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Investigating the correlation between monthly average temperatures and tithe proxy data from the Low Countries

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Corresponding Author:	Adriaan DE KRAKER Institute for Geoarchaeology and Bioarchaeology, Amsterdam, NETHERLANDS
Corresponding Author Secondary Information:	
Corresponding Author's Institution:	Institute for Geoarchaeology and Bioarchaeology,
Corresponding Author's Secondary Institution:	
First Author:	Adriaan DE KRAKER
First Author Secondary Information:	
Order of Authors:	Adriaan DE KRAKER
	Ricardo Fernandes
Order of Authors Secondary Information:	
Abstract:	This paper investigates the correlation between monthly average temperatures and tithe leasing dates in the Low Countries between 1600 and 1810. The information was obtained from manorial tithe leasing records distributed across the Netherlands and Belgium. Similar research in France and in Switzerland relied on annual dates of grape harvest as a temperature proxy and provided a strong correlation between harvest dates and average monthly temperatures. However, the analysis of our data indicates a low correlation between average monthly temperatures by using the Labrijn reconstructed temperature series starting in the early 18th century and tithe leasing dates. Possible reasons for this behaviour include soil variety such as clay, sand and loamy soils and diversity in crop growth patterns, such as typical winter crops and summer crops, while within both these categories there again is a variety of crops grown. The complexity of variables, therefore, does not permit using tithe leasing dates in ancient temperature reconstruction. However, useful information on crop behaviour under extreme conditions of precipitation and temperature was obtained.
Suggested Reviewers:	Aryan van Engelen Royal Dutch Meteorological Institute aryan.van.engelen@knmi.nl Aryan van Engelen is the Dutch specialist on climatic documentary sources and knows the Labrijn temperature series very well.
	Peter Dobrovolny Institute of Geography, Masaryk University dobro@sci.muni.sc He is a specialist in working with climatic documentary sources and has publishes on the issue of using phenoligcal data
	Rudolf Brazdil Institute of Geography, Masaryk University, Brno, Czech Republic bradzdil@geogr.muni.cz He is a specialist in the research of climatic related documentary sources and has publishes many times in Climatic Change
	Gaston Demaree Belgian Meteorogical Institute

	gaston.demaree@meteo.be He is a specialist in 18th century documentary sources from Flanders, which are a major part of the article submitted.

Investigating the correlation between monthly average temperatures and tithe proxy data from the Low Countries

Kraker, A.M.J. de (VU-University, Amsterdam, Institute for Geoarchaeology and Bioarchaeology); e-mail a.m.j.de.kraker@vu.nl; tel. +31 205986328

Fernandes, R. (Leibniz-Laboratory for Radiometric Dating and Isotope Research and Graduate School "Human development in Landscapes", Kiel University, Germany); e-mail ldv1452@gmail.com

Abstract
This paper investigates the correlation between monthly average temperatures and tithe leasing dates in the Low Countries between 1600 and 1810. The information was obtained from manorial tithe leasing records distributed across the Netherlands and Belgium. Similar research in France and in Switzerland relied on annual dates of grape harvest as a temperature proxy and provided a strong correlation between harvest dates and average monthly temperatures. However, the analysis of our data indicates a low correlation between average monthly temperatures by using the Labrijn reconstructed temperature series starting in the early 18th century and tithe leasing dates. Possible reasons for this behaviour include soil variety such as clay, sand and loamy soils and diversity in crop growth patterns, such as typical winter crops and summer crops, while within both these categories there again is a variety of crops grown. The complexity of variables, therefore, does not permit using tithe leasing dates in ancient temperature reconstruction. However, useful information on crop behaviour under extreme conditions of precipitation and temperature was obtained.

Key words
Temperature reconstruction, precipitation, The Netherlands, Belgium, tithes, crops, climatic proxies

1 Introduction

This paper investigates the potential use of tithe documental data as a climatic proxy. Tithe evidence, usually related with the revenue in terms of money or the amount of grain per ha, has previously been used as a temperature proxy (Le Roy Ladurie et al. 1980). Other climatic studies based on tithe evidence have also been undertaken in Norway (Nordli et al 2003), and in the Baltic region (Tarand et al. 1994). These studies indicate a clear correlation between harvest date and monthly average temperatures. Here, we have investigated if tithe evidence from the Low Countries (Belgium and the Netherlands) would also exhibit a similar correlation. To achieve this goal, tithe information from various locations in the Low Countries was collected including tithe leasing dates, type of crops grown, soil types, precipitation, temperature, and other elements.

2 Previous research and historical background

2.1 Harvest dates as a temperature proxy

A reference work on historical harvest dates is the data compilation done by Le Roy Ladurie (1967) on French grapes. This work was extended in Le Roy Ladurie (et al. 1980) and Chuine (et al. 2004). Observed correlations between monthly average temperatures and grape harvest dates established that an early beginning of harvest is related to warm weather during summer, while a late harvest date is related with colder weather in the preceding months. This result led others to study other phenological proxies, including dendroclimatological evidence (Briffa & Matthews 2002), and blossoming dates of cherry trees and commercial crops (Burri et al 2008; Aono et al. 2008). In Norway high correlations between the beginning of grain harvest and monthly average temperatures (Nordli 2004) were confirmed. For the Baltic region similar results have been obtained (Tarand et al 1994). From East Anglia (UK) dates of grain harvesting have been studied and established that for the time period between 1256 and 1431 average temperature dropped from 13° C to 12.4° C (Pribyl et al. 2011). Phenological evidence from the Low Countries, in particular tithe proxy data, has not been previously studied, raising the question of its potential as a temperature proxy.

2.2 Historical background

Tithe records, also referred simply to as tithes, were established by the Church in 8th century Europe as a 10% taxation on crops and cattle. Tithe privileges were typically owned by feudal lords and ecclesiastical institutions and by the 15th century also by merchants. Initially tithes were directly collected in the fields, though later tithe revenues were sold to lease holders. Tithe proxy evidence from the Low Countries, used in this study, covers the time period between 1600 and 1810 for the Netherlands, and till 1794 for Flanders when it was abolished.
Most tithe owners, aiming at higher profits, leased out their tithes. Tithe leasing occurred publicly and typically in large local inns by bidding and following a strict procedure. This meeting functioned as a tithe auction where competition amongst bidders ensured tithe owners the best deals. The winning bidder went out to collect every tenth sheaf on the land as soon as possible. Therefore, tithe leasing occurred immediately before harvesting, on average within one week. Tithe leasing date and place were recorded in manorial rolls. Some accounts distinguish between early crops (winter crops) and late crops (summer crops).

2.3 Tithe distribution

For the present study, tithe records were collected from several locations in the Flanders region of Belgium and distributed across the Netherlands (Figure 1).

2.3.1 Flanders tithes

Collected tithe evidence from Flanders originates from nine parishes of Saint Baafs cathedral (Ghent) distributed in the Flemish Ardennes to the south of Ghent (Figure 1). The geomorphology of this area is characterized by wet sandy and loamy soils having a low maximum altitude (153 metres ASL) (Table 1). Remaining Flemish tithe records were obtained from eleven parishes of the Bishop of Bruges and are mainly distributed across coastal Flanders. Coastal parishes are located in a flat landscape dominated by clayey and loamy soils. Three parishes are located further inland in the Flemish Ardennes.

2.3.2 Dutch tithes

Listed Dutch tithes (Figure 1 and Table 1) were propriety of the Orange-Nassau, or simply Nassau family and were widely distributed across the Netherlands.

Fig.1 Locations of tithes of the Bishop of Bruges (nos. 1-11), Saint Baafs cathedral (nos 12-20) both in Flanders (Belgium) and the Nassau Domains (21-30) in the Netherlands. The location numbers correspond with those mentioned in Table 1. B: Borculo, C: Lichtevoorde and T: Tholen.

Tithes from the localities of Dieren, Borculo and Lichtevoorde in central Netherlands and Eindhoven in the south are located mainly in sandy areas distant approximately 150 km from the coast (Table 1). These areas were dominated by an open field system where intensive fertilisation occurred with rye, barley and oats as the main crops, though also buckwheat was grown. Zevenbergen-Geertruidenberg, North-Beveland and Hulst were situated in marine clayey areas where mostly commercial crops, such as wheat, flacks, rape seed, beans, peas, and madder were grown. IJsselstein and Leerdam were partly placed in river clay and peat areas. Crops here were generally grown in river clayey areas and coincide with marine clayey areas, while the peat soils were mainly used as pasture.

Table 1 Studied tithe records from the Low Countries and their representativity throughout the period under study.

	Name		Location NL		EL		Tithe owner	Soil type	Time period	Missing Tithe years
1	Knokke	B	51	20	3	17	BoB	marine clay	1706-1790	6.0%
2	Klemskerke	B	51	14	3	1	BoB	marine clay	1740-1788	31.0%
3	Oostkamp	B	51	8	3	14	BoB	wet sandy loam	1740-1788	39.5%
4	Eernegem	B	51	7	3	1	BoB	wet sandy loam	1740-1788	47.9%
5	Westkerke	B	51	9	3	0	BoB	wet sandy loam	1740-1788	18.0%
6	Rumbeke	B	50	55	3	9	BoB	wet sandy loam	1740-1788	39.0%
7	Lichtevelde	B	51	1	3	8	BoB	wet sandy loam	1740-1788	39.0%
8	Snaaskerke	B	51	10	2	56	BoB	marine clay	1740-1788	35.0%
9	Iezegem	B	50	55	3	12	BoB	wet sandy loam	1740-1788	
10	Ichtegem	B	51	5	3	1	BoB	wet sandy loam	1740-1788	31.0%
11	Roksem	B	51	10	3	1	BoB	wet sandy loam	1740-1788	58.0%
12	Zingem	B	50	54	3	39	SB	wet sandy loam	1600-1794	14.4%
13	St. Lievens Houtem	B	50	55	3	51	SB	wet sandy loam	1616-1794	16.5%
14	St. Martens Latem	B	50	53	3	42	SB	wet sandy	1644-1793	24.8%
15	St. Maria Latem	B	51	17	3	38	SB	wet sandy loam	1646-1794	8.1%
16	St. Denijs Boekel	B	50	51	3	42	SB	wet sandy loam	1604-1762	14.4%
17	Bavegem	B	50	56	3	51	SB	wet sandy loam	1619-1794	13.9%
18	Vlierzele	B	50	55	3	53	SB	wet sandy loam	1624-1794	16.9%
19	Munkzwalm	B	50	52	3	43	SB	wet sandy loam	1600-1794	8.6%
20	Gijzenzele	B	50	58	3	48	SB	wet sandy loam	1633-1794	12.3%
21	Hulst	N	51	22	4	0	ND	marine clay	1648-1792	4,86%
22	North-Beveland	N	51	35	3	50	ND	marine clay	1600-1810	9.5%
23	Zevenbergen	N	51	39	4	36	ND	marine clay	1649-1810	w: 21.1%
									1694-1810	s: 8.7%
24	Leerdam	N	51	53	5	5	ND	river clay / peat	1620-1795	w: 0.0%
									1620-1795	s: 9.7%
25	Prinsenland	N	51	38	4	22	ND	marine clay	1610-1810	1%
26	Cuijk	N	51	43	5	49	ND	sandy / river clay	1652-1810	16.4%
27	Eindhoven	N	51	26	5	26	ND	sandy	1653-1810	w: 3.5%
									1639-1810	w: 3.1%
28	Dieren	N	52	2	6	5	ND	sandy	1701-1800	0%
29	Niervaart (Klundert)	N	51	39	4	32	ND	marine clay	1600-1795	w: 15.3%
									1600-1799	s: 14,5 %
30.	IJsselstein	N	52	1	5	2	ND	river clay/peat	1621-1799	w: 14.0%
									1621-1799	s: 5,0%
31.	Geertruidenberg	N	51	42	4	5	ND	marine clay	1646-1749	0.9%

B: Belgium; N: Netherlands; BoB: Bishop of Bruges; SB: Saint Baafs Cathedral; ND: Nassau Domain
s: summer crops; w: winter crops

3 Methods

3.1 Building high quality time series

The analysis of phenological data to identify the existence of correlations with climatic variables requires the use of high quality data. High quality phenological or climatic proxy data should meet a set of criteria:

- Multi-decadal. Thus enabling the observation of climatic trends over long periods.
- Continuous. Limited data gaps during the period under study.
- Homogeneous. Selected crops and agricultural techniques should remain constant throughout the period under study (Bieleman 1987, 520-540; Dejongh et al 1999; Thoen 2001).
- Uniformity. This criterion refers to uniformity in administrative accounting and date inclusion throughout the period under study.
- Data control. Possibility of comparing data from multiple tithe series within a same region.

These listed criteria are overall met by selected tithe data presented in this study (Table 1), except for the tithes belonging to the Bishop of Bruges where large data gaps are observed.

3.2 Building time series

The large time gaps observed for the nine tithe series of Saint Baafs Cathedral can be addressed, given their spatial proximity and soil uniformity, by averaging the data into a single record, referred as Ghent (Table 2). Given the existence of large time gaps only two of eleven tithe series belonging to the Bishop of Bruges were analysed.
Nassau manors' evidence have only minor gaps and therefore each single manorial account is directly useable, at instances providing leasing dates for both summer and winter crops.
Tithe dates were redefined by using the date of July 31st as a fixed reference with a value set at 1. A backwards counting systems was used (e.g. 31st of May corresponds to a reference value of 62).

3.3 Statistical analysis

The approach here described follows very closely that described in Nordli (2001) where high correlations between average monthly temperature and Norwegian harvest dates were identified.

Simple correlation analysis was performed on tithe records in order to establish the relationship between the predictor harvest date, as defined by tithe leasing reference dates, and the average monthly instrumental temperature. Data from the Labrijn instrumental temperature data series (van Engelen and Nellestijn, 2011) was used to establish monthly average temperature for the period under study (1760-1800). Monthly air temperature (Celsius) measurements from Utrecht (1848-1897) and Zwanenburg (1735-1848) were reduced to the central Netherlands location of De Bilt by Labrijn (Labrijn, 1945). The Labrijn temperature series was subsequently expanded using data from Delft/Rijnsburg (1706-1734), and is currently available up to the present day (van Engelen and Nellestijn, 2011).

Harvest date variable (d) was defined by considering the difference, in days, between the fixed reference date and the actual tithe leasing date.

Several factors will determine which month sequence presents the best correlation between harvest date and average temperature. Thus, different month sequences were evaluated, namely May-June, May-August, May-July, June-July, July-August and June-August. Also considered were the single months of June, July and August. To account for variations in temperature, measuring instrumental techniques correlations were verified for the entire study period (1706-1800), and for the first (1706-1753) and second (1753-1800) halves of this period.

A measure of the relationship between the variables under study is given by the correlation coefficient (r) defined as:

$$r = \frac{\sum\left(d - \bar{d}\right)\left(t - \bar{t}\right)}{\sqrt{\sum\left(d - \bar{d}\right)^2 \sum\left(t - \bar{t}\right)^2}}$$

Where $\bar{d}$ and $\bar{t}$ t represent respectively the average harvest date and average temperature for the time series under study. The correlation coefficient offers a simple quantification of the relationship between two variables. It is not physically expectable that negative correlations are observed as such a result would imply that earlier harvest dates are associated with lower average monthly temperatures.

4 Results

Table 2 lists the correlation analysis results for all the tithe records under study. Table 2 includes the number of data entries for all periods under study and the corresponding month interval with the highest correlation value.

Table 2 Correlation analysis on data provided from listed tithe record.

Tithe	Number of data entries (1706-1800)	Month interval with highest correlation (1706-1800)	Correlation value (1706-1800)	Number of data entries (1706-1753)	Month interval with highest correlation (1706-1753)	Correlation value (1706-1753)	Number of data entries (1753-1800)	Month interval with highest correlation (1753-1800)	Correlation value (1753-1800)	Number of data entries (1760-1800)*	Mon terval est elation 0- 0)*	Correlation value (1760-1800)*
1. Knokke	80	June	0.03	47	June	-0.07	34	June - July	0.22	27	July	0.05
2. Klemskerke	33	June	0.06	9	June	0.04	25	June	0.26	19	May - June	0.24
3. Oostkamp	30	June	0.00	6	June	0.80	24	August	-0.07	19	May - June	-0.08
4. Eernegem	26	June - July	0.10	7	June	0.25	19	May - August	0.39	16	May - August	0.2
5. Westkerke	38	June	0.03	9	June	0.62	29	May - June	0.15	23	August	0.12
6. Rumbeke	30	July	0.14	8	June	0.44	23	July	0.16	19	August	-0.13
7. Lichtevelde	23	June	-0.16	5	May - June	0.28	18	August	-0.12	15	May - June	-0.11
8. Snaaskerk	31	July	0.28	7	May - July	0.50	25	July	0.26	20	July	0.3

e												
9. Iezegem	1	-	-	0	-	-	1	-	-	1	-	0.23
10. Ichtegem	34	August	0.04	8	August	0.14	26	August	0.21	21	May - August	
11. Roksem	54	July	0.13	34	August	0.10	20	June	0.13	19	June	0.07
12-20. Herrekend (average of tithe records for Ghent)	89	August	-0.02	48	August	-0.06	42	August	0.06	35	August	0.08
21. Hulst	83	May - July	0.04	47	July	0.11	37	May - June	0.21	30	July	0.21
22. North-Beveland	93	May - July	0.31	47	May - August	0.36	47	May - July	0.34	41	July	0.3
23a. Zevenbergen Summer	92	May - June	0.29	46	May - June	0.35	47	June	0.36	40	June	0.18
23b. Zevenbergen Winter	79	June	0.10	45	July	-0.01	35	June	0.43	28	June	0.36
24a. Leerdam Summer	90	May - June	0.09	48	May - June	0.10	43	June - July	0.35	36	July	0.2
24b. Leerdam Winter	82	May - June	0.20	40	August	0.25	43	May - June	0.28	36	July - August	0.03
25. Prinsenland	94	May - June	0.15	47	May - June	0.02	48	May - June	0.40	41	May - July	0.25
26. Cuijk	85	May - June	0.19	39	May - June	0.16	47	June	0.33	40	June	0.26
27a. Eindhoven Summer	94	May - June	0.31	48	May - August	0.37	47	May - June	0.35	40	May - June	0.23
27b. Eindhoven Winter	79	August	0.27	48	August	0.36	32	August	0.19	25	August	0.11
28. Dieren	95	July	0.05	48	July	0.03	48	May - July	0.06	41	August	0.16
29a. Niervaart Summer	90	July	-0.11	44	July	-0.12	47	June	-0.17	40	June	0.11
29b. Niervaart Winter	9	July	-0.17	1	-	-	8	July	-0.28	8	July - August	0.16
30a. IJsselstein Summer	90	May - June	0.32	46	May - June	0.41	45	May - July	0.32	39	July	0.19
30b. IJsselstein Winter	91	May - June	0.20	45	May - August	0.40	47	July	0.08	40	May - July	0.2
31. Geeetruidenberg	34	May - June	0.18	34	May - June	0.18	0	-	-	0	-	-

Three time intervals were analysed (1706-1800, 1706-1753, and 1753-1800). For each period the number of data entries, and the month interval with the highest correlation indicated. Last three columns, marked with an asterisk, refer to the correlation analysis performed on Central European temperature data between 1760 and 1800 (Dobrovolný et al. 2010).

The correlation coefficients (r) during the entire period under study (1706-1800) indicate a low or absent correlation, with some locations presenting negative correlation values (Ghent average, Lichtevelde, Niervaart Summer, Niervaart Winter). The average correlation value for all of the series was very low (r=0.11). Values for the correlation coefficient above 0.25 were only recorded for Snaeskerke, Eindhoven Summer, Eindhoven Winter, IJsselstein Summer, Zevenbergen Summer, and North-Beveland. The comparison of the average correlation value for 1706-1800 ($r_{average}$ = 0.11) with the sub-periods 1706-1753 ($r_{average}$ = 0.23) and 1753-1800 ($r_{average}$ = 0.19) indicates that there is a slight increase in correlation performance. However, the increase is insufficient to be significant and no secure statement can be put forward on break of homogeneity. Comparing specific tithes there is an increase in correlation values in 17 cases comparing the full study period with the 1706-1753 sub-period, and in 20 cases comparing the full period with the 1753-1780 sub-period. Comparison of the two sub-periods indicates that the sub-period 1706-1753 presents a higher correlation value than 1753-1800 in 15 out of 27 cases. These results can be partially explained by the non-uniform distributions in the number of recorded dates. The high correlation values observed for some tithes for the sub periods can be explained by the limited number of recorded dates (e.g. for the period 1706-1753 Westkerke (r = 0.62, n = 9) and Oostkamp (r = 0.80, n = 6).

Correlation analysis was also performed using Central Europe monthly average temperature provided by Dobrovolný et al. (2010). Correlation results are presented in the last three columns of Table 2. However, in most cases, the correlation values remain extremely low.

5 Discussion

The correlation coefficients between tithe harvest dates and the Labrijn temperature series are overall low and do not demonstrate any correlation (Table 2).

The low observed correlations in our data contrasts with other that of other proxies (e.g. French grape harvesting dates). Ladurie et al. (1980) published the first time series on French grape harvesting dates, and a revised time series was published by Chuine et al. (2004). The comparison of French grape harvesting dates with tithe leasing dates in the Ghent area is shown in Figure 2 corresponding to an eleven year’s smooth average.

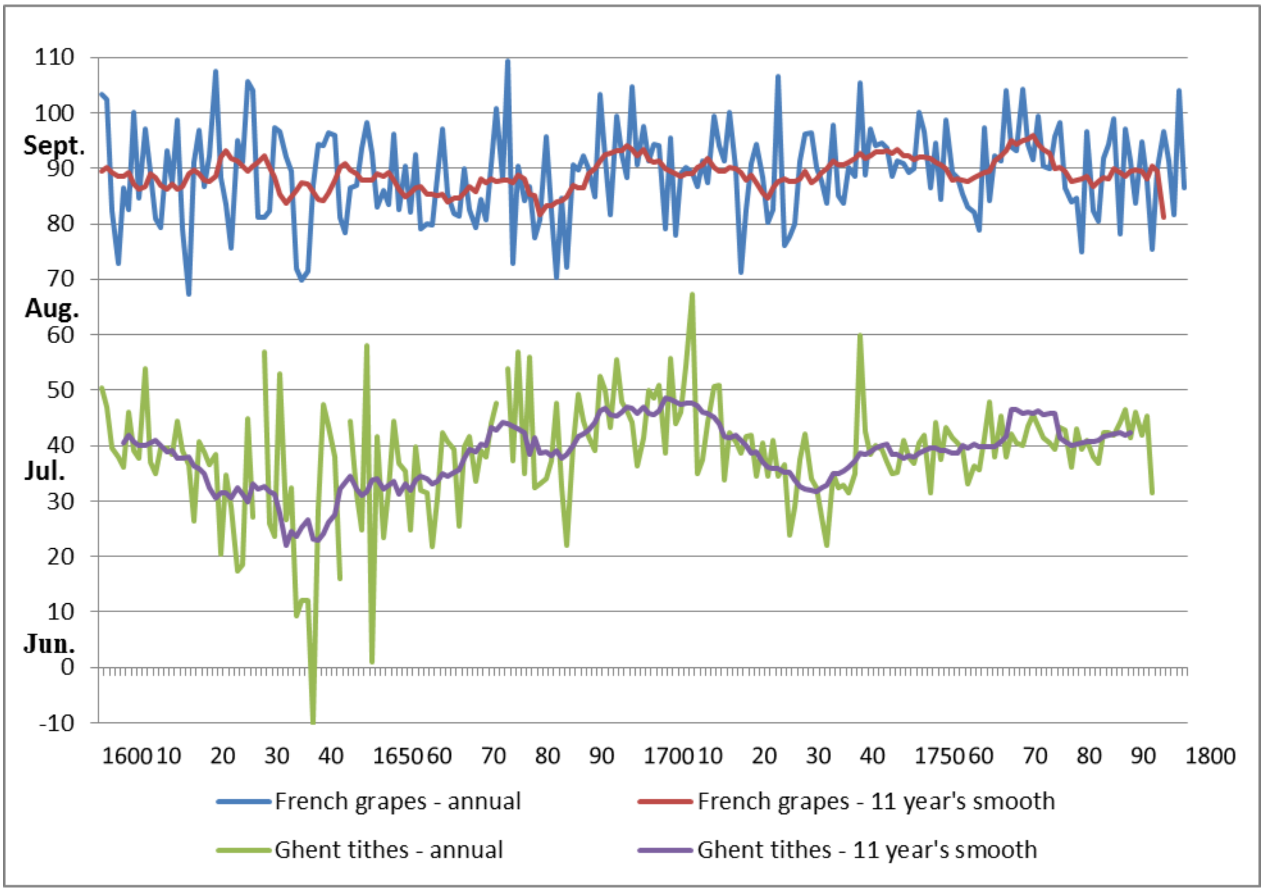

Fig. 2 Annual tithe proxy's and 11 year's smooth of tithe information from Saint Baafs Cathedral compared with the proxy data of the grape harvest in France, 1600-1800 (Chuine et al. 2004)

There is a low correlation between the two data series (r=0.46) and Figure 2, in spite of certain curve regions having a similar behaviour, still shows significant deviations between the two curves.

Different and complementary explanations can be put forward to justify the observed results. These include the variety of crops associated with each tithe, distance to the North Sea, differences in sowing season e.g. winter vs. summer crops, and variety of soil types and how these variables were influenced by varying climatic conditions and especially extreme events. Additionally the reliability of the Labrijn series and the influence of human water management will be discussed.

5.1 Main crop types and weather conditions

Prior to 1800 farmers grew a variety of crops while tithe records refer only to lease dates regardless of type of sown crops. This point has relevance as each crop may be grown in different periods and respond differently to varying weather conditions, though having some common features.

Grains such as wheat, rye and buckwheat were grown for bread, barley for beer, and oats as fodder for horses. Rye and buckwheat were typically sown in sandy areas (Bieleman, 1987, 522-523), whereas, wheat was mainly grown in clayey and loamy soils. Wheat, rye and barley had summer variants and winter variants with the latter being sown in late autumn. These three crops were very vulnerable to lengthy dry spells in spring and long and heavy rainfall during the harvest season. Heavy rainfall could knock down the wheat to the ground which subsequently led to a dispersion or re-germination of grains. The extreme low winter temperatures of 1708/09 had a devastating effect on the barley harvest

at Leerdam[1], and similar consequences were observed for the rye harvest in 1789 and 1793 at Borculo.[2] Buckwheat was especially vulnerable to low temperatures, and for this reason was usually grown late. A single night's frost, often occurring in May, was potentially sufficient to destroy an entire buckwheat harvest. Oats with a longer growing period could more easily recover from extreme temperature events. Similar to grains extreme weather conditions such as long drought or precipitation were also damaging to crops such as flax[3], beans and peas[4] as well.
The widely grown oilseed rape *(Brassica napus)* used for oil production was sown in late autumn. Severe winters such as those in 1708/09 could easily destroy an entire oilseed rape harvest.[5]

From the description above it becomes obvious that there were some variations in the growing seasons of the listed crops. Furthermore, although different crops had similar responses to the same weather conditions there are also some variations on how some crops were affected by isolated extreme climatic events.

5.2 Main soil types and weather conditions

For the study area three main soil types need to be discussed together with their response to varying climatic conditions.

Clayey soils
Clayey compact soils present a high nutrient content, constituting a preferential food production area. During long periods of precipitation clayey soils may become water saturated harming crop growth. Such an event is more often associated with the winter season, as recorded at St. Maartensdijk (Tholen) in 1756.[6] In contrast, the water retention capacity of clayey soils permits a more resistant crop development during dry spells.

Sandy soils
Sandy soils are nutrient poor and require intensive fertilization. These soils have a coarse granular structure and drain well. Thus, heavy rainfall is not usually harmful to crop development unless occurring during the harvest season. Long dry spells cause a lowering of the water table limiting crop development. An additional factor is the location of sandy areas in particular their distance to the North Sea. Nassau tithe locations of Cuijk, Eindhoven, Dieren and Borculo are all situated in the east, at a distance of approximately 150 km from the North Sea. In summertime these areas exhibit a slightly higher average monthly temperature when compared with marine clayey areas, while winter temperatures are in average lower.

Wet sandy loam
Wet sandy loam soils represent an optimal balance between water and nutrient soil content. In this type of soil crop development is typically only affected under extreme weather conditions.

5.3. The instrumental temperature data series

The Labrijn series are reduced to the central Dutch location of De Bilt and it may fail to capture local temperature variations e.g. of areas more to the east with slightly higher summer temperatures and lower winter temperatures. However, given the relative small extension of the entire study area and its relative climatic uniformity it may be hypothesized that local temperature variations are not the main cause for the observed low correlations.

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[1] National Archives of the Netherlands at The Hague (NA), Nassau Domain (ND), no 5549 (Leerdam, 1709).
[2] NA ND, no. 2032 (Borculo, 1788/89 and 1793.
[3] NA ND, no. 7428 (Zevenbergen, 1789); very wet spring.
[4] NA ND, no. 11394 (Prinseland, 1762); drought during spring; no. 7428 (Zevenbergen, 1787): heavy rainfall.
[5] NA ND, no 5549 (Leerdam 1709).
[6] NA ND, no. 13,813 (St. Maartensdijk, 1756).

5.4. Water management

Marine clayey areas (embankments) presented a network of drainage canals and sluices. This system allows for water drainage during heavy rainfall periods and during drought water tables could be sustained artificially high. Thus, water management in embanked areas may introduce a signal noise into the proxy data.

6 Conclusion

The present study aimed at investigating the possibility of using tithe leasing data from the Low Countries as a temperature proxy.

Most of the selected tithe records were homogeneous, uniform and often continuous for more than a century. Tithe evidence originated from three major land owners: Saint Baafs cathedral at Ghent (Belgium), Bishop of Bruges (Belgium) and the Nassau Dynasty (Netherlands). Tithe locations were classified into three major soil types: clayey soils in coastal areas, sandy soils in eastern Netherlands and loamy/sandy soils south of Ghent.

Correlation coefficients determined between harvest date and the Labrijn temperature series, during the 18th century overlap, show an overall low correlation. This result suggests that temperature is not the sole climatic factor determining crop growth.

The spatial distribution of the tithe evidence implies a lack of homogeneity in crop growth behavior, reflecting essentially the differentiated physical response of the considered soil types to varying precipitation patterns. Furthermore, it was demonstrated that tithe records refer to a variety of crop types that may present considerable differences in growth patterns under similar weather conditions.

In conclusion, it has been observed that tithe data for the Low Countries, in contrast to other regions, cannot be used for pre-instrumental temperature reconstruction. The data suggests a far more complex behavior of crop growth dependent on climatic parameters, isolated climatic events, soil classification, and type of crop.

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References

Archival References

National Archives of the Netherlands (The Hague, The Netherlands): Nassause Domeinraad (van Hoof et al, 1997)
Borculo and Lichtvoorde: 2032-2037, 2129, 2130, 2140, 2142
Bredevoort and Buren: 2296-2298, 2358-2376, 2472, 2552-2557, 2681-2693
Dieren: 3157-3161, 3169-3171, 3439-3630
Geertruidenberg: 3986, 4180-4183, 4214-4415
Hulsterambacht: 13472-13479, 13481-13483, 13528-13530, 13569-13723
IJsselstein: 4732, 4827-4935, 5056-5234
Leerdam: 5340-5348, 5351-5352, 5448, 5449, 5461-5782
Niervaart: 6242, 6303-6314, 6325-6518
Zevenbergen: 7420-7427, 7446, 7449, 7456-7610
Zwaluwe: 7619
Eindhoven and Cranendonck: 9294-9303, 9406-9423, 9508-9932
Grave and Cuijk: 9962-9971, 10151, 10152, 10158-10160, 10215-10722
Prinsenland: 11393-11404, 11514-11552, 11611-11812
Oosterhout and Dongen: 11919-11935

Steenbergen: 12578-12583
St. Maartensdijk: 13813-13821
North Beveland: 14225-14228, 14303-14308, 14324-14518

State Archive (Ghent, Belgium): Bisdom (Gysseling 1997-2000)
Zingem: B1950/1, B1950/2, B1951/1, B1951/2, B1952/1, B1952/2, B1953/1, B1953/2, B3415, B3403, B3405A, B3411/3, B3411/4
St. Lievens Houtem: K 8187/1, K8187/2, K8187/3, K8188/1, K 8188/2. K8188/3, , K 9668, K9647. K9649, K9652
St. Lievens Houtem, Vlierzele, Bavegem and Gijzenzele: K4172 – K4482, K 8290/4, K8121/1, K8121/2, K8121/3
Munkzwalm (also St. Maria Latem and St. Denijs Boekel): B1945/1 – B1945/11, B1946/1, B 1946/2, B1947/1, B1947/2, B1947/bis1, B1947/bis2, B1600 – B1632, (including Zingem) B1633-B1941
St. Denijs Boekel: K 8117/2, B 8117/2

State Archive (Bruges, Belgium): Bisdom (Nieuw Kerkarchief): (Anonymus 1993)
Tithes of Knokke, Klemskerke, Oostkamp, Eernegem, Westkerke, Rumbeke, Lichtevelde, Snaaskerke, Iezegem and Roksem, 298-333

Literature References

Anonymus (1993) Bisdom Brugge (Nieuw Kerkarchief). Brussels

Aono Y and Kazui K (2008) Phenological data series of cherry tree flowering in Kyoto, Japan, and its application to reconstruction of springtime temperatures since the 9th century. Int. J. Climatol 28: 905-914

Bieleman J (1987) Boeren op het Drentse zand 1600-1910. Een nieuwe visie op de oude landbouw. HES STDIA HISTORICA, XV Hes Uitgevers- Utrecht

Briffa KR,Matthews JA (2002) Advance-10k: a European contribution towards a hemispheric dendroclimatology for the Holocene. The Holocene 12.6, 639-642

Buisman J (1984) Bar en Boos. Zeven eeuwen winterweer in de Lage Landen. Bosch & Keuning NV Baarn

Burri M, Rutishauser T (2008) Pflanzenphanologische Beobachtungen – Dank Johann Jakob Sprunglis Aufzeichnungen zu gesteigerten Ernten und neuen Erkenntnissen in der Klimaforschung. In:Stuber M, Moser P, Gerber-Visser G, Pfister C, Bütschi D, (eds) Kartoffeln, Klee und kluge Köpfe. Die Oekonomische und Gemeinnützige Gesellschaft des Kantons Bern OGG (1759-2009) Paul Haupt Verlag (Bern)

Chuine I, Yiou P, Viory N, Seguin B, Daux V, Le Roy Ladurie E (2004), Grape ripening as a past climate indicator. Summer temperature variations are reconstructed from harvest dates since 1370. *Nature*, vol. 432, 289-290

Dejongh G & Thoen E (1999) Arable productivity in Flanders and the former territory of Belgium in a long perspective (from the Middle Ages to the end of the Ancien Regime). Bavel BJP,Thoen E (eds) Land productivity and agro-systems in the North Sea area (Middle Ages – 20th century) Elements for comparison. Corn Publication no 2. Brepols Gent, 30-64

Dobrovolný P, Moberg A, Brázdil R, Pfister C, Glaser R, Wilson R, van Engelen A, Limanówka D, Kiss A, Halíčková M, Macková J, Riemann D, Luterbacher J, Böhm R (2010), Monthly, seasonal and annual temperature reconstructions for Central Europe derived from documentary evidence and instrumental records since AD 1500. Climatic Change, vol. 101, 69-107

van Engelen AFV, Nellestijn JW (2011), *http://climexp.knmi.nl/getindices.cgi?KNMIData/labrijn+Tdebilt+i+someone@somewhere, retrieved 1-06-2009*

Gysseling M (1997-2000) Inventaris van het archief van de Sint-Baafs en het Bisdom tot eind 1801. 5 vols. Brussels

Van Hoof MCJC, Schreuder EATM & Slot BJ (eds) (1997) De archieven van de Nassause Domeinraad 15891-811 met retroacta vanaf de dertiende eeuw. National Archives The Hague de Kraker AMJ (2006) Flood events in the southwestern Netherlands and coastal Belgium, 1400-1953 Hydrological Sciences-Journal 51 (5), 913-930

Labrijn A (1945) *The climate of the Netherlands during the last two and a half centuries*, KNMI Mededelingen en Verhandelingen 49

Le Roy Ladurie E (1967) Le climat depuis l'an mil. Paris. Champs-Flammarion. Reprinted in 1983 in 2 vols

Le Roy Ladurie E. Baulant M (1980) 'Grape harvests from the fifteenth through the nineteenth centuries' *Journal of Interdisciplinary History*, X, 4, 839-849

Le Roy Ladurie E, Baulant M (1980) Grape harvest from the fifteenth through the nineteenth centuries, *Journal of Interdisciplinary History*, X, 839-849

Nordli PO (2001) *Reconstruction of nineteenth century summer temperatures in Norway by proxy data from farmers' diaries*. Climatic Change 48, 201–218

Nordli PO, Lie O, Nesje A, Dahl S (2003) Spring-summer temperature reconstruction in western Norway, 1734-2003: a data-synthesis approach. *International Journal of Climatology*, 23, 1821-1841

Pribyl K, Cornes RC, Pfister C (2011) Reconstructing medieval April-July mean temperatures in East Anglia, 1256-1431 (in print)

Slicher van Bath, BH 1966. Le climat et les récoltes en haut Moyes Ages, Estrato da Settimane di studio del Centro italiano di studi sull'alto medioevo XIII. Agricoltura e mondo rurale in Occidentes dell'alto medioevo. Spoleto 22-23 aprile 1965. 399-447

Tarand A, Paavo K (1994) The beginning of the rye harvest - a proxy indicator of summer climate in the Baltic area. In: Burkhardt, F., Pfister, C. and Gläser, B., (eds.) *Climatic trends and anomalies in Europe 1675-1715. High resolution spatio-temporal reconstructions from direct meteorological observations and proxy data. Methods and results*. Stuttgart-Jena-New York, Gustav Fisscher Verlag, 61-73

Thoen E (2001) A commercial survival economy in evolution. The Flemish countryside and the transition to capitalism (Middle Ages – 19th century). In: Hoppenbrouwers P & van Zanden JL (eds) Peasants into farmers? The transition of rural economy and society in the Low Countries (Middle Ages – 19th century) in the light of the Brenner Debate. Corn Publications no 4. Brepols – Ghent, 85-101