glósz 2014: 47).

Data on October weather in the Highlands are only sparsely available (Figure 10). Examining the time series as a whole, we can assume prevalent mild and balanced precipitation. The most notable among the years with extreme October weather was 1825, when it was not only very cold but also extremely wet. In terms of climate change trends, the period from the late 1830s to the mid-1840s is particularly interesting: Octobers in 1839 and 1841 were warm, while in 1840 and in 1844, it was very wet.

Despite the considerable lack of data, it can be stated that contemporaries living in the Highlands often perceived March in the first half of the 19th century to be cold, and very cold in nine years (1817,

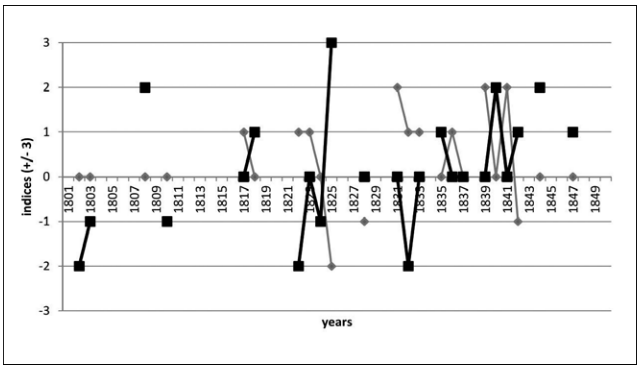


Figure 10. *Temperature (grey line) and precipitation (black line) indices of October in the Highlands region in the first half of the 19th century. The indices of the time series are the author's research results.*

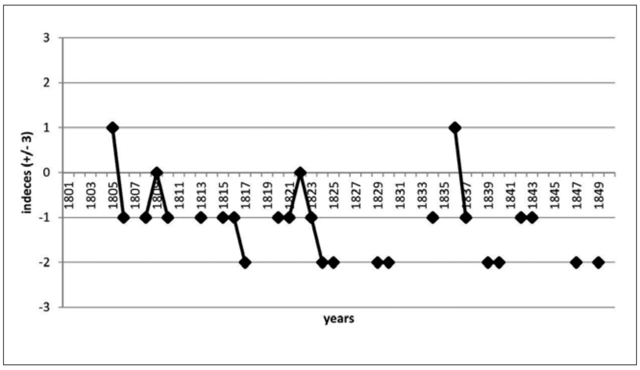


Figure 11. *Temperature indices of March in the Highlands region in the first half of the 19th century. The indices of the time series are the author's research results.*

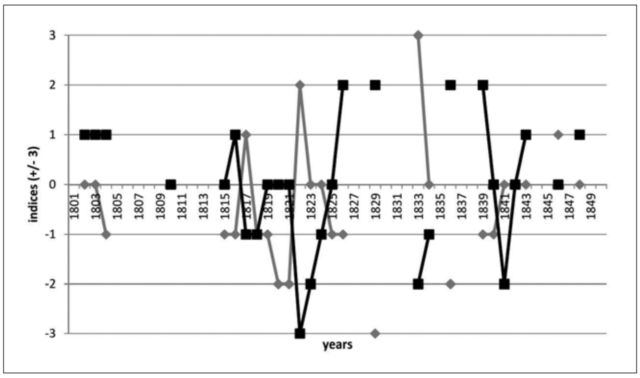


Figure 12. *Temperature (grey line) and precipitation (black line) indices of May in the Highlands region in the first half of the 19th century. The indices of the time series are the author's research results.*

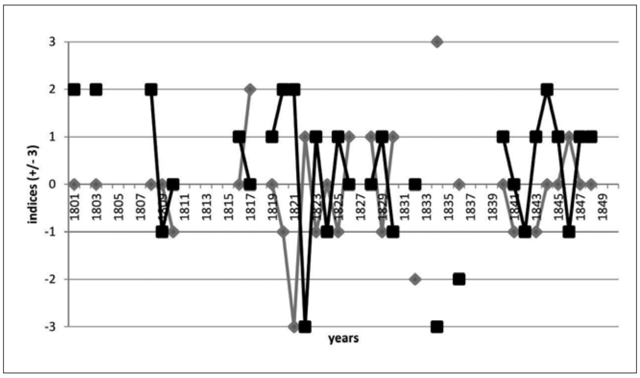


Figure 13. *Temperature (grey line) and precipitation (black line) indices of June in the Highlands region in the first half of the 19th century. The indices of the time series are the author's research results.*

1824, 1825, 1829, 1830, 1839, 1840, 1847 and 1849). In all likelihood, the cold early spring precipitation greatly hindered the start of vegetation in Northern Hungary in the decades of the reform era (Figure 11).

According to the sparsely available information, May was mostly cool in the Highlands, with precipitation data showing significant fluctuations in both directions (Figure 12). There were two meteorological profiles of extreme May weather in Northern Hungary: very (or extremely) hot and extremely (or very) dry years (1822 and 1833) and very (or extremely) cold and very wet years (1829 and 1836).

In the first decade of the 19th century, there were three years with an unusually wet June (1801, 1803 and 1808). The next marked period in climatic history was the turn of 1810s to 1820s, with a very hot 1817, a hot and extremely dry 1822, and a cold to extremely cold and very wet (1820 and 1821) June. In the mid-1830s, we have records of several early summers with extreme weather, of which the extremely hot and extremely dry June of 1834 was particularly memorable (Figure 13).

The weather in July and August in the first half of the 19th century was mostly dry in the Highlands (Figure 14). Only four years (1801, 1833, 1844 and 1845) are known to have had a truly rainy harvest period. However, in five years (1822, 1830, 1836, 1842 and 1846), the dry weather, which had been favourable for field work, turned into a pronounced drought.

The grain yields of the Highlands in the first half of the 19th century were largely below the expectations of their time (Figure 15). In the first two decades of the century, there were two consecutive years of extremely poor harvests (1804–1805 and 1815–1816). The grain harvest of 1816 in particular

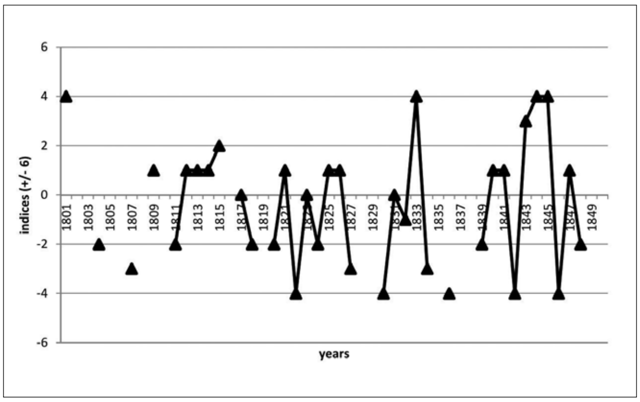


Figure 14. *Precipitation indices of July and August in the Highlands region in the first half of the 19th century. The indices of the time series are the author's research results.*

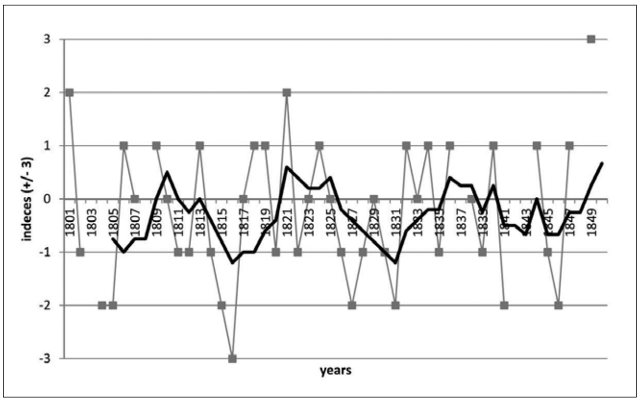


Figure 15. *Wheat harvest yields in the Highlands region in the first half of the 19th century (grey line) and the five-year moving average of the time series (black line). The indices of the time series are the author's research results.*

was disastrous, but significant grain deficits can also be found in the second half of the 1820s and the mid-1840s. Occasionally, the extremely dry (1804) or very rainy (1841) October greatly hampered field work in the Highlands. But cold March weather (1815 and 1816) and cold (1815 and 1816) and dry (1841) May weather also had a negative impact on crop prospects. Summer precipitation anomalies in both directions could cause poor grain yields, both in wet summers (1815 and 1816) and in times of drought (1827 and 1846). However, the significant lack of data warns us to proceed with caution when drawing climate historical conclusions.

WHEAT YIELDS IN TRANSYLVANIA IN THE FIRST HALF OF THE 19TH CENTURY

In the basins and valleys of historical Transylvania beyond the Királyhágó (Bucea, western gate of Transylvania), there was extensive and diversified cereal production to feed the local peasant population and city dwellers, but it needs to be taken into account that most of Transylvania was not the most optimal area for growing winter wheat. However, wheat was cultivated on a relatively large area in the Mezőség (Câmpia Transilvaniei, Transylvanian Plain), while the quality of the arable land was greatly impaired by soil degradation due to overuse in the first half of the 19th century.

Unintentionally, the Transylvanian climate history database is limited to the decades of the reform era in its narrow sense. October weather over the two and a half decades that can be analysed was relatively balanced (Figure 16). However, there were five years when both temperature and rainfall were severe. In 1823, October was cold and dry, in two years, 1832 and 1846, the ploughing season was hot and dry, and in 1840 and 1847, cold and wet.

March in reform-era Transylvania was overwhelmingly cold according to contemporary accounts, differing only in whether it was very or moderately so (Figure 17). Except for the mild March of 1823, the start of vegetation was delayed almost every year. In fact, for more than a decade, between 1837 and 1848, every March was cold, with seven years being very cold (1839, 1840, 1841, 1845, 1846, 1847 and 1848), and in 1843, a terrible, biting cold weather was reported.

May in the decades of the reform era was also found by contemporaries to be mostly cold in Transylvania, but the precipitation varied a lot in both directions (Figure 18). May was mostly cold and rainy (1826, 1843, 1845 and 1848), but there was a year (1833) with very cold and dry May weather. The weather in Transylvania in the late spring of the 1840s was extremely diverse: there were cold and wet Mays, but also the dry May in 1844.

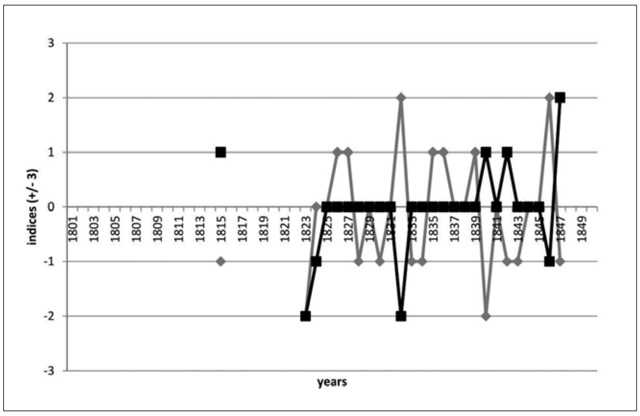


Figure 16. *Temperature (grey line) and precipitation (black line) indices of October in Transylvania in the first half of the 19th century. The indices of the time series are the author's research results.*

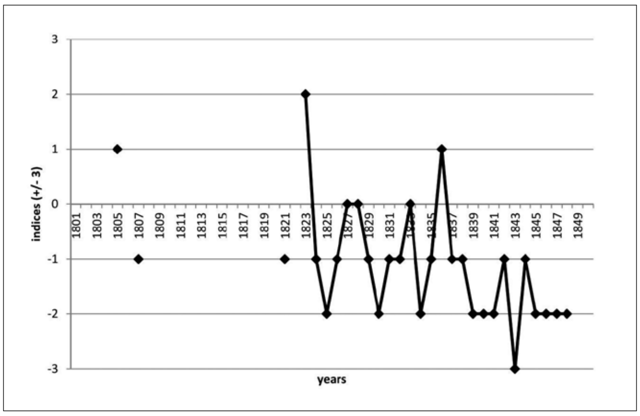


Figure 17. *Temperature indices of March in Transylvania in the first half of the 19th century. The indices of the time series are the author's research results.*

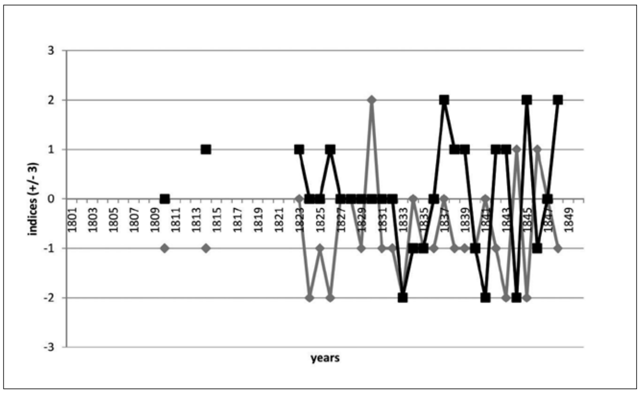


Figure 18. *Temperature (grey line) and precipitation (black line) indices of May in the Transylvania region in the first half of the 19th century. The indices of the time series are the author's research results.*

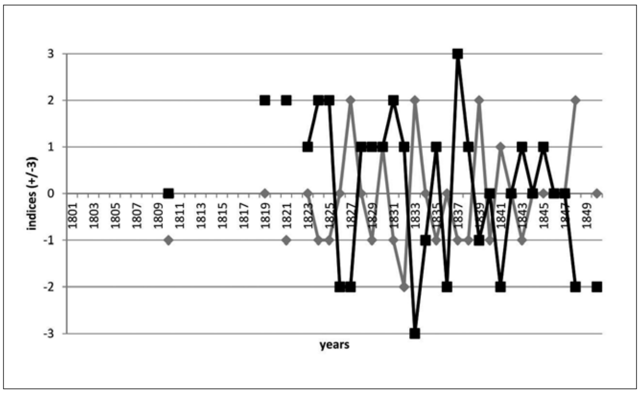


Figure 19. *Temperature (grey line) and precipitation (black line) indices of June in Transylvania in the first half of the 19th century. The indices of the time series are the author's research results.*

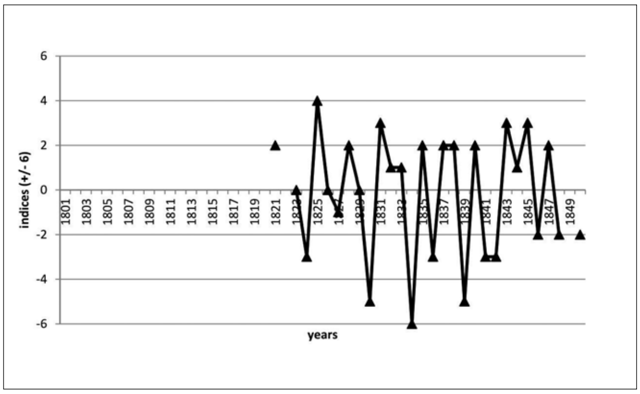


Figure 20. *Precipitation indices of July and August in Transylvania in the first half of the 19th century. The indices of the time series are the author's research results.*

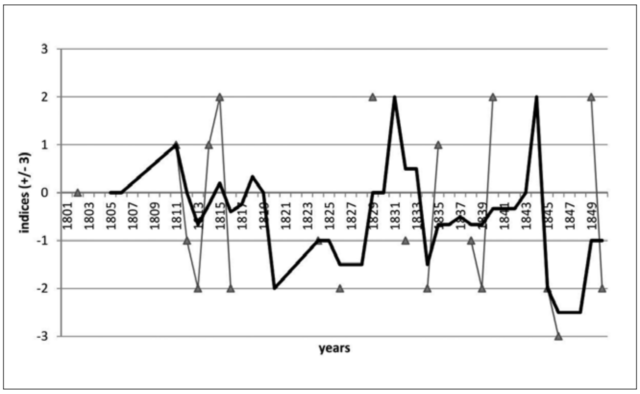


Figure 21. *Wheat harvest yields in Transylvania in the first half of the 19th century (grey line) and the five-year moving average of the time series (black line). The indices of the time series are the author's research results.*

Temperatures and precipitation in June were highly variable during the reform era, alternating between cool–cold and wet (1821, 1824, 1825, 1831, 1832 and extremely wet in 1837) and warm–hot and dry (1827, 1833 – extremely dry, 1839, 1841 and 1848). It is particularly noteworthy that in Transylvania the longest period of balanced June weather during the reform era lasted from 1842 to 1847 (Figure 19).

Concerning harvest seasons, dry years favourable for harvesting were slightly less frequent in Transylvania during the reform period than humid seasons (Figure 20). Only in 1825, July and August were consistently and heavily rainy, while three years (1830, 1834 and 1839) were exceptionally dry, and moderately humid and moderately dry years were frequent.

Winter wheat yields during the reform era were quite often far below the expectations of the time (Figure 21). There were a few good years (1815, 1829, 1840 and 1849), but poor years were relatively frequent (1813, 1816, 1826, 1834, 1839, 1845 and 1850), and in 1846, the Transylvanian wheat harvest was considered disastrous according to contemporary records. In most of the years with poor harvests (1826, 1834, 1839, 1845 and 1846), March weather was very cold, which hindered the development of cereal crops. Surprisingly, a more frequent weather precursor of poor harvests in Transylvania was summer drought (1826, 1834, 1839, 1846 and 1850) rather than wet weather (1845).

WHEAT YIELDS IN THE GREAT HUNGARIAN PLAIN IN THE FIRST HALF OF THE 19TH CENTURY

Even in the first half of the 19th century, the Great Hungarian Plain was still a sparsely populated region, where it was possible to increase the area under cultivation by one third. It was extensive livestock farming that suffered the greatest loss due to the increase in arable land. The yield capacity of the Great Hungarian Plain is well illustrated by the fact that, in addition to subsistence economy, it could make up for the grain deficits of the Highlands and Transylvania and even made it possible to export wheat abroad. As a result of grain trade within the country, grain production was abandoned in those areas of the Highlands and Transylvania that had the most adverse conditions. However, the Great Hungarian Plain, which covers an area of more than 100,000 km^2, cannot be considered a completely homogeneous region. The sandy Kiskunság or the floodplains of the rivers offered markedly different production conditions than the excellent grain-growing regions of the Bácska, the Bánát or the area between the Maros and Körös Rivers (Glósz 2014: 35).

The sowing season in the Great Hungarian Plain was often mild and precipitation there was moderate in the first half of the 19th century (Figure 22). There were very typical weather anomalies in the decades examined: October in 1802 was the driest in the time series, ploughing season in 1825 was very cold and it was wet, October in 1832 was warm and very dry, and October in 1847 was mild and very wet.

In the first half of the 19th century, especially in the decades of the reform era, March weather was usually cold to very cold (Figure 23). There were a few early springs in the 1810s, when the weather was milder, but in the three decades between 1820 and 1850 there was only one March (1836) that was mild according to the records.

In the first half of the 19th century, the weather in May was diverse in the Great Hungarian Plain (Figure 24). In nearly half of the cases, contemporaries classified the weather as exceptional or far from average in some way. There was a wide range of years with characteristically extreme weather: there were cold and wet Mays (1814, 1826, 1829, 1832, 1837 and 1842), hot and dry (1822, 1833 and 1846), and cold and dry (1825 and 1836) as well.

Temperature and precipitation patterns in June were highly variable, and only a minority of early summers in the time series had average or near-average weather (Figure 25). At the same time, the pattern of weather anomalies can be regarded fairly typical: there were some years with a very hot and dry June and some when June was cool–cold and wet. Among the monthly weather anomalies, the decade of 1830s stood out, as there was no year with near-average June weather at that time.

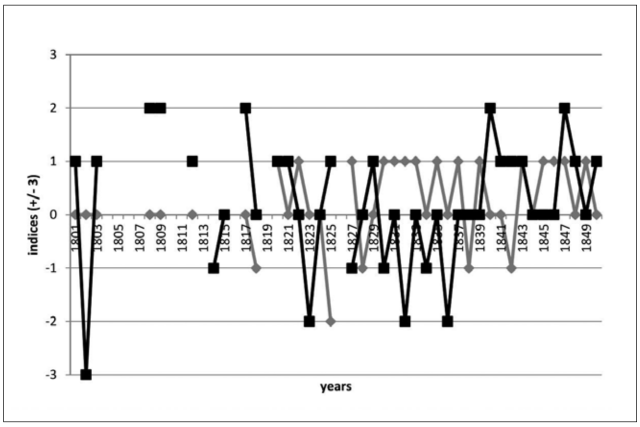


Figure 22. *Temperature (grey line) and precipitation (black line) indices of October in the Great Hungarian Plain in the first half of the 19th century. The indices of the time series are the author's research results.*

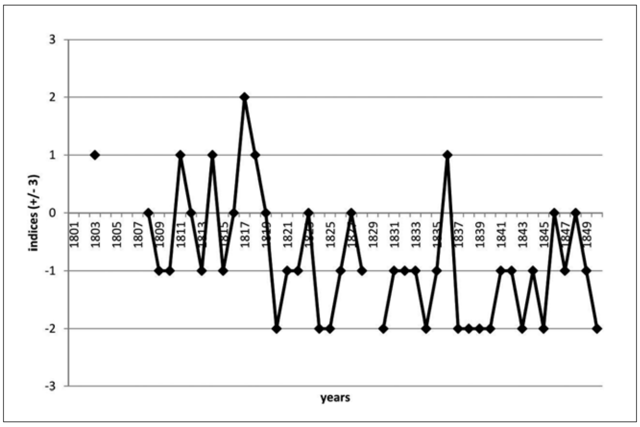


Figure 23. *Temperature indices of March in the Great Hungarian Plain in the first half of the 19th century. The indices of the time series are the author's research results.*

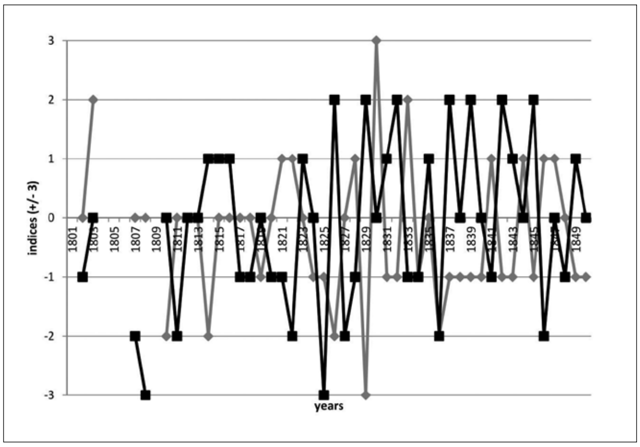


Figure 24. *Temperature (grey line) and precipitation (black line) indices of May in the Great Hungarian Plain in the first half of the 19th century. The indices of the time series are the author's research results.*

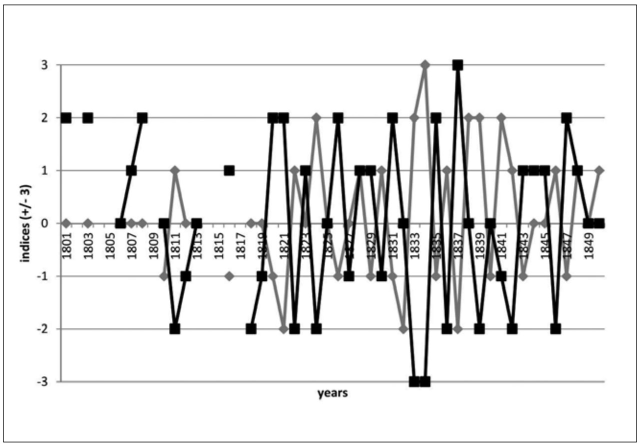


Figure 25. *Temperature (grey line) and precipitation (black line) indices of June in the Great Hungarian Plain in the first half of the 19th century. The indices of the time series are the author's research results.*

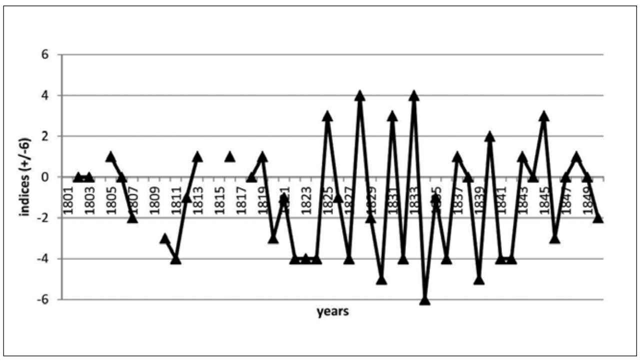


Figure 26. *Precipitation indices of July and August in the Great Hungarian Plain region in the first half of the 19th century. The indices of the time series are the author's research results.*

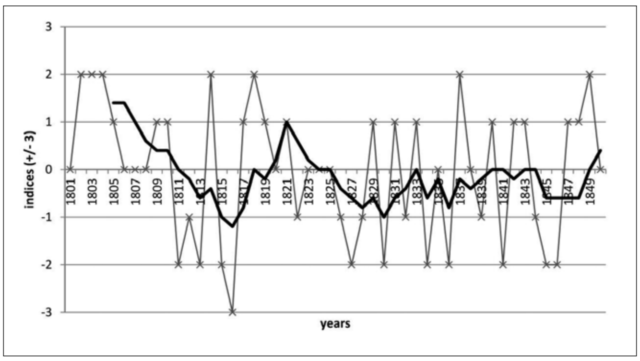


Figure 27. *Wheat harvest yields in the Great Hungarian Plain in the first half of the 19th century (grey line) and the five-year moving average of the time series (black line). The indices of the time series are the author's research results.*

July and August in the first half of the 19th century were very often dry in the Great Hungarian Plain (Figure 26). The weather anomalies were particularly pronounced between 1822 and 1842, as in these two decades there were only eight mid-summer and late summer periods when monthly precipitation was classified by contemporaries as average or close to it. The vast majority of the precipitation anomalies documented in historical sources were dry years (1811, 1822, 1823, 1824, 1827, 1832, 1836, 1841 and 1842), with three years (1830, 1834 and 1839) experiencing severe drought. In the first half of the 19th century, there were only two years, 1828 and 1833, with significant excess rainfall in July and August. Moderately dry weather helped harvesting for the most part, but prolonged or severe drought could severely damage wheat grain development.

Focusing on the trend,, positive deviations of grain yields in the Great Hungarian Plain to a certain degree offset the negative ones, in the first half of the 19th century (Figure 27). That did not mean, of course, that there were not alternating years of good and bad harvests. However, three periods can be clearly identified when grain yields in the Great Hungarian Plain were below expectations for extended periods. One such period was the 1810s, particularly the disastrous grain harvest of 1816, then another was the second half of the 1820s and later the half-decade between 1841 and 1846. From the point of view of climate and agricultural history, the most intriguing question is what weather pattern can be identified in the years of poor harvests in the Great Hungarian Plain. On several occasions, dry weather in October (1827, 1830 and 1836) played a role in a poor harvest, since it slowed down the germination process. The cold weather in March (1813, 1815, 1841 and 1845) hindered the start of vegetation and the tillering of wheat. The lack of rainfall in May (1827, 1830, 1836, 1841 and 1846) was also a common cause of poor harvests, delaying the development of the stem and the spikes. However, according to contemporary accounts, the most common reason for a poor wheat harvest was the fluctuation in summer rainfall. Most often, it was summer droughts (1811, 1827, 1830, 1836, 1841 and 1846) that resulted in poor yields, but there were also years with wet summers (1813, 1816 and 1845) that caused severe crop losses.

CONCLUSION

Following the climate history analysis of wheat production in the macroregions of the Carpathian Basin, it is worth examining which regional agricultural crises developed into countrywide production crises. Macro-regional analyses show that in the first half of the 19th century the riskiness of wheat production was highest in the mountainous fringes of the Danube basin, the Highlands, and Transylvania. The sum of half-century index values for wheat production was –10 for both macro-regions. In Transdanubia, the wheat harvest index sum was average in all respects, i.e. 0, while that of the Great Hungarian Plain was –2, which can be considered close to average (Table 3).

Table 3. *The summary table of wheat yields in the Carpathian Basin, aggregation of data from the four macroregions, the extrems are marked in grey. The column on the right shows sums for the whole Carpathian Basin (as this is a sum of four regions, the index there is four times the average value for macroregions)*

	Transdanubia	Highlands	Transylvania	Great Hungarian Plain	Carpathian Basin
1801	0	2		0	2
1802	1	-1	0	2	2
1803	0			2	2
1804	-2	-2		2	-2
1805	0	-2		1	-1
1806	1	1		0	2
1807	0	0		0	0
1808	0			0	0
1809	1	1		1	3

	Transdanubia	Highlands	Transylvania	Great Hungarian Plain	Carpathian Basin
1810	1	0		1	2
1811	0	-1	1	-2	-2
1812	0	-1	-1	-1	-3
1813	-2	1	-2	-2	-5
1814	1	-1	1	2	3
1815	-2	-2	2	-2	-4
1816	-2	-3	-2	-3	-10
1817	0	0		1	1
1818	1	1		2	4
1819	1	1		1	3
1820	-1	-1		0	-2
1821	0	2		1	3
1822	-1	-1		-1	-3
1823	0	0		0	0
1824	1	1	-1	0	1
1825	0	0		0	0
1826	0	-1	-2	-1	-4
1827	0	-2		-2	-4
1828	-1	-1		-1	-3
1829	2	0	2	1	5
1830	0	-1		-2	-3
1831	-1	-2		1	-2
1832	1	1	-1	-1	0
1833	2	0		1	3
1834	0	1	-2	-2	-3
1835	-1	-1	1	0	-1
1836	0	1		-2	-1
1837	2			2	4
1838	0	0	-1	0	-1
1839	1	-1	-2	-1	-3
1840	1	1	2	1	5
1841	-3	-2		-2	-7
1842	-1			1	0
1843	0			1	1
1844	0	1		-1	0
1845	-1	-1	-2	-2	-6
1846	0	-2	-3	-2	-7
1847	0	1		1	2
1848	1			1	2
1849		3	2	2	7
1850	0		-2	0	-2
Sum	0	-10	-10	-2	-22

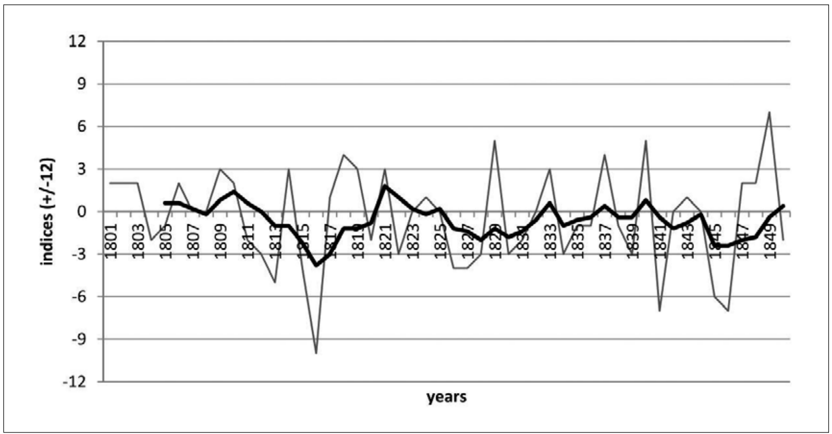


Figure 28. *Wheat harvest yields in the Carpathian Basin in the first half of the 19th century (grey line) and the five-year moving average of the time series (black line). The indices of the time series are the author's research results.*

Due to the poorer wheat harvests in the Highlands and Transylvania, the yield in Carpathian basin as a whole was also below average, albeit only slightly, in the first half of the 19th century (Figure 28). Three periods can be identified in the countrywide time series when wheat yields were below expectations in the Carpathian Basin. The first and strongest was the period 1811–1816, during which only one of the six years examined, namely 1814, produced a moderately favourable harvest, at the same time, there were three countrywide negative anomalies. The production crisis of 1813 severely affected three quarters of the country, with the exception of the Highlands. The crisis was clearly most severe after the disastrous wheat harvests of 1815 and 1816; the climate history explanation for this is the eruption of the Tambora volcano in Indonesia on 5 April, 1815. The shielding effect of the 80 km^3 of volcanic material injected into the atmosphere caused "years without summers", in Hungary in these two years (Rus 2020). Mid-1920s was the second period when wheat yields declined and stayed predominately low until 1831. In all but one year (1829) out of the six years from 1826 to 1831, the wheat harvest was below expectations countrywide, but never did a serious production crisis develop. In the third crisis period, between 1841 and 1846, there were three countrywide and significant crop failures: in 1841, 1845 and 1846. The analysis and interpretation of the production crisis of 1845 and 1846 deserve special attention, partly because of the cumulative impacts in successive years of poor harvests and partly because of the temporal proximity of the crisis to the 1848 revolution.

In eight years of the half-century under investigation, there were records of poor wheat harvests countrywide: 1813, 1815, 1816, 1826, 1827, 1841, 1845 and 1846. When looking at the weather profile of the countrywide wheat production crises, the following months were considered to be the most decisive: cold and wet weather in October (1813, 1815, 1816, 1826 and 1841) did not favour the autumn field work, and in almost all the years with poor harvests, March weather was cold (1813, 1815, 1816, 1826, 1841, 1845 and 1846), delaying the start of vegetation and thus diminishing prospects for harvests. The cold (1815, 1826 and 1845) and dry (1827, 1841 and 1846) May was the most unfavourable for the development of wheat. In the summer months, on the other hand, precipitation extrems in both directions caused serious damage to the harvest, whether it was drought (1827, 1841 and 1846) or persistent summer rains (1813, 1815, 1816 and 1845).

I am convinced that in order to know, be able to present and understand the historical agroecosystems of the Carpathian Basin in the first half of the 19th century, including the reform era, the interactions between the natural environment and the agricultural economy need to be researched, which I attempted to perform in this study. The revolution in travel and transport in the mid-19th century, marked by the spread of railways, brought an end to the traditional era of subsistence crises. The first half of the 19th century is the last period, rich in historical sources, in which we can examine the interaction between the natural environment and traditional society. The next level of analysis I plan to conduct is the examination of the historical agroecosystem of the Carpathian Basin, partly during the Napoleonic Wars at the turn of the century and partly during the Hungarian reform era.

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SAŽETAK

Glavni fokus istraživanja je razumjeti kako su promjene vremena i klima malog ledenog doba u prvom dijelu 19. stoljeća utjecale na prinose ozime pšenice, najvažnije prehrambene kulture u Mađarskoj toga vremena i glavni izvozni proizvod zemlje. U Panonskom bazenu, malo ledeno doba imalo je regionalna obilježja poput promjena u uzorcima oborina i strukturi godišnjih doba. Istraživanje se temelji na detaljnoj analizi interakcija između klimatskih promjena i životnog ciklusa pšenice u različitim regijama i u različito vrijeme. Područje koje se proučava obuhvaća teritorij Panonskog bazena (Panonske nizine), a on uključuje Transdanubiju, planine, Transilvaniju (Erdelj) i Veliku Mađarsku nizinu. Poljoprivreda je u tradicionalnim društvima imala ključnu ulogu u održavanju društvene i političke stabilnosti, stoga uzastopne godine loših uroda mogu dovesti do društvenih, ekonomskih i političkih kriza. Istraživanje također ističe ranjivost poljoprivrede na klimatske i okolišne promjene, čak i u modernom dobu. Vremenski profil kriza otkrio je da su hladno i kišovito vrijeme u listopadu, hladno vrijeme u ožujku i nepovoljni uvjeti u svibnju (suša, kasni mraz, tuča) te ljetni mjeseci (lipanj: suh i vruć ili kišovit; srpanj i kolovoz: kišoviti) bili presudni čimbenici lošim žetvama pšenice. Makroregionalne analize pokazale su da su planinski rubovi Podunavlja, planine i Transilvanija bili najugroženiji u pogledu proizvodnje pšenice u prvom dijelu 19. stoljeća. U Panonskom bazenu identificirana su tri razdoblja kriza u proizvodnji pšenice, s najtežom krizom koja se dogodila od 1811. do 1816., a pripisuje se erupciji vulkana Tambora 1815. godine. Drugo razdoblje kad je zabilježeno opadanje prinosa pšenice bilo je krajem 1820-ih i početkom 1830-ih. Kriza u proizvodnji 1845. i 1846. godine bila je posebno primjetna zbog nakupljanja uzastopnih godina loših žetvi i vremenske blizine revoluciji 1848. Zaključno, malo ledeno doba imalo je značajan utjecaj na poljoprivredu u Panonskom bazenu. Ipak, različiti vremenski čimbenici utjecali su na krize u proizvodnji pšenice u cijeloj zemlji, a razumijevanje povijesnih klimatskih obrazaca može pružiti uvid u ranjivost poljoprivrednih sustava.

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