

Farming at the margin: climatic impacts on harvest yields and agricultural practices in central Scandinavia, c.1560–1920*

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Abstract

This study estimates the impact of climatic variability on agriculture in central Scandinavia between the sixteenth and early twentieth centuries. Climate indicators are analysed in tandem with time series of harvest size, yield ratios and dates of agricultural activities. Harvests are estimated using c.9,000 parish-level tithe observations. Near continuous series of sowing, harvest, and hay-cutting dates between the late seventeenth and early twentieth centuries are estimated using a variety of sources. Mean growing season temperatures alone explain up to 26, 31, and 53 per cent of the variation in tithes, barley yield ratios, and harvest dates, respectively. Combinations of temperature indicators and the timing of agricultural activities explain up to 34 per cent of variations in tithes and up to 49 and 57 per cent of barley and rye yield ratios, respectively. While climate-agriculture relationships were consistent throughout the study period, the introduction of potato cultivation in the late eighteenth century helped reduce climatic vulnerability.

The constraints imposed on agriculture by the climate is a repeated theme in the agrarian history of Jämtland and Härjedalen. Previous studies have emphasized the potential role of lower growing season temperatures during the Little Ice Age (LIA) in the restructuring of agrarian farming systems or the role of different microclimates in shaping the exposure of crop cultivation to early autumn frosts.¹ However, no study up until now has quantitatively examined relationships between climate and agriculture in the region using annually resolved data over a longer period.

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¹ Both H. Antonsson, 'Landskap och ödesbölen: Jämtland före, under och efter den medeltida agrarkrisen' (PhD thesis, Stockholm University, 2004), and J. Larsson, 'Fäbodsväsendet 1550–1920: Ett centralt element i Nordsveriges jordbrukssystem' (PhD thesis, Sveriges Lantbruksuniversitet, 2009) make the former point while O. Holm, 'Självägarområdenas egenart: Jämtland och andra områden i Skandinavien med småskaligt jordäggande 900–1500' (PhD thesis, Stockholm University, 2012) make the latter.

Jämtland and Härjedalen are mostly highland regions (with a majority of their land area being above 300 m, and 650 m altitude, respectively) located in north-central Sweden or central Scandinavia (roughly 63°N 14°E), in the northern boreal zone. The climate of Jämtland and Härjedalen has a mild subarctic character with short and mild summers coupled with long and severe winters, although the latter are moderated by proximity to the North Atlantic and thus comparatively mild for this latitude. Farmers in medieval and early modern Jämtland and Härjedalen were highly reliant on grain harvests for their sustenance. Similar to other parts Europe, farmers practised a mixed farming system where crop production was combined with livestock husbandry in a mutually integrated system, albeit with an emphasis on livestock. In contrast to some other northern European regions, e.g., parts of Scotland or Ireland, winter grazing was generally not possible due to the extended and thick snow cover. Evidence on cereal cultivation, mostly of six-row barley varieties (*Hordeum vulgare*), can be found for many parts of central Scandinavia in the historical period, even in many of the mountainous areas.²

From an agrometeorological perspective, Jämtland and Härjedalen are very marginal farming regions, where farming operates at tight margins. Nonetheless, farmers have been insistent on practising settled agriculture in Jämtland for over a millennium, especially on the fertile plains with abundant moraine clay soils around Lake Storsjön.³ This article aims to study how tight these margins have been. With the help of a variety of sources, relationships between climate and agriculture in central Scandinavia, specifically in Jämtland and Härjedalen, from the mid-sixteenth century until the early twentieth century are analysed. Specifically, the article explores how farmers structured their agricultural practices in terms of sowing, harvesting and hay-cutting in a variable and harsh climate and how these factors affected harvests. Previous research has highlighted the significance of temperature during the growing season for agriculture in the region. Accordingly, growing season temperatures will be the main climatic factor considered.⁴

This article contributes to the state of current research by providing quantitative estimates of the extent of climate sensitivity in agriculturally marginal Jämtland and Härjedalen. The study

² For most of the study period Jämtland and Härjedalen were usually sorted into different administrative and episcopal districts. Jämtland county was first established in 1811. E. A. Pedersen and M. Widegren, 'Agriculture in Sweden: 800 BC–AD 1000', in J. Myrdal and M. Morell (eds), *The agrarian history of Sweden: from 4000 BC to AD 2000* (2011), pp. 46–7. Antonsson, 'Landskap'. R. A. Dodgshon, 'Strategies of farming in the western highlands and islands of Scotland prior tocrofting and clearances', *EcHR* 46 (1993), pp. 679–701. E. Costello, *Transhumance and the making of Ireland's uplands, 1550–1900* (2020). See M. N. A. Larsson, M. Wiking Leino, and J. Hagenblad, 'Genetic diversity in 19th century barley (*Hordeum vulgare*) reflects differing agricultural practices and seed trade in Jämtland, Sweden', *Diversity* 13 (2021), pp. 1–14, for an analysis of historical barley landraces in Jämtland. According to phenological observation data, two-row barley

varieties were becoming increasingly common in the late nineteenth century, see O. Langvall, Å. Dahl, and K. Blomgren, 'Swedish Historical Phenology Dataset', *Swedish National Data Service* 1.0 (2019). Data can be downloaded from <https://snd.gu.se/en/catalogue/study/snd1105#dataset>, last accessed 14 Sept. 2022.

³ M. Lindeberg, 'Järn i Jorden: Spadformiga ämnesjärn i Mellannorrland' (PhD thesis, Stockholm University, 2009), pp. 37 and 211. S. Welinder, 'The northern margin of cereal cultivation in Sweden during the Middle Ages', *J. Swedish Antiq. Res.* 114 (2019), pp. 36–42.

⁴ C. Pfister and H. Wanner, *Climate and society in Europe: the last thousand years* (2021), p. 282. H. Wichman, *Jämtlands och Härjedalens historia. Fjärde delen 1720–1880* (1962). H. Huhtamaa and F. Charpentier Ljungqvist, 'Climate in Nordic historical research – a research review and future perspectives', *Scand. J. Hist.* 46 (2021), pp. 665–95.

area is in some respects comparable to northern areas such as Scotland and Finland or the mountains of Bosnia and Switzerland.⁵ Additionally, this article introduces long-time series of historical sowing, hay-cutting and harvesting dates, which hitherto has been exceedingly scarce in the Nordic historiography. The former two types of dates are rare even from a wider European perspective.⁶ This important source material allows for insights into the actual actions taken by farmers faced with a variable climate.

I

Holger Wichman discussed the role of autumn frost before harvest in causing harvest failures in Jämtland and Härjedalen in the eighteenth century, particularly in the 1740s, 1760s, 1770s, and 1780s. He further stressed the important role of climate more generally in the development of agriculture in the region. This role was, and continues to be, predominantly characterized as a constraint.⁷ While the soils of Jämtland have a long history of being described as of excellent quality and of great agricultural potential, the prevailing climate has been seen as a hindrance to the development of agriculture, together with (a lack of) improvements in agricultural practices.⁸

Hans Antonsson has argued that the reduction in average temperatures during the Little Ice Age contributed to farm abandonment in the most marginal areas of Jämtland during the late medieval agrarian crisis.⁹ Similar models of farm abandonment and expansion can be found in earlier research on northern European conditions. Both Hubert Lamb and Martin Parry have argued that colder climatic periods led to farm desertion in the uplands of England and Scotland. Reijo Solantie has argued that periods of expansion of settled agriculture in Finland was associated with warmer climatic periods.¹⁰ In his study of the system of summer farms in northern Sweden, Jesper Larsson associated the increased importance of livestock production at the expense of arable production with the reduction in average temperatures during the

⁵ M. L. Parry and T. R. Carter, 'The effect of climatic variations on agricultural risk', *Clim. Change* [hereafter CC] 7 (1985), pp. 95–110. J. Mrgić, 'Wine or "Raki" – The interplay of climate and society in early modern Ottoman Bosnia', *Environ. Hist.* 17 (2011), pp. 613–37. C. Pfister, 'Changes in stability and carrying capacity of lowland and highland agro-systems in Switzerland in the historical past', *Mountain Res. Dev.* 3 (1983), pp. 291–97. Huhtamaa and Ljungqvist, 'Climate'. P. Martin, T. A. Brown, T. S. George, B. Gunnarson, N. J. Loader, P. Ross, J. Wishart and R. Wilson, 'Climatic controls on the survival and loss of ancient types of barley on North Atlantic Islands', CC 4 (2023).

⁶ For notable exceptions, see H. Holopainen, S. Helama and M. Timonen, 'Plant phenological data and tree-rings as palaeoclimate indicators in south-west Finland since AD 1750', *Int. J. Biometeorol.* 51 (2009), pp. 61–72. Ø. Nordli, 'Spring and summer temperatures in Trøndelag 1701–2003', *MET report* 5 (2004),

pp. 1–23, and L. Andersson Palm, *Gud bevare utsädet!: produktionen på en västsvensk ensädesgård: Djäknebol i Hallands skogsbygd 1760–1865* (1997). None of these examples contain long time series of hay-cutting, and Palm only contains sowing dates. Examples from the broader European historiography are given further below.

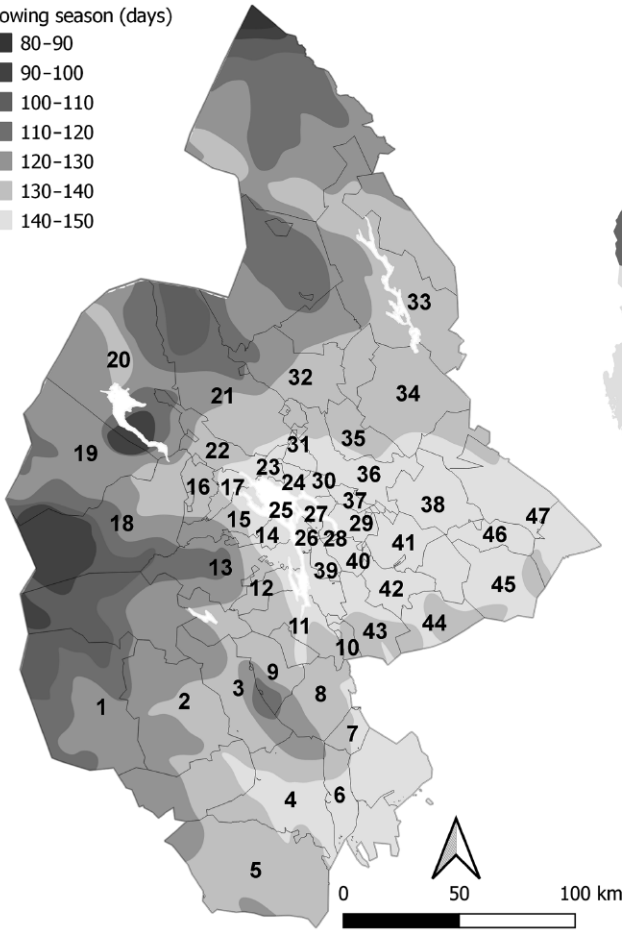
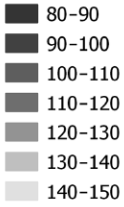
⁷ Wichman, *Jämtlands*. H. Antonsson, *Jämtlands äldre agrarlandskap, lantmäteriakter 1650–1899* (1993) and Larsson, *Fäbodväsendet*, p. 53 also stresses these climatological constraints.

⁸ J. O. Hagström, *Jemtlands økonomiska beskrifning* 1749 (1751).

⁹ Antonsson, *Landskap*, pp. 63–4 and 126–7.

¹⁰ H. Lamb, *Climate, history and the modern world* (1995), M. L. Parry, *Climatic change, agriculture and settlement* (1978). R. Solantie, 'Klimatperioder och Finlands kolonisering', *Historisk Tidsskrift för Finland* 77 (1992), pp. 86–96.

Growing season (days)



MAP 1. Map showing study area location within Sweden with parish borders. Parishes included in the present study are numbered, with names listed in Table A1 in the Appendix. Grey-scale showing the average length of the growing season (days above 5°C) between 1961–1990.

Source: The author using data from <https://www.smhi.se/data/meteorologi/kartor/normal/veg-langd>, last accessed 13 Oct. 2022.

Little Ice Age, in tandem with other factors of the late medieval agrarian crises (plague being the dominant factor).¹¹

Other recent research has been concerned with exploring the spatial differences induced by the microclimatological differences *within* Jämtland. Olof Holm has argued that differences in microclimates across Jämtland shaped conditions for grain production during the medieval period. Farms located near large bodies of water were at reduced risk of early autumn frosts due to the water acting as a reservoir of heat. In contrast, arable lands surrounded by marshes and forests were more exposed to frosts due to increased heat loss. Lowlands and valleys with no large bodies of water were also at increased risk of frosts. Tilted slopes or smaller hills could in contrast offer milder conditions, especially if southward-facing.¹²

¹¹ Larsson, 'Fäbodsväsendet'. See also Welinder, 'Margin'. This can be contrasted by the argument of E. Costello, K. Kearney and B. Gearey, 'Adapting to the Little Ice Age in pastoral regions: An interdisciplinary approach to climate history in north-west Europe', *Hist.*

Methods: A Journal of Quantitative and Interdisciplinary History (2023), which states that cereal cultivation in pastoral areas of Ireland and Scotland was an adaptive strategy in the face of colder conditions.

¹² Holm, 'Självvägarområdenas'.

Autumn frosts occurring before a completed harvest have been proposed as the main agrometeorological threat facing farmers in other parts of northern Europe as well. Heli Huhtamaa, Samula Helama, Jari Holopainen, Carolin Rethorn, and Christian Rohr proposed that in Finland summer and especially spring temperatures were important in determining the outcome of the race between the ripening of the crop and the onset of the frost season.¹³ According to Jan Lindgren, pre-harvest autumn frosts occurred at such a frequency in many parts of Jämtland as to make two or more consecutive harvest failures so common that farmers had to account for them in their subsistence strategy, by relying on intra-regional trade amongst farmers. In most northern European, indeed in most European contexts, consecutive harvest failures often implied subsistence crises.¹⁴

II

Historical time series of sowing dates are exceedingly rare in the published European historiography. A Swedish exception is the study by Lennart Andersson Palm, who published sowing dates for several grains at a farm in Halland, south-western Sweden, during the period 1758–1865. This is the only longitudinal series of sowing dates in Sweden to the author's knowledge prior to the late nineteenth century. Barley was usually sown at the start of the last week in May at this farm, with the earliest sowing occurring on 7 May 1785 and the latest on 6 June 1843.¹⁵

There are other publications which shed some light on general dates in the agricultural calendar in Jämtland. In 1764, the county governor of Västernorrland ordered the county bailiffs and deputies to provide descriptions of the annual work rhythm in agriculture in the parishes of the county, including the parishes in Jämtland. Holger Wichman, Hans Medelius, and Vidar Reinhammar have subsequently published these descriptions, which include rough sowing, hay-cutting and harvesting dates. Weather (*väderlek*) is often mentioned as a factor determining the time spent on those tasks. Sowing could be held up by rainfall or snow, or if the thaw was slow. Harvests could likewise be delayed if the crop was slow in ripening. Alternatively, harvests could be prematurely forced by autumn frosts, leading to 'green years' (*grönår*) during which farmers were forced to harvest when the crop was still green.¹⁶

¹³ H. Huhtamaa, 'Crop yield responses to temperature fluctuations in nineteenth century Finland: provincial variation in relation to climate and tree-rings', *Bor. Environ. Res.* 20 (2015), pp. 707–23. Huhtamaa and Ljungqvist, 'Climate', pp. 680–1 further propose similar agrometeorological risk patterns in other parts of the Nordic countries. An alternative term for early autumn frosts is late summer frosts, for example used by T. Myllyntaus, 'Summer frost. A natural hazard with fatal consequences in pre-industrial Finland', in C. Mauch and C. Pfister (eds), *Natural disasters and cultural responses: Case studies toward a global environmental history* (2009), pp. 77–102.

¹⁴ J. Lindegren, 'Folk, hästar och bröd. Om Jämtland som agrarlogistiskt system under äldre tid', in O. Holm

(ed.), *Jämtland och den jämtländska världen före 1645*] (2011), pp. 91–6. For a European context, see D. Collet and M. Schuh, *Famines during the 'Little Ice Age' (1300–1800): Socionatural entanglements in premodern societies* (2018) as well as Pfister and Wanner, *Climate*. B. Campbell, *The great transition* (2016), pp. 6, 222 and 226 also emphasizes the subsistence crises threatening after back-to-back harvest failures.

¹⁵ Palm, *Gud*. Even though Palm analysed the relationship between yield ratios and climatic variables, he did not perform a corresponding analysis for sowing dates.

¹⁶ Holm, 'Självvägandeområdenas', pp. 23, cites a source noting a 'green-year' resulting from a forced premature harvest.

Based on the descriptions in Wichman *et al.*, it can be concluded that the dominant grain crop in Jämtland – which was spring-sown barley (rye or oats constituted only a very small proportion of overall production and wheat cultivation was non-existent) – was ideally sown sometime in early May and harvested in late August.¹⁷ According to the meteorological reference period 1961–90, the autumn frost season on average began in late August or early September in most parts of Jämtland, and could start as early as late July in the mountainous areas of western Härjedalen.¹⁸ Considering that harvesting took about two weeks, depending on local conditions, the frost and harvest seasons actually overlap. A very tight race indeed.

In tandem with the cultivation of crops, farmers kept livestock which was a crucial (and in central Scandinavia the dominant) component of the farming system, providing fertilizer, draught power for transport and arable cultivation as well as for providing food products like milk, butter, and cheese. Hay-cutting was the most labour-intensive activity in the agricultural calendar in most parts of Jämtland and Härjedalen, employing everyone on the farm for four to eight weeks during July and parts of August, taking two to four times as long as the grain harvest.¹⁹ Hay-cutting occurred at a more reliably warm part of the growing season compared to sowing or harvesting (of grains), although the date of hay-cutting could still be affected by weather, the status of the meadows, and the logistics of labour supply.

In June, it was common for the women of the household, especially the younger women, to depart to summer farms where animals were kept on summer pastures and secondary milk products were produced. These summer farms were an integral part of the overall farming system practised in Norway and northern Sweden.²⁰ The rest of the year was spent doing a multitude of tasks, e.g., cleaning up meadows or improving ditches, threshing, preparing timber, household work, and small-scale industries. Additionally, fishing, forest-related industries and transporting goods to markets were crucial components of the overall subsistence strategy of farmers in Jämtland and Härjedalen.²¹

III

Agricultural dates

To date most evidence pertaining to agricultural dates in Jämtland and Härjedalen is based on qualitative official descriptions from the eighteenth century or later. Here I employ a range of sources to reconstruct series of sowing, harvesting, and haying dates in the Lake Storsjö district between the years 1699–1920. After extensive archival research, agricultural dates have been collected from annual chronologies, farmers' diaries, agrometeorological observations, and official surveys. Farmers who kept chronologies or diaries were for the most part keen to

¹⁷ H. Wichman, H. Medelius, and V. Reinhammar, *Norrländskt arbetsliv under 1700-talet: Länsmännens berättelser 1764 om allmogens årliga arbeten i Medelpad, Ångermanland och Jämtland* (1968).

¹⁸ Maps of average frost incidence across Sweden can be found at the Swedish Meteorology and Hydrological Institutes website: [https://www.smhi.se/data/meteorologi/temperatur/genomsnittliga-datum-for-den-](https://www.smhi.se/data/meteorologi/temperatur/genomsnittliga-datum-for-den-forsta-hostfrosten-1.4074)

[forsta-hostfrosten-1.4074](https://www.smhi.se/data/meteorologi/temperatur/genomsnittliga-datum-for-den-sista-varfrosten-1.4072) and <https://www.smhi.se/data/meteorologi/temperatur/genomsnittliga-datum-for-den-sista-varfrosten-1.4072>, both last accessed 14 Sept. 2022.

¹⁹ Wichman *et al.*, *Norrländskt*, pp. 118–51.

²⁰ Larsson, 'Fäbodsväsendet'.

²¹ Wichman, *Jämtlands*. Wichman *et al.*, *Norrländskt*, pp. 118–51.

note agricultural dates. Similarly, many educated officials were interested in both agriculture (themselves often practising farmers) and meteorology (a highly fashionable science in the late eighteenth century), and the links between them, and thus kept chronologies of weather and phenology or even conducted daily instrumental meteorological measurements with notations on agricultural dates. A final source employed in this article is the Swedish Historical Phenology Dataset, covering sowing, harvesting and haying dates for up to 20 locations across Jämtland County between 1873 and 1917.²²

The relationship between the harvest dates of various crops and growing season temperatures has been researched for many parts of Europe. Øyvind Nordli was able to use barley harvest dates from several farmers diaries in neighbouring Trøndelag to reconstruct spring-summer temperatures in the eighteenth and nineteenth centuries.²³ Further south in Europe, it is mainly grape and winter-rye harvest dates that have been used to reconstruct growing season temperatures: for example, for Tallinn going back to 1734, for south-western Germany and northern Switzerland going back to 1454 and for England during the late middle ages. Combinations of various phenological dates, including harvests, have been used to reconstruct temperatures in southern Finland going back to 1750.²⁴ A common factor that facilitated all these studies was the large degree of spatial synchronicity in year-to-year temperature variations as well as of temperature-sensitive phenomena within a given region. This study operates under the assumption similar spatial synchronicities pertained to conditions in Jämtland and Härjedalen as well. Accordingly, separate series of agricultural dates are combined into longitudinal time series extending over centuries.

The sowing and harvesting dates estimated here concern spring-sown barley. Barley was the dominant cereal in the study area, constituting more than nine-tenths of total cereal cultivation. In fact, barley continues to be the predominant cereal in Jämtland and Härjedalen to this day.²⁵ A total of 33 and 37 series based on individual sources for sowing and harvesting dates were obtained, respectively, as well as 25 series from sources describing hay-cutting dates.²⁶

²² Sources for agricultural dates are listed in Table A2. Langvall *et al.*, 'Phenology'. See also O. Eriksson, K. Bolmgren, A. Westin and T. Lennartsson, 'Historic hay-cutting dates from Sweden 1873–1951 and their implications for conservation management of species-rich meadows', *Bio. Con.* 184 (2015), pp. 100–7.

²³ Nordli, 'Spring'.

²⁴ I. Chuine, P. Yiou, N. Viovy, B. Seguin, V. Daux, and E. Le Roy Ladurie, 'Grape ripening as a past climate indicator', *Nature* 432, pp. 289–90, O. Wetter and C. Pfister, 'Spring-summer temperatures reconstructed for northern Switzerland and southwestern Germany from winter rye harvest dates, 1454–1970', *Clim. Past.* 7 (2011), pp. 1307–26, K. Pribyl, R. C. Cornes, and C. Pfister, 'Reconstructing medieval April–July mean temperatures in East Anglia, 1256–1431', *CC* 113, pp. 393–412 (2012). A. Tarand, Ø. Nordli, 'The Tallinn temperature series reconstructed back half a millennium by use of proxy data', *CC* 48, pp. 189–99 (2001), Holopainen *et al.*, 'Plant'.

²⁵ Autumn-rye cultivation increased during the nineteenth century to roughly ten per cent of total cereal production (excl. potatoes), BiSOS N, *Jordbruk och boskapsskötsel Jemtlands län 1865–1911* (1872 and 1899). In 2021, rye and wheat crops together constituted less than four per cent of total cereal production, see *Jordbruksverkets statistikdatabas, Preliminära grödarealer efter Län, År och Gröda* (2021) https://statistik.sjv.se/PXWeb/pxweb/sv/Jordbruksverkets%20statistikdatabas/Jordbruksverkets%20statistikdatabas__Arealer__Preliminar%20arealstatistik/JO0104Co1.px/table/tableViewLayout1?loadedQueryId=3508562e-1cbd-4d51-a898-e374e1b002f6&timeType=item, last accessed 26 Sept. 2022.

²⁶ Hay (*hö*) presumably constituted a more heterogeneous group of different plant vegetation, cultured in more varied types of lands compared to barley. Nonetheless, the parish descriptions published by Wichman *et al.*, *Norrländskt*, suggests a coherence in hay-cutting similar to sowing and harvests.

Series describing sowing or (barley) harvesting were discarded if they numbered less than five observations contemporaneous with other series. Three series covering unique years (i.e., not covered by any other series) were kept even though they did not fulfil this criterion, in order to obtain a more continuous series. Discarding or keeping these 3 latter series did not affect the results in any significant way. After the selection process, a total of 23, 20, and 17 series of sowing, harvesting and hay-cutting dates remained, henceforth denoted as the sub-series.

The longest series of sowing and harvesting dates originates from the Lake Storsjö district, covering roughly 80 years from the late seventeenth century and early eighteenth century until the 1780s, which henceforth will comprise the main series. Using a main reference series is a common method when combining agricultural or phenological dates.²⁷ These main sowing and harvesting series were collected by the regimental auditor Erik Tryggdahl and his father, published in 1767 by the Swedish Royal Academy of Sciences. After a comparison with the primary material left by Tryggdahl, numerous inaccuracies were found in the published material. Thus, this article chiefly relies on the primary material left by Tryggdahl as the main series.²⁸ Hay-cutting dates with adequate temporal coverage from the Lake Storsjö district are first available from the parish of Myssjö from 1826. This constitutes the main hay-cutting series.

Subsequent or overlapping sub-series of harvesting, hay-cutting and sowing dates have had their means adjusted to the main series, after first converting dates into numerical values representing the number of days into the year. Eq. 1 shows how values for adjusted sub-series, x , are obtained, where $\bar{z}$ is the mean of the main series. Non-adjusted sub-series and the mean of the non-adjusted sub-series are denoted by y and $\bar{y}$, respectively. Adjusted sub-series were subsequently averaged into combined mean values, a , constituting the combined series (Eq. 2).

$$x_{it} = y_{it} - (\bar{z} - \bar{y}_i) \quad (1)$$

$$a_t = \frac{x_{1t} + x_{2t} + x_{3t} \dots + x_{4t}}{n} \quad (2)$$

The combined series of agricultural dates and the temporal coverage of sub-series are visualized in Figure 1. Even though the extent of overlap between series is lower than required for reliable statistical inference, exploratory correlation analysis yielded coefficients ranging between $r = 0.6$ and $r = 0.8$, supporting the assumption of spatial synchronicity.

²⁷ Chuine *et al.*, 'Grape', used a reference series to which other series averages were adjusted. This approach was also recommended by Holopainen *et al.*, 'Plant'.

²⁸ O. Granbom and E. Tryggdahl, 'Meteorologiska och Oeconomiska Anmärkningar, gjorde i Jämtland', *Kongl. Vetenskapsacademiens Handlingar* (1767), pp. 1–11. However, for one year, 1716, the date in the published material, 18 May, appears more realistic than in the primary material, 18 April, and for that year the information from the former is relied upon.

In no other source is such an early sowing date found, and if sowing indeed was performed on 18 April, that would imply a crop season of more than 20 weeks, more than a month longer than what was usual and also unprecedented in other material. In the primary material it is also mentioned that sowing was interrupted by snow on 7 May, further indicating that the later date of 18 May is more representative of actual sowing conditions. Nordli, 'spring', used the published material in his study.

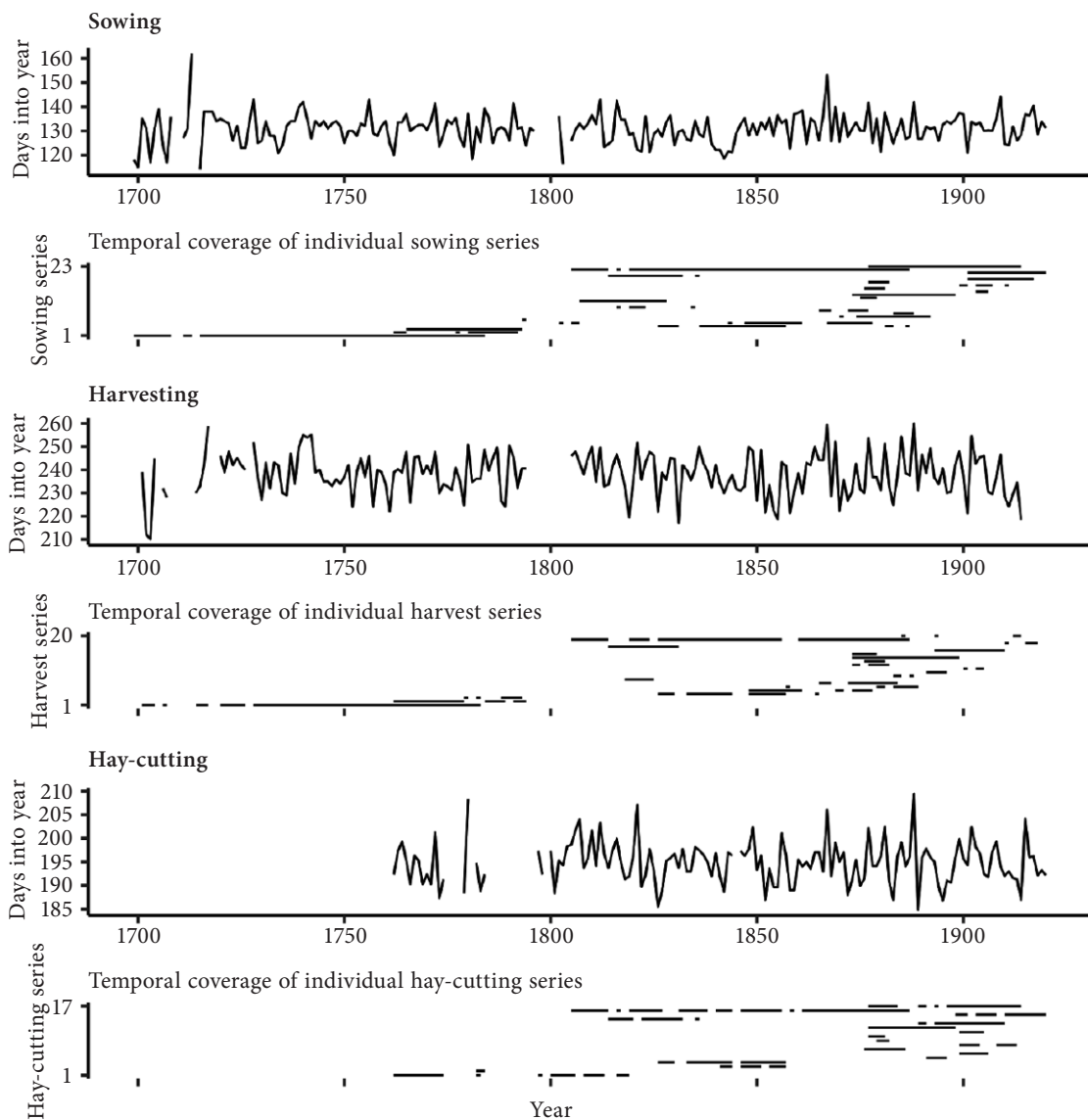


FIGURE 1. Estimated agricultural dates and for Lake Storsjö district and temporal coverage of all individual series, 1699–1920.

Sources: See Table A2.

Finally, using the established series of sowing and harvesting dates, a new series representing the crop season was calculated. Ideally, such a series would be based on the differences in each unique harvesting and sowing series, representing the crop *period*. However, since the main harvest and barley series are constituted by aggregated figures for several parishes and not specific to one location, for consistency a crop *season* series was established by subtracting the combined series of sowing dates from the combined series of harvesting dates across the Lake Storsjö district.

Sometimes sowing could begin on time only to subsequently be interrupted and delayed by bad weather. Presumably, a prolonged sowing could have had effects on the subsequent harvesting date.²⁹ For hay-cutting, bad weather might possibly have led to interruptions to work. However, hay-cutting dates exhibit a lower degree of variability compared to the other agricultural dates (see Table 1 below). Furthermore, the process of hay-cutting was usually extended, up to eight weeks, meaning that some bad weather would have been a normal part of the process.

IV

Tithes

Information on grain production comes from two different sources, grain tithes and official statistics. The grain tithe was a tax of (nominally) one-tenth of grain harvests. The grain tithe fluctuated accordance with actual harvest output, henceforth denoted 'harvest-dependent tithes' or just 'tithes'. However, tithes could also be fixed by contract or vary with harvests but paid in cash.³⁰ After the harvest each year, while the sheaves were still outside drying, local officials inspected the harvest and estimated the tithe to be collected. The structure of the tithe has allowed researchers to reconstruct harvests and the agrarian economy over time in large parts of Europe since medieval times, particularly during the early modern period when abundant source materials are available.³¹ In Sweden, tithes have been used to estimate agricultural production over time, the effects of enclosure on productivity, agricultural risk, and the impact of climate variability on grain harvests.³²

Around 7,500 tithe observations at the parish level after 1665 in Jämtland and Härjedalen have been published by Hallberg *et al.*, with some gaps. These harvest-dependent tithes were paid in kind, i.e., actual grains.³³ Here a further c.1,500 tithe observations have been collected from parish church archives and provincial records (*Landskapshandlingar*) extending back to the year 1565, as well as for some additional years after 1665. Hallberg *et al.* employed specific formulas to convert tithe observations from different parish archives along with those found in county accounts (*Länsräkenskaper*). The same formulas were applied here.³⁴ If there were

²⁹ Such examples are mentioned in Wichman *et al.*, *Norrländskt*. I use the term crop period for individual site-specific series and crop season when referring to the regional estimate.

³⁰ E. Hallberg, L. Leijonhufvud, M. Linde and L. Andersson Palm, *Skördar i Sverige före agrarrevolutionen: Statistisk undersökning av det rörliga tiondet fr.o.m 1665 – Introduktion till databaser* (2016), pp. 1, 15. See also L. Andersson Palm, *Människor och skördar. Studier kring agrarhistoriska metodproblem 1540–1770* (1993).

³¹ E. Le Roy Ladurie, *Tithe and agrarian history from the fourteenth to the nineteenth century* (1982).

³² E.g., Skoglund, 'Scania', L. Nyström, 'Scattered land, scattered risks? Harvest variations on open fields and enclosed land in southern Sweden c.1750–1850',

Res. in Econ. Hist. 35 (2019), pp. 165–202. Hallberg *et al.*, *Skördar*, L. Andersson Palm, *Sverige 1690: Åkerbruk, boskapsskötsel, skog, befolkning* (2012), M. Olsson and P. Svensson, 'Agricultural growth and institutions: Sweden, 1700–1860', *Europ. Rev. of Econ. Hist.* 14 (2010), pp. 275–304, and M. Bohman, 'Bonden, bygden och bördigheten. Produktionsmönster och utvecklingsvägar under jordbruksomvandlingen i Skåne ca 1700–1870' (PhD thesis University of Lund, 2010).

³³ Hallberg *et al.*, *Skördar*.

³⁴ Hallberg *et al.*, *Skördar*, pp. 18–20, discusses the size of the barrels and the issue of deviations from nominal leveled-measured barrels. Holm, 'Självägarområdenas', p. 110, estimates that barrels in the sixteenth century constituted roughly 140 litres.

systematic and large alterations to the size of a barrel over time, this could cause distortions to the time series. Further below, the series were checked for structural breaks.

Using the method described above, tithes from various levels were linked to a unified series covering parishes in Jämtland and Härjedalen between the years 1565–1858. However, not all parishes are covered by the entire time span. This is less of a problem when analysing parishes separately but potentially more so when data are aggregated to county level averages. Even though all parishes exhibit a large degree of crosswise correlation with all other parishes in the sample, inserting or omitting parishes in the series could cause artificial structural shifts in the mean of the series. Another issue is that due to armed conflict in some years the tithe was not collected. During the Kalmar War (1611–1613), part of the conflict was fought in Jämtland (also known as the Baltzar feud, *Baltzarfejden*). Large armies (relative to the population size of Jämtland), marched and fought across the region up until the autumn of 1612, often being provisioned by local grain. In 1611, almost no tithes were collected. During 1613, in the aftermath of the war, the Danish crown conducted large-scale investigations and retributions against peasants suspected to have supported the Swedish crown.³⁵ Considering the gaps and large uncertainties in the entire period of the Baltzar feud, the years 1611–13 were removed from the analysis. In the latter part of the Thirty Years' War, Denmark, Norway and Sweden were again at war, this was partly fought in Jämtland and Härjedalen (1643–45, *Hannibalfejden*). In 1645, Jämtland and Härjedalen were ceded to the Swedish crown. During the Swedish occupation and subsequent rule, strict orders were given to maintain the status quo in taxes.³⁶

Furthermore, the army confiscated tithes in 1657 and 1675 during the Second Northern War (1655–60) and the Scanian War (1675–79), respectively. In the latter case, while confiscations were made, efforts undertaken to maintain proper accounting were more stringent, with 1675 tithe records being reported in tandem with the tithe of 1676.³⁷ Due to the obvious distortions of and many gaps of 1657, that year was removed from the analysis, while 1675 was kept but subjected to robustness tests (see below).

New tithe inspection protocols were instituted by the Swedish state in 1775. Holger Wichman argues that this in effect led to a relative increase in estimated tithes, leading farmers in most parishes to negotiate contracts for fixed tithes in 1779. The preceding two decades, the 1760s and 1770s, had been marked by a series of harvest failures and general dearth throughout the county. It is possible that farmers saw it as advantageous to negotiate fixed tithes at this point, since the contract would be based on average harvests during the preceding period.³⁸ After 1779, several parishes resumed or continued with harvest-dependent tithes until 1809, and a

³⁵ Hasse Petrini, 'Räfssten med jämtarna 1613: rannsagningsprotokollen efter Baltzarfejden' (1959).

³⁶ J. Bromé, *Jämtland och Härjedalens Historia. Andra delen 1537–1645* (1945), p. 362. See also N. Betzén, *De kyrliga tiondeprestationerna i Jämtland och Härjedalen* (1945), pp. 38 & 52.

³⁷ In the church account books in Aspås parish it is noted in both 1657 and 1675 that the tithes were confiscated by the army, although tithe accounts for

1675 are available in the 1676 accounts, *Landsarkivet Östersund, Aspås kyrkoarkiv*, vol. L I a:1, pp. 94 and 115. Troop marches through Jämtland in 1718 and 1719 have in previous research been noted to not have affected tithes, despite numerous complaints from the peasantry regarding the devastating effects of the troop marches, Wichman, *Jämtlands*, pp. 34–6.

³⁸ Wichman, *Jämtlands*, also describes the harvest failures of the 1760s, 1770s and 1780s.

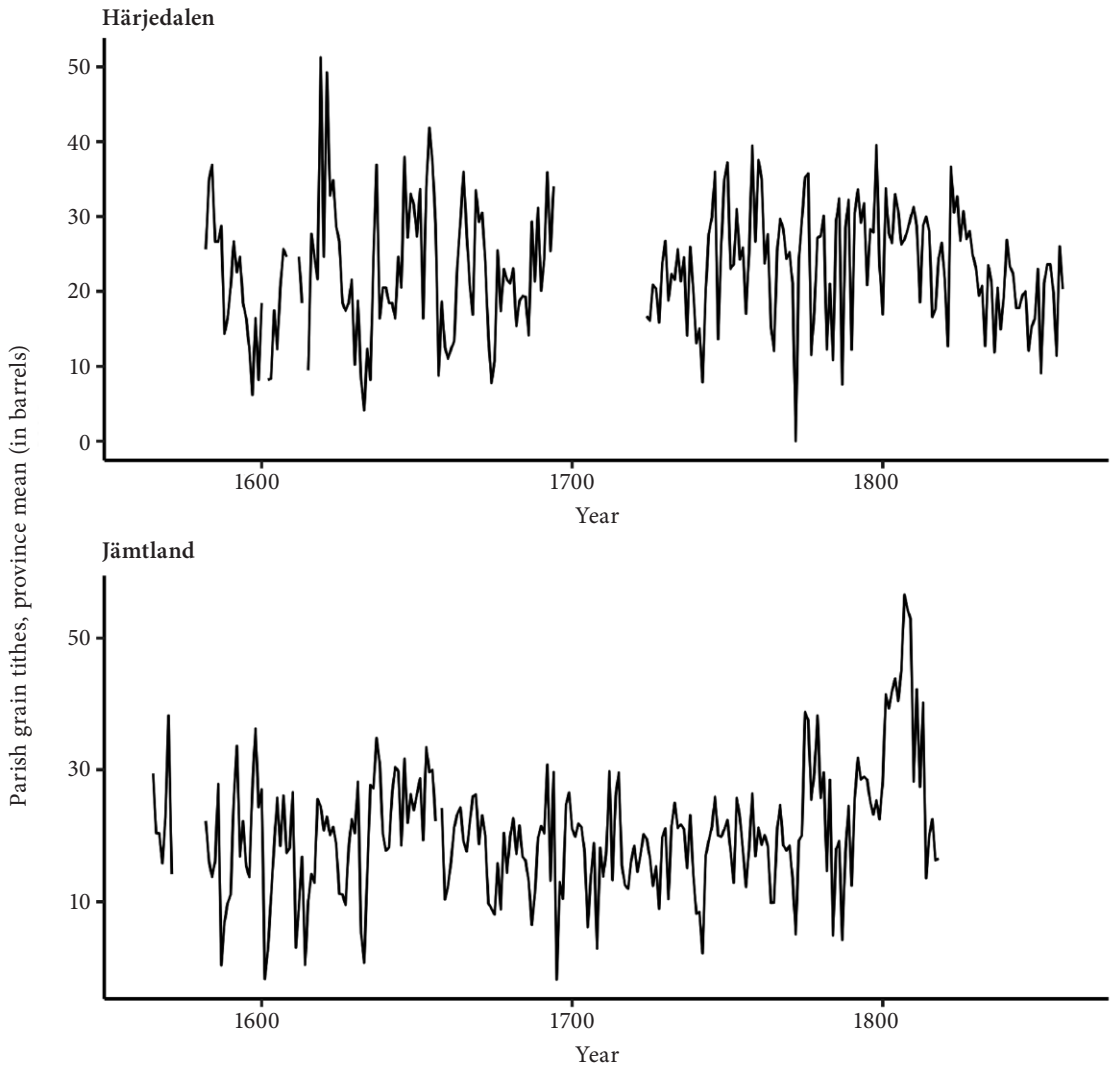


FIGURE 2. Mean tithes in barrels of grain in Jämtland and Härjedalen, 1565–1858.

Sources: Hallberg *et al.*, 'Skördar', *Kyrkoarkivens räkenskaper, 1582–1858*, Landsarkivet Östersund, *Landskaps-handlingar Jämtlands och Härjedalens handlingar, 1564–1571*, Riksarkivet.

few of them continued for yet another decade or so. In Härjedalen most parishes continued with harvest-dependent tithes until 1858, see Figure 2.

Negotiations over tithes, exemptions or outright tax avoidance could weaken the climate signal in tithe series. While farmers are usually assumed to avoid taxation, regular tithe

³⁹ Palm, 'Skördar', discusses the issue of tithe exemptions. L. Leijonhufvud, 'Grain tithes and manorial yields in early modern Sweden – Trends and patterns of

production and productivity c.1540–1680' (PhD thesis, Swedish University of Agricultural Sciences, 2001), pp. 80–3. See also, Olsson and Svensson, 'Agricultural'.

inspections and incentives for parish priests to be efficient in collection helped mitigate against tax avoidance. In her extensive work on early modern Swedish grain tithes, Lotta Leijonhufvud found little evidence of systematic changes in tithe exemptions over time.³⁹ In the present study, checks were made to control for structural breaks in the tithe series mean (see below).

Tithes in Jämtland and Härjedalen experience an upward trend after the 1770s, related to population growth and general agricultural improvements. Before this, tithe levels are very consistent, with no apparent long-term trends. Previous research has stressed that there were few changes to agriculture between the sixteenth and early eighteenth centuries. Population numbers, measured as the number of farming households, underwent large up- and downturns with little discernable long-term growth. However, after c.1750 population growth becomes dramatic. In comparison to the growth in population, the tithe series appears stagnant, albeit with a positive trend. Several factors could explain why tithe increases did not match the increase in population. In previous centuries, wars had regularly devastated Jämtland and Härjedalen. With the relative peace following 1719, population numbers were allowed to align more closely with the food-producing potential. Establishment of public granaries gradually diminished subsistence crises related to harvest failures, theoretically facilitating a larger population at a given level of production. There were other significant sources of food supply not subject to the grain tithes, most notably livestock and potatoes, but also trade, reindeer herding, fishing, hunting, garden plots, potatoes, and possibly some swidden plots as well.⁴⁰ Livestock numbers in northern Sweden increased dramatically during the so-called agrarian revolution of the eighteenth and nineteenth centuries. Increase in potato cultivation in Jämtland and Härjedalen was similarly large, especially in the nineteenth century, even overtaking barley cultivation in terms of harvest weight in the second half of that century.⁴¹ In sum, the stagnation and subsequent weak (relative to the population) trend in tithes appears realistic.

Issues related to trends and non-stationarity in the data are addressed by detrending data using a locally weighted 30-year Butterworth high-pass (henceforth HP) filter. Locally weighted detrending techniques have proven superior relative to other common detrending approaches in multiple studies looking at the relationship between agriculture, grain prices, and climate variability.⁴² To further control for potential sample biases over time, I ran formal tests to check for structural breaks in the mean in both the raw and detrended series using an

⁴⁰ The armies involved were huge in proportion to the population size of the provinces. The total number of troops operating in the region during the wars of the 17th century regularly exceeded 3,000, compared to a population of about 15,000. J. Bromé, *Jämtlands och Härjedalens historia. Tredje delen 1645–1720* (1954). See also Wichman, *Jämtlands*.

⁴¹ Larsson, 'Fäbodsväsendet'. E. Hallberg, L. Nyström, L. Leijonhufvud, and L. Andersson Palm, 'Sweden's agricultural revolution reassessed', *AgHR* 70 (2022), pp. 70–95.

⁴² See F. Charpentier Ljungqvist, P. Thejll, B. Christiansen, A. Seim, C. Hartl, and J. Esper, 'The significance of climate variability on early modern European

grain prices', *Climetrica* 16 (2022), employ a 30-year high-pass filter (HPF) which is the technique also employed in this present study. Other similar detrending techniques obtaining *normalized yield anomalies* using loess regressions include D. Beillouin, B. Schauburger, A. Bastos, P. Ciais, and D. Makowski, 'Impact of extreme weather conditions on European crop production in 2018', *Phil. Trans. R. Soc. B* 375 (2020), pp. 1–13 and J. Lu, G. Carbone, and P. Gao, 'Detrending crop yield data for spatial visualization of drought impacts in the United States, 1895–2014', *J. Ag. For. Met.* 237–8 (2017), pp. 196–208. Using normalized yield anomalies and the 30-year HPF for detrending in the present study yielded very similar results.

Indicator Saturation technique.⁴³ Identified outliers and structural breaks were then compared with known changes to the sample as well as information pertaining to the historical context.

Using a $p < 0.01$ significance level, five significant breaks were identified in the raw series, the first beginning in 1635 and lasting until 1659 following distortions most likely caused by the Second Northern War (1655–60). Another break occurred in 1801 which coincides with a large shift in the sample in 1800/01 as a number of parishes, where fixed tithes were agreed in 1779, reappear with harvest-dependent tithes for a few years. Finally, 1810 was identified as a break in the mean, the year after 1809 during which most parishes except those in Härjedalen and a few in Jämtland permanently fixed their tithes. Given that almost all these identified breaks can be associated with changes in tax collection or sample composition, adjustments were made in accordance with the identified changes in the mean, yielding a means-adjusted series.⁴⁴

In the HP-filtered tithe series, 1775 and 1777 constitute years of detected breaks possibly related to sampling biases. That year several parishes drops out of the sample, and the new tithe inspections protocols were instituted that presumably raised tithe levels. However, the break only lasts until 1777 after which the mean returns to normal levels. Furthermore, the growing seasons of 1775–76 were warmer than usual, and above average harvests for these two years do appear realistic. Therefore, no adjustment was made to the HP-filtered tithe series.

For the period 1818–70, yield ratios based on county governor reports compiled by Rodney Edvinsson are used, as well as BiSOS, *Bidrag till Sveriges officiella statistik* (Contributions to the Official Statistics of Sweden), statistics after 1865. These series were likewise detrended using HP-filtering. Yield ratio data was aggregated at the county level where year-to-year variations appear reliable.⁴⁵ HP-filtered tithes and barley yield ratio data show good correspondence in the common period 1818–58 ($r = 0.62$, see Table 3).

V

Sources on the climate in central Scandinavia, 1560–1920

Central Scandinavia is one of the best covered regions of Europe with regards to warm season temperature reconstructions. These are mainly based on tree-ring maximum latewood density (MXD) chronologies from Scots pine (*Pinus sylvestris* L.).⁴⁶ According to these reconstructions,

⁴³ G. Sucarrat, 'User-specified general-to-specific and indicator saturation methods', *Royal J.* 12 (2020), pp. 388–401.

⁴⁴ The break occurring in 1635 is more difficult to contextualize. In 1628 and in 1635 the Danish crown instituted fiscal decrees with the intent to improve relations between local and central authorities with regards to taxation. Both decrees contained explicit orders for county deputies to justify previous laxity in tax collection and without hesitation collect previously owed and current taxes. H. Bennike Madsen, *Det Danske Skattevaesen: Kategorier og Klasser – skatter på landbefolkningen 1530–1660* (1978), argues that these decrees had real consequential effects. Nominally, these reforms

would have applied to Jämtland and Härjedalen as well.

⁴⁵ R. Edvinsson, 'New annual estimates of Swedish GDP, 1800–2010', *EcHR* 66 (2013), pp. 1101–26. BiSOS N, *Jordbruk och boskapsskötsel Jemtlands län(1865–1911)*. BiSOS statistics for Scania were used in a similar study by Skoglund, 'Climate'.

⁴⁶ Notable examples here are H. Linderholm and B. Gunnarsson, 'Were medieval warm-season temperatures in Jämtland, central Scandinavian mountains, lower than previously estimated?' *Dendrochron.* 57 (2019), pp. 1–10, and P. Zhang, H. W. Linderholm, B. Gunnarson, J. Björklund, and D. Chen, '1200 years of warm-season temperature variability in central Scandinavia inferred from tree-ring density', *Clim. Past*

cold temperatures (compared to the 1961–90 mean) prevailed throughout the study period until the 1910s. This prolonged cold period constitutes the latter part of the LIA.⁴⁷ High-frequency temperatures exhibit large year-to-year variations and even during colder periods there were mild or warm years, for example the 1660s and 1820s experienced many warm summers (see Figure 3 below).⁴⁸

The study period begins during a particularly cold period starting in the 1570s and lasting until the early 1600s. These decades were exceptionally cold and wet across large parts of Europe, contributing to repeated years of severe harvest failures and dearth.⁴⁹ The late 1690s constitutes another markedly cold period, causing large harvest losses across Europe and known for harvest failures, famine, and severe hardships across the Baltic region.⁵⁰ Another markedly colder period occurs in the 1780s and early 1790s.⁵¹

Instrumental temperature observations are available sporadically and with large gaps from different locations in the Lake Storsjö district during the years 1762–1828. Consecutive instrumental temperature records from Östersund, the main town in Jämtland, located at the eastern edge of Lake Storsjön, are available from 1860 onwards. Trondheim in Trøndelag province, located in Norway to the west of Jämtland, has consecutive records from 1761 onwards.⁵² The Trøndelag series will be employed here because of its greater consistency and homogeneity compared to the intermittent and heterogeneous early instrumental records from the Lake Storsjö district. Instrumental records from Östersund exhibit a large degree of coherence with those from Trøndelag in the period 1861–1979 (Pearson's r for all months between 0.89 and 0.97).⁵³

In addition, this study will rely on central Scandinavian tree-ring MXD temperature reconstructions for the warm season (April–September). These reconstructions have the highest skill in reconstructing August temperatures, with a descending skill going backwards to April or forwards to September. The recent reconstruction by Linderholm and Gunnarson, henceforth LG19, has the largest sample depth (of tree-ring samples)

[henceforth CP] 12 (2016), pp. 1297–1312, M. Fuentes, R. Salo, J. Björklund, K. Seftigen, P. Zhang, B. Gunnarson, J.-C. Aravena, and H. W. Linderholm, 'A 970-year-long summer temperature reconstruction from Rogen, west-central Sweden, based on blue intensity from tree rings', *Holocene* [henceforth H] 28 (2018), pp. 254–66 as well as B. Gunnarson, H. W. Linderholm, and A. Moberg, 'Improving a tree-ring reconstruction from west-central Scandinavia: 900 years of warm-season temperatures', *Clim. Dyn.* 36 (2011), pp. 97–108.

⁴⁷ H. Wanner, C. Pfister, and R. Neukom, 'The variable European Little Ice Age', *Quat. Sci. Rev.* 287 (2022), pp. 1–13.

⁴⁸ Linderholm and Gunnarsson, 'Medieval temp.', p. 5.

⁴⁹ For a European overview, see Pfister and Wanner, *Climate*, pp. 193–206, 271–3. An English case study can be found in R. W. Hoyle, 'Shrewsbury, dearth, and extreme weather at the end of the sixteenth century', *AgHR* 68 (2020), pp. 22–36.

⁵⁰ L. Brunt, 'Weather shocks and English wheat

yields, 1690–1871', *Expl. in Econ. Hist.* 57 (2015), pp. 50–8. M. Dribe, M. Olsson and P. Svensson, 'Nordic Europe', in G. Alfani and C. Ó Gráda (eds) *Famine in European history* (2017), pp. 185–211, discusses this event.

⁵¹ Linderholm and Gunnarsson, 'Medieval temp.', Gunnarsson *et al.* 'Improving'.

⁵² J. H. Lawrimore, M. J. Menne, B. E. Gleason, C. N. Williams, D. B. Wuertz, R. S. Vose, J. Rennie, 'An overview of the Global Historical Climatology Network monthly mean temperature data set, version 3', *J. Geophys. Res.* 116 (2011), D19121. B. J. Birkeland, 'Old meteorological observations at Trondheim – Atmospheric pressure and temperature during 185 years', *Geof. Publ.* 15 (1949), pp. 5–38.

⁵³ Instrumental measurements from Östersund can be downloaded from SMHI, *SMHI öppna data – ladda ner meteorologiska observationer* <https://www.smhi.se/data/meteorologi/ladda-ner-meteorologiska-observationer#param=airtemperatureInstant,stations=core> last accessed 28 March 2023.

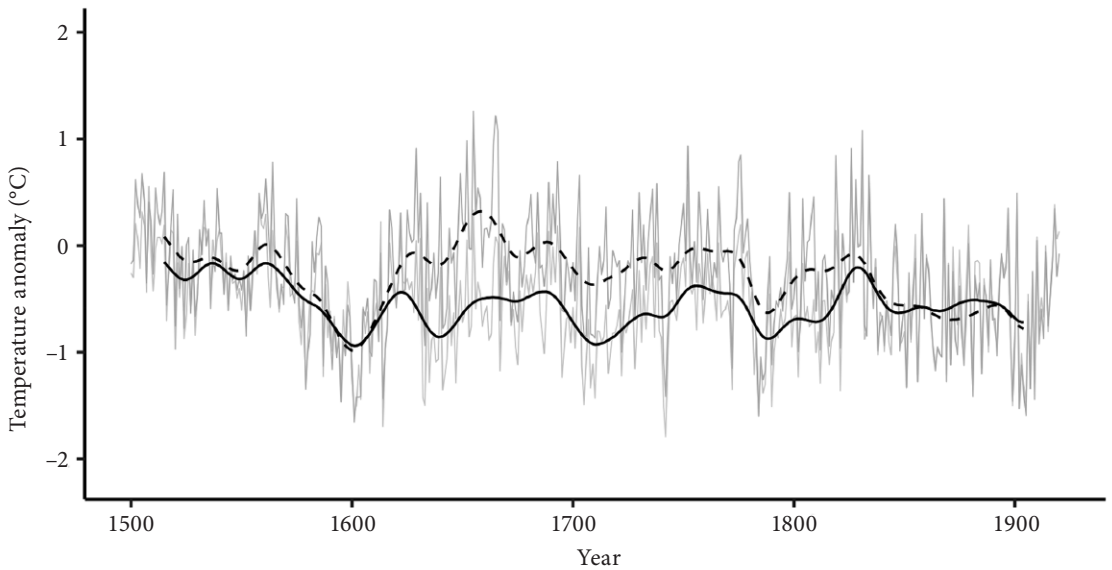


FIGURE 3. Comparison between G11 (solid line) and LG19 (dashed line) temperature anomalies (relative to the 1961–1990 mean) smoothed using a 31-year Gaussian filter during the years 1500–1920. Non-smoothed values are shown in light grey (G11) and grey (LG19).

Sources: Linderholm and Gunnarson (2019) and Gunnarson *et al* (2011).

between the fourteenth and sixteenth centuries. The reconstruction by Gunnarson *et al.*, henceforth G11, has the largest sample depth of these reconstructions between the sixteenth and eighteenth centuries. G11 has been argued to contain a bias through its inclusion of timber from historical buildings at lower altitudes in a sample that was otherwise concentrated in high-altitude mountainous regions.⁵⁴ For the present study, this bias potentially makes the reconstruction more relevant since the settled areas at lower altitudes were the main agricultural areas.⁵⁵ The larger sample depth in G11 from the sixteenth through the eighteenth centuries also aligns with the period when tithe records are most abundant. Reconstructed temperatures in G11 and LG19 differ during the seventeenth and eighteenth centuries, with LG19 generally proposing a warmer climate, as seen in Figure 3. Given these differences, both G11 and LG19 are employed here.

Parametric analysis and spatial mapping

Relationships between harvests, agricultural dates and climate variability were investigated using Pearson's correlation coefficients and regression analysis (see details in Tables 3 and 5).

⁵⁴ Linderholm and Gunnarsson, 'Medieval temp.', Gunnarsson *et al.*, 'Improving', Zhang *et al.*, '1200 years', P. Zhang, J. Björklund and H. W. Linderholm, 'The influence of elevational differences in absolute maximum density values on regional climate reconstructions', *Trees* 29 (2015), pp. 1259–71.

⁵⁵ A possible downside with the series is the presence of non-temperature climatic signals, like precipitation. No precipitation signal was found in the series in exploratory analysis using monthly precipitation data from Östersund 1863–1980, SMHI, *öppna data*.

To distinguish spatial patterns in the relationship between mean warm season temperatures and parish-level tithes, Geographic Information Systems (GIS) mapping was performed using the QGIS software.⁵⁶

V

Based on previous research, sub-regional differentiation in the degree of temperature sensitivity should be expected given the variability in geographical factors like ruggedness, forest cover and the availability of large bodies of water.⁵⁷ As noted above, growing season temperatures has been argued to play an important role in determining the risk for harvest losses caused by autumn frosts in northernmost Europe.⁵⁸ In the following, correlation coefficients between growing season temperatures and tithes at the parish level, representing temperature sensitivity, are presented using GIS mapping (Map 2).

The highest correlation coefficients between raw and HP-filtered tithes and mean growing season temperatures were obtained from the southern mountainous parishes of Härjedalen, parishes like Åre and Kall in the north-western mountainous region and northern parishes like Ström and Hammerdal. The eastern parts of the county, e.g., the parishes in the Ragunda and Revsund court districts, as well as several parishes around Lake Störsjön like Norderön, Frösön, Näskott, and Rödön, yield generally lower coefficients, indicating a lower degree of temperature sensitivity. These latter parishes are usually presented as hosting conditions more favorable to agriculture compared to other parts of Jämtland. Norderön for example was known as one of the best localities for grain (barley) production in Jämtland, offering exceptional soils that were less prone to suffer autumn frosts before harvest. Court records from Hallen report on terrible crop damages inflicted by cold and frost in 1708, leaving most farmers without seed grain, with the important exception of the farmers on Norderön. During one of the worst harvest failures of the nineteenth century following the exceptionally cold summer of 1821, Norderön was the only parish that managed to bring in a sufficient harvest.⁵⁹

VI

The average start of spring sowing, i.e., the sowing date, was on 10 May. The earliest sowing date was on 24 April 1715 (which was exceptionally early) and the latest was on 11 June 1713. Harvests were well above average in 1715 and low in 1713, according to tithe records. Another notable year with sowing in June was 1867, a year with an exceptionally cold spring and notorious for

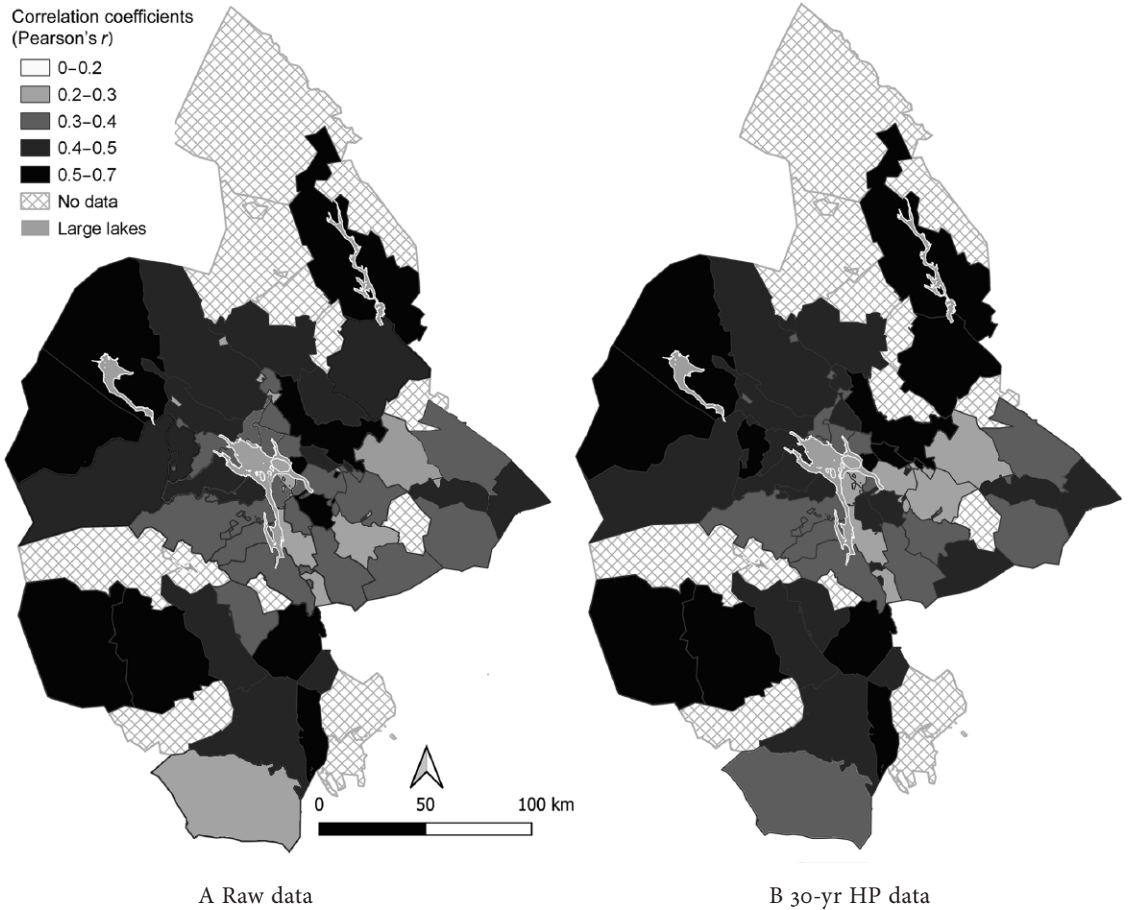
⁵⁶ T. Sutton, O. Dassau, and M. Sutton, 'Gentle GIS introduction', *QGIS project* (2022), <https://docs.qgis.org/3.22/pdf/en/QGIS-3.22-GentleGISIntroduction-en.pdf> last accessed 12 October 2022.

⁵⁷ Holm, 'Självägarområdenas', pp. 22–5.

⁵⁸ Huhtamaa and Ljungqvist, 'Climate', p. 681.

⁵⁹ Holm, 'Självägarområdenas', pp. 22–5. S. Olofsson, 'Till ömsesidig nytta: Entreprenörer, framgång och sociala relationer i centrala Jämtland ca. 1810–1850' (PhD

thesis, Uppsala University, 2011), pp. 42–4 describes the comparably favorable conditions in Rödön. S. J. Kardell, *Jämtlands läns kungl. hushållningssällskap: 1817–1917 / på grund af uppdrag och under medverkan af fackmän* (1917), p. 47, describes the harvest failures of 1821. A. Tegen, 'Hallens tingslags domboksprotokoll 1701–1710' (2021), p. 141, see <http://fornskrift.se/wp-content/uploads/2021/05/Hallens-dombok-1701-1710.pdf> last accessed 20 March 2023.



MAP 2. Spatial representation of correlations between parish-level tithes and mean summer temperatures.

Notes: A) shows results from raw non-detrended tithe data between the years 1565–1779 and B) shows results from 30-year High-Pass filtered tithe data during the same years. Parishes vary in their temporal coverage.

its very severe harvest failures in both Finland and northern present-day Sweden.⁶⁰ Descriptive statistics of agricultural dates are shown below (Table 1).

Harvesting began, on average, on 26 August, with the latest harvest date on 16 September, occurring in the years 1717, 1867, and 1888. The harvest output of 1717 was the lowest for a nearly two-decade long period, according to tithe records. The earliest harvest occurred on 24 July 1703, which was an unprecedentedly early harvest. The previous year likewise experienced an exceptionally early harvest date. Tithes and mean growing season temperatures were above average in both 1702 and 1703. On average, the crop season, i.e., the time between sowing and harvesting, lasted c.15 weeks. The shortest crop seasons occurred in 1702 and 1703, lasting c.11.5 and 12.5 weeks, respectively.

⁶⁰ D. Curran, L. Luciuk and A. G. Newby (eds), *Famines in European economic history: the last great European famines reconsidered* (2019).

TABLE 1. Descriptive statistics of series of agricultural dates, 1699–1920

	<i>Coverage (years excl. gaps)</i>	<i>Mean (date)</i>	<i>SD</i>	<i>Min. (date/year)</i>	<i>Max. (date/year)</i>
Sowing	1699–1920 (214)	131 (11 May)	6.38	114 (24 April)	162 (11 June)
Hay-cutting	1762–1920 (142)	195 (14 July)	4.54	185 (4 July)	209 (28 July)
Harvesting	1701–1914 (194)	238 (26 Aug.)	9.32	205 (24 July)	260 (16 Sept.)
Crop season	1701–1914 (194)	107	8.56	81 (1702)	130 (1821)

Notes: In the coverage column, the number of years are designated in parenthesis, whereas in the Mean, Min. and Max. columns, dates/years are given in parenthesis. Mean, standard deviations (SD), min. and max. values are based on number of days into year.

The crop season of 1821 was the longest in the series and lasted roughly 18.5 weeks. Sowing began early, but was followed by cold weather throughout the summer, severely delaying the harvest, which was subsequently subject to frost damages and ultimately harvest failures (tithes were exceptionally low in 1821).⁶¹ The earliest hay-cutting date occurred on 4 July 1889, and the latest on 28 July 1888, each year experiencing a warm and cold summer, respectively. Greater stability is displayed by hay-cutting dates with a smaller range and a lower standard deviation compared with harvesting or sowing. Results from the analysis of the relationships between agricultural dates, temperatures and harvests are presented below.⁶²

Temperature, agricultural dates and harvests

Tithes aggregated at the county level exhibited statistically significant positive correlations with both mean spring and growing season temperatures (i.e., warmer temperatures were associated with larger harvests), where the effect from growing season temperatures was larger than that of spring temperatures alone. However, the growing season-tithe correlation was based on 281 pair-wise observations whereas that of spring tithe was based on only 96 paired values. Table 2 lists these and other correlation coefficients. All the reported associations except hay-cutting dates vs tithes ($p < 0.05$), were highly statistically significant ($p < 0.01$). Sowing-, hay-cutting-, and harvesting dates were all significantly negatively correlated with tithes, i.e., a later sowing or harvesting date reduced harvests, with harvest dates in particular having the largest effect. The means adjusted tithe series provided results comparable to those of the HP-filtered tithe series (1565–1858), with slightly lower coefficients for the former.

Comparing results obtained using tithes with yield ratios in Jämtland between 1818–1911 gave similar results (see Table 3). Barley yield ratios, but also yield ratios for autumn rye and

⁶¹ Wichman, *Jämtlands*, p. 464.

⁶² In exploratory analysis, performing correlations between harvests or agricultural dates and precipitation indicators (available from 1862 from Östersund) gave mostly insignificant and weak results. Similarly, the Palmer Drought Severity Index from E. R. Cook *et al.*, 'Old World megadroughts and pluvials during the Common Era', *Sci. Adv.* 1, 10 (2015), gave only

insignificant and inconsistent results. Correlations between harvests and lagged (one year) growing season temperatures gave positive but weak and mostly insignificant results. Considering maximum or minimum monthly temperatures (available from Östersund from 1860), gave results very similar to using mean temperatures but of consistently smaller magnitudes.

TABLE 2. Pairwise correlations (Pearson's *r*) between tithes, dates in the agricultural cycle and temperatures

Tithe vs.	1565–1858 (<i>raw</i>)	1565–1858 (30-yr HP)
Sowing date (from 1699)	-0.30*	-0.31*
Harvest date (1762–1914)	-0.42*	-0.44*
Barley crop season (from 1701)	-0.24*	-0.24*
Hay-cutting date (from 1762)	-0.27	-0.32
AMJJAS temperature (G11/LG19)	0.45*/0.37*	0.51*/0.45*
MAM temperature (from 1761)	0.31*	0.35*
Harvest date vs.	1701–1914	
Sowing date	0.44*	0.44*
Hay-cutting date (from 1762)	0.72*	0.72*
AMJJAS temperature (G11/LG19)	-0.66*/-0.57*	-0.73*/-0.71*
MAM temperature	-0.40*	-0.41*
Sowing date vs.	1699–1920	
MAM temperature (from 1761)	-0.52*	-0.55*
Hay-cutting date	0.40*	0.42*
Hay-cutting date vs.	1762–1920	
MAM temperature	-0.46*	-0.47*
AMJJAS temperature (G11/LG19)	-0.47*/-0.36*	-0.48*/-0.41*
Crop season vs.	1701–1914	
AMJJAS temperature	-0.51*/-0.42*	-0.57*/-0.57*
MAM temperature (from 1761)	-0.05	-0.06
Hay-cutting date (from 1762)	0.51*	0.51*

Notes: Months have been abbreviated to single letters, e.g., JJA denotes June, July and August, $p < 0.05$ is marked in bold, $p < 0.01$ is marked with a *. Non-detrended correlations are indicated under 'raw' and 30-year High-Pass filtered data under '30-yr HP'.

peas showed correlations with mean growing season temperatures akin to those obtained from tithes, albeit with larger coefficients. Consistent signs were obtained through yield ratio agricultural date correlations and of greater magnitudes when compared with tithes. Yield ratios for potatoes stood out by their much weaker relationships with temperature variables as well as agricultural date variables. Considering monthly temperature variables and yield ratios, the month of August stood out for barley, autumn sown rye and pulses; whereas January and June temperatures conveyed moderate positive correlations with potato yield ratios. Only about half of the variance for potato yield ratios was explained in regression models using harvest dates and mean growing season temperatures compared with other crops (see Table 4).

TABLE 3. Correlations between crop yields, temperatures and agricultural dates, 1818–1911

Crop	Jan _T	Feb _T	Mar _T	Apr _T	May _T	Jun _T	Jul _T	Aug _T	Sept _T
Barley	0.13	0.16	0.30	0.25	0.35	0.40	0.34	0.48	0.30
Potatoes	0.26	0.13	0.15	0.26	0.33	0.48	0.26	0.37	0.16
Rye	0.14	0.06	0.29	0.15	0.35	0.38	0.49	0.58	0.26
Oats	0.13	0.21	0.30	0.33	0.40	0.33	0.31	0.46	0.24
Peas	0.08	0.25	0.28	0.27	0.32	0.34	0.33	0.50	0.22
	JFMA _T	MAM _T	JJA _T	AMJJAS _{TRC}	MAMJJAS _T	Tithes (1818–1858)	Sowing	Harvesting	Hay-cutting
Barley	0.29	0.41	0.54	0.56	0.61	0.62	−0.40	−0.67	−0.60
Potatoes	0.26	0.31	0.48	0.39	0.49	0.41	−0.33	−0.50	−0.49
Rye	0.23	0.37	0.64	0.62	0.64	0.53	−0.37	−0.75	−0.60
Oats	0.31	0.45	0.47	0.61	0.58	0.58	−0.44	−0.64	−0.62
Peas	0.31	0.41	0.52	0.63	0.57	0.48	−0.42	−0.67	−0.57

Notes: Statistically significant coefficients (p -value < 0.05) are marked in bold. Climatic and other agricultural data are described in the sources section. Combinations of months are abbreviated using single letters, all temperature values are given in mean values and indicated by _T. Data on crop-yields between 1818–70 were compiled by Prof. Rodney Edvinsson at Stockholm University as part of a research project to reconstruct The Swedish historical national accounts who generously shared this data. See R. Edvinsson, 'New annual estimates of Swedish GDP, 1800–2010', *EcHR* 66 (2013), pp. 1101–26. For the period after 1870 data from official statistics (BiSOS) were used. Considering the samples separately yielded similar results, albeit with larger magnitudes in the latter sample and smaller with the former, compared with the full period 1818–1911. Previous year autumn and winter temperatures yielded no statistically significant effects. All series were detrended using a 30-year HP filter.

TABLE 4. Estimation of effects on crop yields (1818–1911)

	<i>Dependent variable:</i>				
	<i>Barley</i> (1)	<i>Potato</i> (2)	<i>Autumn-rye</i> (3)	<i>Oats</i> (4)	<i>Peas</i> (5)
MAMJJAS temp.	0.507*** (0.192)	0.556* (0.314)	0.524** (0.236)	0.577** (0.240)	0.426 (0.279)
Harvesting	−0.070*** (0.017)	−0.072** (0.028)	−0.122*** (0.021)	−0.079*** (0.021)	−0.121*** (0.024)
Constant	17.982*** (5.233)	18.612** (8.616)	31.588*** (6.504)	18.000*** (6.565)	29.505*** (7.608)
Observations	92	92	92	92	92
R ²	0.498	0.288	0.583	0.446	0.483
Adjusted R ²	0.487	0.271	0.573	0.433	0.471
Residual Std. Error (df = 88)	1.044	1.703	1.285	1.302	1.511
F Statistic (df = 2; 88)	43.7***	17.8***	61.4***	35.4***	41***

Notes: Variables were detrended using a 30-yr HP-filter. Cochrane-Orcutt estimation, see Table 5.

* $p < 0.1$; ** $p < 0.05$; *** $p < 0.01$

TABLE 5. Estimations of effects on grain tithes

	<i>Dependent variable:</i>					
	<i>HP-filtered tithes</i>			<i>Raw tithes</i>		
	<i>(1701–1858)</i>	<i>(1699–1858)</i>	<i>(1701–1858)</i>	<i>(1701–1858)</i>	<i>(1699–1858)</i>	<i>(1701–1858)</i>
AMJJAS temp.	6.804*** (1.578)	7.318*** (1.027)	6.533*** (1.547)	5.041*** (1.451)	6.474*** (1.004)	5.271** (1.439)
Harvest date	–0.072 (0.074)		–0.036 (0.075)	–0.123* (0.070)		–0.065 (0.072)
Sowing date		–0.206*** (0.064)	–0.199** (0.081)		–0.226*** (0.064)	–0.200** (0.082)
Constant	–15.607 (29.659)	–10.742 (13.932)	3.960 (29.690)	12.507 (27.483)	–0.2987 (13.992)	22.317 (27.987)
Observations	138	152	137	138	152	137
R ²	0.303	0.349	0.329	0.264	0.330	0.300
Adjusted R ²	0.293	0.340	0.315	0.253	0.320	0.281
Residual Std. Error	5.050 (df = 134)	4.938 (df = 148)	4.929 (df = 132)	5.289 (df = 134)	5.193 (df = 148)	5.182 (df = 132)
F Statistic	29.1*** (df = 2; 134)	39.6*** (df = 2; 148)	21.7*** (df = 3; 132)	24.0*** (df = 2; 134)	36.3*** (df = 2; 148)	18.5*** (df = 3; 132)

Notes: Time series of temperatures and agricultural dates were all approximately normally distributed and did not exhibit any significant autocorrelation. Tithe series, even after detrending, exhibited a weak AR(1) structure. Similarly, autocorrelation (1) was identified in the residuals in OLS multivariate regressions. To account for this, all models were adjusted using Cochrane-Orcutt estimations. Multicollinearity was checked for all models, with the Variation Inflation Factor never exceeding 1.9 for any variable. *p < 0.1; *p < 0.05; **p < 0.01

Dates for sowing, hay-cutting, harvesting, and the length of the crop season all showed negative associations with growing season (the latter three) or spring temperatures (all three types of dates), where the largest coefficients were obtained for harvest dates *vs* mean growing season temperatures ($r = -0.73$). In other words, colder growing seasons were associated with later hay-cutting and harvesting dates, and colder springs with later occurrences of all types of agricultural dates. There were also significant associations between the various dates in the agricultural cycle. Harvest dates were positively correlated with both sowing dates and hay-cutting dates, implying that later sowing or hay-cutting in the season delayed harvests. The correlation between hay-cutting dates *vs* harvesting dates was especially large with a positive coefficient of $r = 0.72$. Using linear regression, an attempt was made to control for the independent effects of climatic and agricultural dates. In the first series of regression models the effects of mean growing season temperatures and agricultural dates on tithes were estimated (Table 5). Controlling for mean growing season temperatures, neither harvest date nor hay-cutting date yielded statistically significant results, whereas the negative effect of sowing date on harvest (i.e., later sowing leading to lower harvests) remained statistically significant when controlling

TABLE 6. Estimations of effects on harvesting

	<i>Dependent variable: Harvest date</i>			
	(1701–1914)	(1762–1914)	(1761–1914)	(1762–1914)
AMJJAS temp.	–13.043*** (1.027)	–8.038*** (1.126)	–12.121*** (1.203)	–8.114*** (1.154)
Sowing date	0.362*** (0.079)	0.181** (0.089)	0.332*** (0.109)	0.196* (0.103)
Hay-cutting date		0.965*** (0.121)		0.971*** (0.123)
MAM temp.			–0.187 (0.499)	0.140 (0.488)
Constant	307.164*** (16.215)	98.114*** (29.440)	303.387*** (19.726)	95.329*** (31.210)
Observations	193	129	144	129
R ²	0.585	0.709	0.563	0.710
Adjusted R ²	0.580	0.702	0.553	0.700
Residual Std. Error	6.230 (df = 189)	5.317 (df = 124)	6.369 (df = 139)	5.337 (df = 123)
F Statistic	133*** (df = 2; 189)	100.6*** (df = 3; 124)	59.6*** (df = 3; 139)	75*** (df = 4; 123)

Notes: See Table 5. *p < 0.1; **p < 0.05; ***p < 0.01

for other variables. Hence, a 1°C increase in mean growing season temperatures lead to an increase of 5–7 barrels in the average tithes paid across parishes. This corresponds to an 18–25 per cent increase, relative to the long-term mean, in tithes. One day later sowing reduced tithes by 0.2 barrels or a roughly 0.8 per cent decrease in tithes.

Running similar models but using harvest date as the dependent variable, mean growing season temperatures, hay-cutting dates (included in two models) and sowing date in all models but one, remained statistically significant, when controlling for other factors (Table 6). Mean spring temperatures were not statistically significant when controlling for other factors like sowing and hay-cutting dates. Finally, the effects of spring and growing season temperatures as well as sowing dates were all found to have statistically significant effects on hay-cutting dates (Table 7). All variables had consistent relationships, albeit not always statistically significant, across all regression models. The effects of mean growing season temperatures on harvest date ranged between an 8–13 days decrease for every one-point increase in temperature, whereas hay-cutting performed one day later corresponded to a delayed harvest of roughly one day. The effects of a one-point increase in sowing date varies across models between ca 0.2–0.4 days, when controlling for other factors like growing season temperatures and hay-cutting dates.

Results from estimations of the effects on hay-cutting dates from other agricultural dates and temperature variability indicated that a one-point increase in mean growing season temperatures lead to a 3–4.5 day decrease in the hay-cutting date, whereas a 1°C increase in

TABLE 7. Estimations of effects on hay-cutting

	<i>Dependent variable: Hay-cutting date</i>			
	(1762–1920)	(1762–1920)	(1762–1920)	(1762–1920)
AMJJAS temp.	–4.510*** (0.694)	–3.750*** (0.703)	–3.199*** (0.744)	–3.177*** (0.742)
Sowing date		0.223*** (0.059)		0.149** (0.068)
MAM temp.			–1.081*** (0.278)	–0.693** (0.325)
Constant	235.263*** (6.221)	199.207*** (11.537)	226.710*** (6.342)	205.805*** (11.777)
Observations	142	138	142	138
R ²	0.233	0.326	0.310	0.344
Adjusted R ²	0.228	0.313	0.300	0.329
Residual Std. Error	4.017 (df = 139)	3.813 (df = 134)	3.828 (df = 138)	3.764 (df = 133)
F Statistic	42.3*** (df = 1; 139)	32*** (df = 2; 134)	31*** (df = 2; 138)	23.2*** (df = 3; 133)

Notes: See table 5. *p < 0.1; **p < 0.05; ***p < 0.01

mean spring temperatures led to up to one day earlier hay-cutting. Finally, a one-day delay in sowing led to a delay of roughly one fifth of a day in hay-cutting. The variation explained by the models ranged from 23–33 per cent in hay-cutting dates, 55–70 per cent in harvest dates and 25–32 per cent in tithes, respectively.

VII

Long winters and short summers were a standing facet of the climate in Jämtland. The primary concern facing households after long winters were fodder shortages. While not as common, winter conditions with snow, ice-covered lakes and frozen soils could last throughout May and even into June, which delayed sowing, the growth of summer hay and hay-cutting. This in turn, had detrimental effects on the harvesting by prolonging the ripening of the crop further into the threatening frost season. If the summer also proved cold, the situation was set for a disastrous agricultural year. Even if the spring season proved favorable, a cold summer was enough by itself to severely delay harvests and risk large harvest losses or harvest failures, like in 1821. While an exact account is beyond the scope of this article, documentary sources investigated by the author suggests at least one in five years experienced large-scale frost-triggered harvest losses.⁶³

Over the years 1565–1858, mean growing season temperatures alone explained 26 per cent of variations in tithes, and 53 per cent of variations in harvest dates during the years 1701–1914.

⁶³ Huhtamaa and Ljungqvist, 'Climate'.

Combinations of one or two climate indicators and harvest dates could explain 25–34 per cent of variations in tithes during the years 1699–1858. Similar combinations explained 22–70 per cent of variations in agricultural dates, depending on the model. Growing season temperatures alone could explain 25–41 per cent of variations in yield ratios. The combination of growing season temperatures and harvest dates explained 27–57 per cent of yield ratio variations, with potatoes at the lower end and rye at the higher end. Overall, the most important variable in all the estimated agrometeorological relationships was mean growing season temperatures, although when other variables were included the effect from mean growing season temperatures was reduced. Considering monthly temperatures, August was clearly the most important month, followed by June, May, and July. Less important and only partially significant were the months of March, April and September. August being the most important month is probably indicative of the role played by frosts.

Seen in a broader European perspective, the temperature sensitivity of agriculture in Jämtland and Härjedalen contrasts starkly to areas in latitudes further south. For example, in southern Sweden or the Low Countries, single climate indicators have explained about ten per cent or less of medieval or early modern harvest variations.⁶⁴ Of course, monthly or seasonal climate indicators can only account for part of the climatic impact on historical harvests. As the example of autumn frosts make clear, weather outcomes in single days or combinations of days, could have large effects on harvests. To come closer to explaining the full climatic impact on harvests would require more detailed and differentiated climatic and harvest data. Furthermore, climate-harvest/yield relationships are not strictly linear. These relationships tend to take asymmetric bell-shaped forms, meaning that extreme years in either direction could be bad, but with one type of extreme typically being worse than the other, like extremely cold growing seasons in northern Fennoscandia and the north Atlantic region, extreme rainfall in England or drought in southern Europe.⁶⁵

Spring sowing, or *våranden* (roughly translated as ‘springing’ or ‘spring making’) as it is often referred in the sources, was a short process lasting about one week or less. Bad weather, especially heavy rains, but also snow, could cause abrupt halts to sowing. Thus, even though the process of sowing itself lasted only about a week, it nonetheless operated on a limited time-window when the weather was adequate. Most importantly, sowing had to be completed speedily to give the crop sufficient time to ripen before the autumn frosts. Later sowing, furthermore, led to delays in hay-cutting. Given the ample time between sowing and hay-cutting, this probably had more to do with the fact that very same cold conditions that contributed to delayed sowing also delayed growth in the meadows, than due to a postponement of the agricultural work season. However, even after controlling for spring and growing season temperatures, the date of sowing still had a negative effect on hay-cutting

⁶⁴ Skoglund, ‘Scania’ show estimates for southern Sweden, and T. Soens, ‘No second Lord: Agriculture and climatic variability in the late medieval Low Countries’, in C. Weeda, R. Stein, and L. Sicking (eds), *Communities, environment and regulation in the premodern world*, CORN 20 (2022), pp. 71–98 shows estimates for the Low Countries.

⁶⁵ M. Dell, B. F. Jones, and B. A. Olken. ‘What do we learn from the weather? The new climate-economy literature’, *J. Econ. Lit.* 52 (2014), pp. 740–98. Parry, *Climatic*. Brunt, ‘Weather’, K. Pribyl, ‘A survey of the impact of summer droughts in southern and eastern England, 1200–1700’, *CP* 16 (2020), p. 1027. Martin *et al.*, ‘Climatic’.

dates. Thus, it appears hay-cutting was not only determined by climatic variability and weather but also by human decision-making and labour availability during the agricultural season. Sowing and hay-cutting were crucial events, but there were many other important tasks to be performed during the summer and any delays to a fully packed schedule would necessarily require prioritizations and risk-taking.

The autumn frost was a very real and always present threat given the overlap with the harvest season. However, the exact date when the frost season would begin on any given year would have been unknown. Furthermore, frost could appear one night and then not reappear for days or even weeks. These uncertainties created obvious risks but at the same time they gave room for active decision-making, for example regarding whether to continue the important hay-cutting for as long as possible before harvesting or to wait with harvesting a little longer if the frost season had not yet begun. Descriptions from the eighteenth century describes how hay-cutting often continued until the very start of harvesting and how hay-cutting sometimes had to continue after the harvest had been completed.⁶⁶ The importance of decisions regarding hay-cutting was observed in the regression analysis as well where hay-cutting dates had a statistically significant effect on harvest dates even when controlling for other important variables like growing season temperatures and sowing dates.

Choice of crops

The barley varieties cultivated were presumably quick to ripen, necessitated by the risks of cold springs and early autumn frosts. According to documentary sources, it took between 8 to 12 weeks for the most rapidly ripening barley varieties to mature.⁶⁷ However, the sources employed here indicate that the average barley crop period was about 15 weeks. Barley varieties that ripened too quickly appears to have had lower yields, hence over time selection practices most likely favored the development of varieties that took full advantage of the growing season.⁶⁸ Archaeobotanical research has identified some differences between the cultivated barley varieties within Jämtland. Varieties from the Lake Storsjö district appear as more distinct and homogenous compared to other parts of Jämtland that had greater seed exchange with present-day Norway to the west and present-day Sweden to the east, indicating some cultural influence on the type of varieties that were cultivated. Considering the high risk of harvest failures in many parts of Jämtland, intra- and cross-regional exchange in grain seeds do appear to have been crucial in maintaining persistent cultivation in the region, as suggested by previous scholars.⁶⁹

The differentiation between western, central and eastern barley varieties was to some extent mirrored by differences in the magnitude of temperature sensitivity in crop cultivation across Jämtland which exhibits a tendency for a similar geographical differentiation (see Map 2).⁷⁰ The degree of temperature sensitivity in tithes was high in mountainous areas in the west and

⁶⁶ Wichman *et al.*, *Norrländskt*, pp. 118–51.

⁶⁷ M. Leino, *Spannmål: Svenska lant sorter* (2017).

⁶⁸ Granbom and Tryggdahl, 'Meteorologiska', pp. 6–7, describes how in warm summers barley ripened in only 12–13 weeks with high quality grains but with low

yields. See also Larsson *et al.*, 'Genetic'.

⁶⁹ Larsson *et al.*, 'Genetic'. The role of intraregional trade has been emphasized in Lindegren, 'Folk' and Wichman, *Jämtlands*.

⁷⁰ Larsson *et al.*, 'Genetic'.

southern parts of the county. Northerly parishes like Ström can also be considered to belong to this group. The growing season was very short in these areas, which can be related to the topography with large forests and no large bodies of water, above all high altitudes. However, parishes like Lockne and Hallen located in the Lake Storsjö district exhibited similar degrees of temperature sensitivity. The least temperature sensitive parishes were located in islands or along the shorelines of north-eastern Lake Storsjön as well as some eastern parishes like Sundsjö and Revsund, where the magnitude of the correlations between tithes and a single climatic indicator is similar to southern Sweden or thirteenth century Low Countries, i.e., areas with excellent conditions for arable agriculture.⁷¹

Proposals made in previous research or references in documentary sources regarding the importance of micro-climatic conditions were largely confirmed by the analysis performed here, with the caveat that the level of analysis was restricted to parishes and not villages or farms. At the same time, all the analysed parishes were sensitive to mean growing season temperatures, albeit to different degrees, meaning that the county as a whole probably struggled during the years or series of years with extremely cold growing seasons and early autumn frosts.

Yield ratios from the nineteenth century indicated that most other crops were even more temperature-sensitive than barley. Autumn rye showed a particular sensitivity to mean August temperatures and harvest dates, and by implication autumn frosts. This supports the proposition that the climate in Jämtland and Härjedalen was not conducive to large-scale autumn-sown rye cultivation. Barley also dominated the crop mix in comparable regions like northern Finland.⁷² Potatoes were the important exception that appeared less temperature-sensitive compared to barley and the other crops investigated, both with regards to the growing season as a whole, as well as in relation to the important month of August. It is not surprising that potato cultivation increased rapidly in the nineteenth century, since it allowed farmers to reduce their vulnerability to autumn frosts and overall growing season temperatures. Without the potato, there is little evidence to suggest that arable agriculture in the region became less vulnerable over time to the harsh climate. The potato certainly played an important part in facilitating the large population growth of the nineteenth century.⁷³

Hay-cutting and livestock

Livestock provided a vital if not dominant component of the farming system and helped diversify risks. However, in contrast to other northerly parts of Europe like Ireland or Scotland, winter grazing was not possible in Jämtland. This in effect meant that livestock production, similar to grain production, was ultimately dependent on conditions during the growing season. Analysis showed hay-cutting dates were partly determined by spring and growing

⁷¹ Skoglund, 'Scania'. Soens, 'No second lord', p. 81. Note that in Scania and the Low Countries the signs are usually opposite, i.e., higher temperatures are associated with lower tithes.

⁷² Myllyntaus, 'Summer frost', p. 86. H. Huhtamäe and S. Helama, 'Reconstructing crop yield variability in Finland: Long-term perspective of the cultivation

history on the agricultural periphery since AD 760', *H* 27, pp. 3–11.

⁷³ E. Hallberg and L. Nyström, *The Database Sweden's Agricultural Lands 1810 and 1870, Version 1.0* (2022), <https://acreage.dh.gu.se/index.html>, last accessed 20 March 2023.

season temperature conditions, and that there was an interplay between sowing, harvesting, and hay-cutting dates where prioritizations between the various activities appear to have been necessary. Yet, the starting date of hay-cutting represents only one aspect of the overall livestock production complex, besides the important system of summer farms where animals grazed and dairy products were produced during the summer, the quantities of hay actually harvested, the number of livestock kept and yearly dairy production. In most studies of the relationships between climate and agriculture, as well as in quantitative agrarian history in general, there is a bias towards crop, especially grain, production and prices, corresponding to a similar bias in available historical sources. Hence much less is known about conditions of livestock production, not least the relationship between livestock production and climate, with a few notable exceptions.⁷⁴ This is an important area for future research since, not only in regions more dependent on livestock like central and western Scandinavia, but in large parts of Europe where mixed-farming systems were predominant.

VIII

There was a clear dependence of pre-industrial agriculture upon growing season temperatures in central Scandinavia. Above all, growing season temperatures played a crucial role in determining agricultural dates, particularly harvest dates, and harvest output. Temperatures had a positive relationship with harvests, i.e., higher temperatures were associated with larger harvests, and a negative relationship with agricultural dates, i.e., higher temperatures led to (lower) earlier agricultural dates. Reconstructed mean growing season temperatures alone explained up to 26 per cent of variation in tithes and 31 per cent in nineteenth century barley yield ratios. Combinations of temperature indicators and agricultural dates explained 25–34 per cent of variations in tithes and up to 49 per cent and 57 per cent of barley and rye yield ratios, respectively. Models including climate indicators as well as other factors explained 22–70 per cent of variations in agricultural dates, where mean growing season temperatures were the most important variable, except for sowing dates where mean spring temperatures were most important. Sowing, hay-cutting, and harvesting were at the same time subject to prioritization and decision-making not necessarily related to weather and climatic variability. Climate-agriculture relationships were more or less consistent throughout the study period, with the important exception of the introduction of potatoes that appears to have helped to reduce the vulnerability of arable agriculture to growing season temperatures and autumn frosts. The results obtained here only explain part of the relationship between climate and agriculture. Future research should focus on how livestock production was affected by climate variability and on integrating both crop- and livestock impacts in a broader understanding of the relationship between climate and agriculture in the past.

⁷⁴ F. Charpentier Ljungqvist, A. Seim, and H. Huhtamaa, 'Climate and society in European history', *WIREs Climate Change* 12 (2021), p. 15. A notable exception here would be Costello *et al.*, 'Adapting'.

Appendix

TABLE A1. Descriptive statistics to Maps 1 and 2

<i>Parish #</i>	<i>Parish</i>	<i>Longitude</i>	<i>Latitude</i>	<i>Altitude (m.s.l.)</i>	<i>Pearson's r raw</i>	<i>Pearson's r HP-filtered</i>
1	Tännäs	12.57	62.49	648	0.57*	0.56*
2	Hede	13.32	62.43	427	0.63*	0.65*
3	Vemdalen	13.99	62.59	425	0.46*	0.46*
4	Sveg	14.64	61.91	352	0.49*	0.50*
5	Lillhärdal	13.93	61.81	446	0.29*	0.30*
6	Älvros	14.65	62.08	353	0.58*	0.58*
7	Överhogdal	14.77	62.31	483	0.41*	0.43*
8	Rätan	14.53	62.44	367	0.58*	0.59*
9	Klövsjö	14.14	62.58	512	0.36*	0.43*
10	Hackås	14.80	62.67	324	0.22	0.20
11	Berg	14.40	62.74	297	0.37*	0.38*
12	Myssjö	14.27	62.98	311	0.34*	0.38*
13	Oviken	13.87	62.81	363	0.35*	0.38*
14	Marby	14.17	63.09	310	0.41*	0.46*
15	Hallen	13.88	63.07	309	0.40*	0.46*
16	Mörsil	13.79	63.29	338	0.49*	0.54*
17	Mattmar	13.98	63.33	345	0.40*	0.45*
18	Undersåker	12.86	63.14	346	0.41*	0.47*
19	Åre	13.26	63.36	396	0.57*	0.61*
20	Kall	13.02	63.75	394	0.58*	0.65*
21	Offerdal	13.82	63.71	348	0.42*	0.48*
22	Alsen	13.55	63.24	335	0.44*	0.50*
23	Näskott	14.27	63.35	347	0.35*	0.37*
24	Rödön	14.40	63.56	355	0.32*	0.36*
25	Norderön	14.34	63.16	313	0.21	0.23
26	Sunne	14.48	63.09	309	0.31*	0.28*
27	Frösö	14.61	63.06	392	0.24	0.23
28	Marieby	14.77	62.92	313	0.32	0.32
29	Brunflo	14.74	63.07	357	0.33*	0.29*
30	Ås	14.62	63.27	372	0.32*	0.38*
31	Aspås	14.50	63.38	383	0.38*	0.45*
32	Föllinge	14.50	63.72	297	0.49*	0.50*
33	Ström	15.34	64.05	297	0.51*	0.59*
34	Hammerdal	15.46	63.58	288	0.46*	0.52*
35	Häggenås	15.01	63.45	328	0.46*	0.48*

<i>Parish #</i>	<i>Parish</i>	<i>Longitude</i>	<i>Latitude</i>	<i>Altitude (m.s.l.)</i>	<i>Pearson's r raw</i>	<i>Pearson's r HP-filtered</i>
36	Lit	14.97	63.34	260	0.50*	0.53*
37	Kyrkås	14.89	63.21	394	0.51*	0.55*
38	Stugun	15.62	63.19	229	0.25	0.23
39	Näs	14.65	62.97	327	0.37*	0.41*
40	Lockne	15.05	63.14	338	0.51*	0.49*
41	Sundsjö	15.31	63.03	347	0.30	0.30
42	Revsund	15.30	62.95	300	0.27*	0.31*
43	Bodsjö	15.01	62.73	307	0.34*	0.33*
44	Bräcke	15.54	62.72	338	0.37*	0.42*
45	Hällesjö	15.99	62.97	269	0.30*	0.26
46	Håsjö	16.11	63.02	274	0.45*	0.44*
47	Fors	16.66	62.98	186	0.44*	0.43*
48	Ragunda	16.21	63.20	228	0.34*	0.31*

Notes: Longitudes and latitudes are based on centroids on the parish maps, altitude is based on the location of the oldest known church in each parish. p < 0.05 in bold, p < 0.01 marked with *. Raw show results from non-detrended tithe and climate series and HP denotes results using 30-year High-Pass filtered (Gaussian).

TABLE A2. Archival and published sources for agricultural dates

<i>Agricultural dates</i>	<i>Originator(s)</i>	<i>Title</i>	<i>Archive</i>
Source 1	Anders Jönsson, Berg socken	Anteckning af minnen Wäder & Wind, snö, och rägn, sädd och Årsvext	Östersunds Museums Etnologiska Arkiv
Source 2	Erik Ångman, Föllinge socken	Väderleksiaktagelser	Riksarkivet, Meteorologiska observationer till lands Sverige, vol. 50,
Source 3	Anders Kjelsson, Myssjö socken	Dagbok	Landsarkivet Östersund, Anders Kjelssons i Hallom, Myssjö dagbok
Source 4	Anders Petter Fjellman, Östersund	Utdrag av väderleksanteckningar i almanackor	Riksarkivet, Meteorologiska observationer till lands Sverige, vol. 50
Source 5	Anders Johan Hansson, Kyrkås socken	Årsberättelser öfver väderlek och vegetation	Busvebacken, http://busvebacken.se/
Source 6	Anders Johan Hansson, Kyrkås socken	Berättelse öfver vid gården utfördt arbete	Busvebacken, http://busvebacken.se/
Source 7	Erik von Stockenström	Meteorologiska och Oeconomiska Anmärkningar, gjorde i Jämtland	Kongl. Vetenskapsacemiens Handlingar (1767)
Source 8	Hushållningssällskapet i Jämtlands län	Jemtlands län	SCB, BiSOS N Jordbruk, Hushållningssällskapen årsberättelser
Source 9	Olof Ingebretsson, Tännäs socken	Tännäsdagboken	Nordiska Museet, Svenska bondedagböcker, arkiv 54:23

<i>Agricultural dates</i>	<i>Originator(s)</i>	<i>Title</i>	<i>Archive</i>
Source 10	Meteorologiska observatorium Uppsala	Observationer från Offne 1807–[28]	Uppsala universitetsbibliotek, Carolina Rediviva, A 264 a
Source 11	Johan Axel Huss, kyrkoherde Föllinge	Slätter å prästbordet 1797–1820	Landsarkivet i Östersund, Föllinge Kyrkoarkiv
Source 12	Nils Ljung, Fors socken	Nils Ljungs anteckningar, 1840–1890	Nordiska Museet, Svenska bondedagböcker, arkiv 54:23
Source 13	Sven Svensson	Dagbok och räkenskapsbok	Landsarkivet i Östersund, Sven Svenssons, Västerskucku, Berg, arkiv
Source 14	Erik Tryggdahl, Storsjöbygden	Islossning, Sånings och Skörde-Tid	Riksantikvarieämbetet, Ekdahlska samlingen, vol. A4
Source 15	Börön, Lockne socken	Böröns gårdsarkiv, 1616–2016	Landsarkivet i Östersund, Böröns, Lockne gårdsarkiv
Source 16	Erik Jönsson, Näs socken	Dagbok 1806–1868	Landsarkivets i Östersund avskrifts-samling, vol. 28:5.
Source 17	Erik Halvarsson, Ragunda socken	Ant. om sådd och slätter 1899–1924	Landsarkivet Östersund, Karl Bergvalls i Hammarstrand, Ragunda arkiv
Source 18	Ola Langvall, Åslög Dahl, Kjell Blomgren	Swedish Historical Phenology Dataset	Swedish National Data Service. Version 1.0. https://doi.org/10.5878/sa66-2586
Source 19	Olof Granbom, Brunflo	Meteorologiska observationer, Brunflo, 1762–1765	Riksarkivet, Meteorologiska observationer till lands Sverige, vol. 50,
Source 20	Fale Burman, dagboksanteckningar	Fale Burmans dagböcker över resor genom Jämtland, 1793–1802	Källor till Jämtlands och Härjedalens historia, http://www.fornskrift.se/Avskrifter/Burman_dagbocker.pdf