Boyd, D. A. 1939. The estimation of Rothamsted temperature from the temperature of Oxford and Greenwich. *Annals of Eugenics.* 9 (4), pp. 341-352.

THE ESTIMATION OF ROTHAMSTED TEMPERATURE FROM THE TEMPERATURE OF OXFORD AND GREENWICH

By D. A. BOYD
(*Rothamsted Experimental Station*)

1. Introduction

This paper describes the results of an investigation recently carried out at Rothamsted Experimental Station.

The effects of rainfall and sunshine on crop yield have already been the subject of a number of studies. As yet, however, no analysis has been made of crop variation due to temperature fluctuations, except in so far as these are associated with rainfall effects. It is now proposed to undertake an analysis of the effects of temperature also.

Temperature was not recorded at Rothamsted until 1878. Hence it was desired to extend this record back to cover earlier years for which crop yields of the classical experiments are available. As the classical fields were not all under uniform treatment until 1852, and the rainfall record at Rothamsted was not begun until that year, it was considered sufficient to go back as far as 1852.

2. Method employed

Although the temperature may fluctuate widely from day to day and from week to week, it is reasonable to expect that the effect, on the ultimate crop yield, of fluctuations of the same magnitude will change relatively slowly in the course of the whole season. If this is the case, the only components of the fluctuations which need be taken into account are those representable by a smooth curve fitted to the yearly sequence of temperatures, e.g. a fifth degree polynomial. It is not, therefore, necessary to obtain estimates of the daily temperatures at Rothamsted for the period 1852–78; instead, it will be sufficient to estimate yearly values of the mean and of the coefficients of the first five terms of the polynomial regression.

If we wish to fit a polynomial regression line

$$Y = a + bx + cx^2 + \dots + fx^5$$

to a series of observations at equal intervals of x, we may fit instead the equivalent line

$$Y = A + B\xi_1 + C\xi_2 + \dots + F\xi_5,$$

where $\xi_1, \xi_2, \dots, \xi_5$ are orthogonal polynomials of degree 1, 2, ..., 5. In order to reduce the amount of numerical computation weekly means of daily maximum and minimum temperature (which are already available) may be used in place of daily values. In this way, a year's sequence of weekly mean temperatures at any station can be represented by their mean $\bar{y}$ and by the sums of products, $\Sigma y\xi_1'$, $\Sigma y\xi_2'$, ..., $\Sigma y\xi_5'$, where y is the temperature

($n' = 52$, and $\xi' = \lambda\xi$, λ being the smallest multiple which gives integral values to ξ'). For convenience we shall style these quantities Q_0 and $Q_1, Q_2, \ldots, Q_5$. The actual regression coefficients may be obtained by dividing by the sums of squares of the appropriate ξ''s. The values of λ and $\Sigma(\xi'^2)$ are given in the Appendix. Numerical values for all ξ' from ξ'_1 to ξ'_5 are given in *Statistical Tables* (Fisher & Yates, 1938).

Only two long temperature records, those at Oxford and Greenwich, were available from as early as 1852. The major part of the investigation, therefore, consisted in the evaluation and analysis of the quantities $Q_0, Q_1, \ldots, Q_5$ at Rothamsted, Oxford and Greenwich for a period in which the three stations were concurrent. For this purpose, the weekly mean temperatures of each station were extracted from the *Weekly Weather Report* for the period 1878–9 to 1907–8. The crop year, from the first week of September to the last week of August, was used, the values of a fifty-third week being discarded when necessary. The quantities Q were then evaluated for each year, giving thirty annual values of each. These are tabulated in the Appendix.

The means, variances and covariances of each set were calculated for the three stations. Then the linear regression of the quantities Q for Rothamsted on the corresponding set for Oxford and Greenwich was obtained, taking the latter stations individually and simultaneously.

3. Notes on stations used

In Table I are shown the distances and bearings between Rothamsted, Oxford and Greenwich. Their local situations are rather dissimilar, and require brief comment.

Table I. *Interstation distances and bearings*

Pair of stations	Distance in miles	Bearing from N.
Rothamsted-Greenwich	28	146°
Rothamsted-Oxford	38	265°
Oxford-Greenwich	55	110°

Radcliffe Observatory, Oxford, is on the low-lying ground between the Isis and the Cherwell at a height of 202 ft.

Greenwich Observatory lies about ½ mile south of the Thames, but is at a height of 150 ft., the ground sloping steeply to the river on the north, and rather less steeply towards London on the west. Although now encircled by suburbs, it lay on the eastern outskirts of the city during the period with which we are concerned.

Rothamsted's readings are taken on one of the flat-topped interfluves of the eastern Chilterns at an altitude of 424 ft.

At Oxford and Rothamsted the thermometers have been exposed in an orthodox manner, but at Greenwich a Glaisher stand has been in use until very recently. Rothamsted's screen is excellently placed, away from trees or buildings, but at both Oxford and Greenwich the proximity of buildings may well have affected the observations.

4. Results of the investigation

A. *The means of the Q's*

The means and their standard deviations based on differences between years are given in Table II.* Differences between $Q_1 \ldots Q_5$ are not significant, and large differences between the values for Q_0 are mainly the effect of altitude. Table III shows the mean

Table II. *Means of Q_0, Q_1, ..., Q_5 at Rothamsted, Oxford and Greenwich, 1878–9 to 1907–8*

	Rothamsted		Oxford		Greenwich	
	Mean	S.D.	Mean	S.D.	Mean	S.D.
Q_0	+47·67	1·02	+48·69	1·18	+49·31	1·16
$Q_1/10^2$	+67·81	11·20	+68·76	11·95	+70·40	12·11
$Q_2/10^3$	+66·96	8·92	+66·08	9·06	+69·32	9·50
$Q_3/10^4$	−28·19	6·27	−28·58	6·48	−28·86	6·84
$Q_4/10^4$	−10·03	5·05	− 9·61	5·24	−11·22	5·46
$Q_5/10^4$	−12·47	83·55	−16·63	81·91	−20·40	84·37

Table III. *Mean annual temperatures at Rothamsted, Oxford and Greenwich*

Station	Actual	Reduced to sea-level by 1° F. for 300 ft.		
	1878–9 to 1907–8	1878–9 to 1907–8	1881–1915	1906–35
Rothamsted	47·7	49·1	49·6	49·7
Oxford	48·7	49·4	50·3	50·4
Greenwich	49·3	49·8	50·8	51·0

temperatures as observed, and when reduced to sea-level by the correction of 1° F. for 300 ft. Differences between the values of Q_0 are still significant after the correction has been applied. The means published by the Meteorological Office (1919, 1936) have been added for comparison. Owing to the inclusion in the present data of a number of unusually cold years at the beginning of the period, the means for 1878–9 to 1907–8 are lower than for either of the later periods, the difference being rather less at Rothamsted than at Oxford or Greenwich.

From the mean values of the Q's the mean polynomial for seasonal variation at each station can be constructed. Inspection showed that the polynomial for Oxford and Rothamsted were very similar, while Greenwich differed considerably from the other two. Fig. 1 has therefore been drawn to show the mean for Oxford and Rothamsted. It is of interest to note that, during the period under review, the lowest mean temperature occurred at the end of the third week of January (37·3° F.) and the highest mean in the last week of July (61·2° F.). Beneath this mean polynomial are shown the deviations from it of the Greenwich polynomial and the difference between the Oxford and Rothamsted

* The fluctuating date of commencement of the crop-years will contribute a little to the variance from year to year of $Q_1 \ldots Q_5$. However, the departure from the mean date, 1 September, cannot exceed ± 3 days, so that the additional variance will be very small and may well be neglected.

polynomials. It is clear that the seasonal range of mean temperature was greater at Greenwich than at Oxford and Rothamsted. Thus in February and March Greenwich temperature exceeded the mean of the other two stations by 0·6° F., whereas in July Greenwich was the warmer by as much as 1·6° F. It might therefore be assumed that

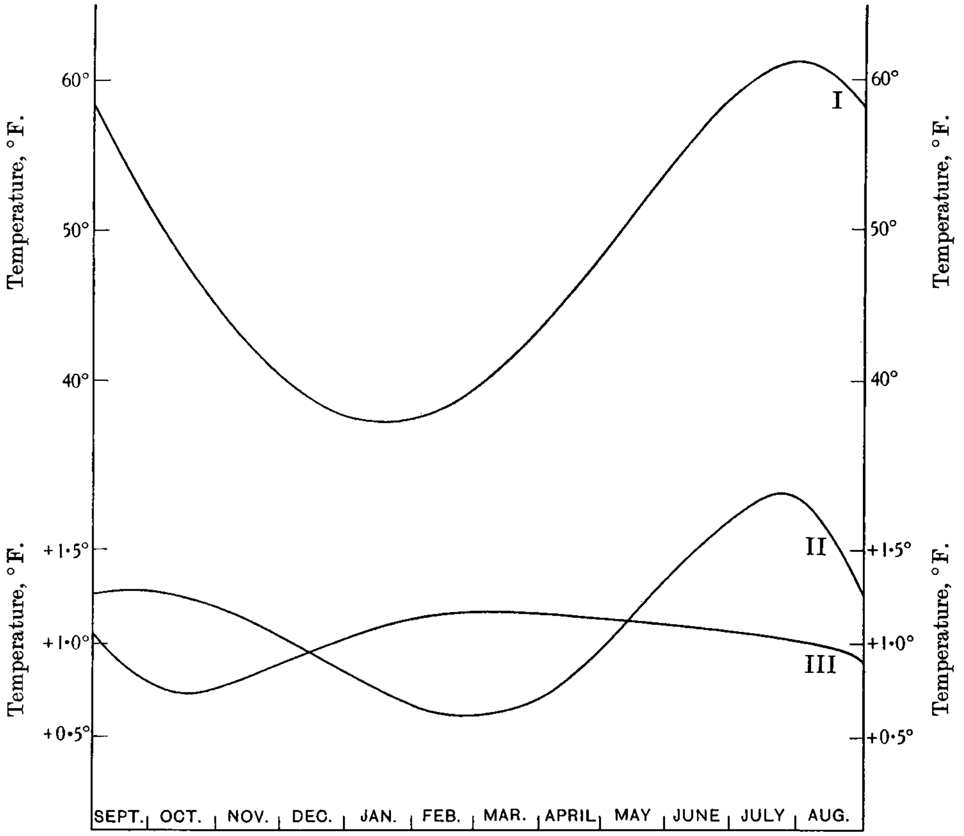

Fig. 1. I. Mean polynomial (mean of Rothamsted and Oxford). II. Deviations of the Greenwich polynomial from this mean. III. Oxford minus Rothamsted.

Greenwich had a slightly more extreme climate than Oxford or Rothamsted. However, part of this difference may well be the result of using a Glaisher stand instead of a Stevenson screen. W. Ellis (1891) gave results of a comparison of thermometer readings taken on a Glaisher stand with corresponding observations in a Stevenson screen for three years, 1887–9 (Table IV). These values indicate that a part (though not all) of the difference

Table IV. *The effect of the method of exposure on mean monthly temperature (Glaisher stand minus Stevenson screen) at Greenwich* 1887–9 (° F.). *See Ellis* (1891)

Jan.	Feb.	Mar.	Apr.	May	June	
+0·02°	+0·06°	+0·25°	+0·63°	+0·70°	+0·80°	
July	Aug.	Sept.	Oct.	Nov.	Dec.	Year
+0·88°	+0·72°	+0·30°	+0·15°	+0·05°	−0·07°	+0·37°

may be purely an effect of the unorthodox exposure. This is borne out by values for other London stations in *The Book of Normals* (M.O. 1917) for 1881–1915; the greatest extremes between the means for January and July occurred at Camden Square and Greenwich, the only stations using the Glaisher stand.

B. *Slow changes*

To determine whether slow changes have occurred in the mean temperature or in its distribution over the year during the period under review, a linear regression was fitted to each set of values $Q_0, Q_1, \ldots, Q_5$. The regression coefficients obtained are shown in Table V.

Table V. *Linear regressions on time of* $Q_0, Q_1, \ldots, Q_4$

	Rothamsted	Oxford	Greenwich
Q_0	$+0.0209 \pm 0.0108$	$+0.0235 \pm 0.0124$	$+0.0287 \pm 0.0123$
Q_1	-1.4909 ± 1.1807	-0.8673 ± 1.2603	-0.5018 ± 1.2776
Q_2	-0.6862 ± 0.9409	-0.4618 ± 0.9550	-0.8085 ± 1.0024
Q_3	-1.0395 ± 0.6615	-0.9933 ± 0.6829	-0.9198 ± 0.7219
Q_4	$+0.4666 \pm 0.5311$	$+0.4808 \pm 0.5523$	$+0.3990 \pm 0.5763$

In the case of Q_0 they are about twice the standard deviation; we may say, therefore, that a real increase of mean annual temperature was taking place, amounting to approximately 0·05° F. per year, during the period 1878–9 to 1907–8. No significant changes have occurred in the distribution values $Q_1 \ldots Q_5$. It is of interest to note that the largest of these values are for Q_3, since Fisher (1924) and Wishart (1930) noted a significant change in the corresponding regression coefficient for Rothamsted rainfall over a much longer period of years.

Differences between the regression coefficients at the three stations are generally small. The standard errors of the differences were computed for Q_1, Q_2 and Q_3, and showed that these differences were not significant.

C. *Analysis of total variance of weekly mean temperature*

The variance of weekly mean temperature at each station is analysed in Table VI. The first four terms of the polynomial are highly significant, but the fifth does not significantly

Table VI. *Analysis of variance of weekly mean temperature* (1878–9 *to* 1907–8)

Variance due to	D.F.	Rothamsted	Oxford	Greenwich
Q_1	1	98,143·01	100,921·96	105,773·31
Q_2	1	212,641·21	207,109·21	227,916·86
Q_3	1	48,950·69	50,314·49	51,293·35
Q_4	1	9,301·44	8,527·18	11,624·86
Q_5	1	58·96	104·96	157·88
Residual	46	82,846·94	200,677·31	186,563·46
Total	51	451,942·25	567,025·11	583,329·72
Mean square:				
Residual	1	1,801·02	4,362·55	4,055·73
Total	1	8,861·61	11,118·14	11,437·84

exceed the residual variance. The proportion of the total variance removed by the polynomial fitting is

Rothamsted	79·7 %
Oxford	60·8 %
Greenwich	64·5 %

The variance accounted for by the polynomial fitting is very similar for all three stations, but there was a markedly smaller residual variance at Rothamsted. Even assuming independence such a difference would occur only once in five trials. Since temperature variations for neighbouring stations are far from independent, there is clearly a real difference of surprising magnitude.

An explanation is doubtless to be found in the dissimilar local situations of the stations, which have been referred to above. Broadly speaking, both Oxford and Greenwich may be said to have a valley situation, whereas Rothamsted lies well up on the dip-slope of the Chiltern plateau. It may well be, therefore, that the contrast is due to the well-known tendency for greater extremes to occur in valleys than on gradually sloping plateaus in anticyclonic weather. Inspection of the actual weekly records for two recent years gave some confirmation of this reasoning.

We cannot, however, exclude the possibility that the effect may be due, in part at least, to the proximity of the Oxford and Greenwich thermometers to the Observatory walls, in contrast with the open situation of the Rothamsted screen.

D. *The variance of* $Q_0, Q_1, \ldots, Q_5$

Not only is the variance of the weekly means within each year notably smaller at Rothamsted, but the year to year variance of the mean and distribution values is also less. Differences are considerable between the values $Q_1 \ldots Q_5$ for Rothamsted and Greenwich, but are less important between Rothamsted and Oxford. Greenwich has a somewhat higher annual variance than the other stations in each case. The variance of Q_0 at Rothamsted is markedly less than Q_0 at Oxford or Greenwich; the variance ratio would give $P = 0{\cdot}2$, even if the deviations from the station means were uncorrelated. Only a small part of this difference can be due to differences in rate of the slow changes noted under (B) above.

E. *The prediction of the Rothamsted values* $Q_0, Q_1, \ldots, Q_5$ *from those of Oxford and Greenwich*

The correlation coefficients between the three stations are shown in Table VII. They are, of course, extremely high; correlations between Rothamsted and Oxford are, on the whole, rather higher than between these stations and Greenwich.

The linear regression of the Rothamsted values, $Q_0, Q_1, \ldots, Q_5$, on the corresponding quantities for Oxford and Greenwich were obtained, taking the two stations individually and simultaneously (Table VIII).

Table VII. *Correlation coefficients between Q_0, Q_1, ..., Q_5 at Rothamsted, Oxford and Greenwich*

Pairs of stations	Q_0	Q_1	Q_2	Q_3	Q_4	Q_5
Rothamsted-Oxford	0·9883	0·9843	0·9888	0·9910	0·9772	0·9776
Rothamsted-Greenwich	0·9792	0·9629	0·9807	0·9743	0·9630	0·9661
Oxford-Greenwich	0·9720	0·9717	0·9808	0·9791	0·9852	0·9625

Table VIII. *Regression coefficients of Q_0, Q_1, ..., Q_5 for Rothamsted, Oxford and Greenwich*

	Linear regression of Rothamsted on				Linear regression of Oxford on				Linear regression of Greenwich on			
	Oxford		Greenwich		Rothamsted		Greenwich		Rothamsted		Oxford	
		S.D.		S.D.		S.D.		S.D.		S.D.		S.D.
Q_0	0·8582	0·0080	0·8593	0·0106	1·1381	0·0105	0·9823	0·0142	1·1157	0·0138	0·9618	0·0139
Q_1	0·9642	0·0103	0·9386	0·0151	1·0047	0·0108	0·9645	0·0140	0·9926	0·0161	0·9789	0·0142
Q_2	0·9744	0·0088	0·9205	0·0110	1·0033	0·0091	0·9342	0·0111	1·0448	0·0125	1·0298	0·0122
Q_3	0·9562	0·0077	0·8894	0·0161	1·0269	0·0083	0·9262	0·0115	1·0674	0·0147	1·0350	0·0129
Q_4	0·9431	0·0122	0·8975	0·0133	1·0126	0·0131	0·9442	0·0098	1·0494	0·0156	1·0281	0·0107
Q_5	0·9970	0·0128	0·9565	0·0153	0·9586	0·0123	0·9352	0·0156	0·9758	0·0156	0·9924	0·0165

	Partial regression of Rothamsted on Oxford and Greenwich	
		S.D.
Q_0	0·8695	0·0071
Q_1	0·9674	0·0103
Q_2	0·9744	0·0084
Q_3	0·9562	0·0080
Q_4	0·9431	0·0123
Q_5	0·9970	0·0118

It will be noticed that most of the regression coefficients of Rothamsted on Oxford, and all for Rothamsted on Greenwich, are significantly less than unity. If there is complete association between two variates having similar means and variances, the linear regression of one on the other will be unity. Such a result may therefore imply that the variance of Rothamsted is smaller, or merely that there is incomplete association between the two stations. The reality of the difference in variance may be tested by reversing the role of the dependent and independent variates. This procedure gives the regression coefficients shown in the last four columns of Table VIII.

The linear regressions of Oxford on Rothamsted are rather greater than unity for Q_0 to Q_4, but only significantly so in the case of Q_0. For the corresponding regression of Greenwich on Rothamsted, Q_0, Q_2, Q_3 and Q_4 give a coefficient significantly greater than unity. (It has already been shown that Q_5 does not contribute a significant amount to the total variance of weekly mean temperature, and we may therefore disregard its otherwise anomalous values.)

It is of interest to consider also the linear regression for Oxford on Greenwich and for Greenwich on Oxford. For Q_0 and Q_1 the differences between the two stations are small and clearly due to random variation, but for Q_2, Q_3 and Q_4 the regression of Oxford on Greenwich is significantly less than unity and the corresponding regressions of Greenwich on Oxford significantly greater, evidently the result of a genuinely greater variance at Greenwich.

Table IX. *Analysis of variance of Q_0, Q_1, ..., Q_5 for Rothamsted, showing the contribution of the regression on Oxford and Greenwich*

Sums of squares	D.F.	Q_0	$Q_1/10$	$Q_2/10^2$	$Q_3/10^2$	$Q_4/10^3$	$Q_5/10^4$
Partial regression on Oxford and Greenwich	2	29·6795	404,775	226,341	111,217	70,870	195,060
Remainder	27	0·5154	12,445	4,446	1,994	3,187	7,299
Total	29	30·1949	417,220	230,787	113,211	74,057	202,359
Regression on Oxford	1	29·4911	404,194	225,625	111,171	70,721	193,399
Remainder	28	0·7038	13,026	5,162	2,040	3,336	8,960
Total	29	30·1949	417,220	230,787	113,211	74,057	202,359
Regression on Greenwich	1	28·9503	388,694	221,944	103,397	69,746	188,874
Remainder	28	1·2446	28,526	8,843	9,814	4,311	13,485
Total	29	30·1949	417,220	230,787	113,211	74,057	202,359
Remainder mean square:							
Regression on Oxford	28	0·0251	465	184	73	119	320
Regression on Greenwich	28	0·0444	1,009	316	351	154	482
Partial regression on Oxford and Greenwich	27	0·0191	461	165	74	118	270
Reduction of remainder due to use of Greenwich in addition to Oxford	1	0·1884	581	716	461	149	1,661

It appears, therefore, that the climate of Rothamsted was distinctly less variable and more equable than the climate of Oxford and Greenwich, not only for individual weeks, but also between the same seasons of different years, and for whole years. The climate of Oxford seems to have differed from that of Greenwich in that the seasonal distribution from one year to another was less variable.

It is now possible to discuss the relative advantages, for predicting the Rothamsted values, of using the partial regression on Oxford and Greenwich or a simple regression on one or the other. An analysis of the variance accounted for by the several linear regressions is given in Table IX.

It is clear that variations of each set of values $Q_0 \dots Q_5$ are reproduced better by Oxford than by Greenwich, significantly so from Q_0 to Q_3. The fit is, on the whole, even better if account is taken of both Oxford and Greenwich simultaneously, the further reduction in the residual variance being significant for Q_0, Q_2 and Q_5.

The percentage variance not accounted for by the linear regressions is very small (Table X). It is clear that, while the Oxford record predicts the Rothamsted values more satisfactorily than does Greenwich, the further reduction in variance obtained by using both simultaneously gives only slightly better results. Hence the computation of the quantities Q_0, Q_1, ..., Q_5 for Oxford only, for each year of the period 1852–78, will be sufficient for an estimation of the corresponding values for Rothamsted.

Table X. *Percentage of variance not accounted for by the regressions of Rothamsted on Oxford and Greenwich*

	Linear regression of Rothamsted on		
	Oxford	Greenwich	Oxford and Greenwich
Q_0	2·41	4·26	1·83
Q_1	3·23	7·01	3·20
Q_2	2·31	3·97	2·07
Q_3	1·87	8·99	1·90
Q_4	4·66	6·03	4·62
Q_5	4·59	6·91	3·87

It is clear that for an element not subject to violent local fluctuations, such as weekly mean temperature, highly satisfactory prediction at any station in lowland England of the mean and the distribution values up to the fifth degree, may be possible from the long records of a neighbouring station. The distance between Rothamsted and Oxford is considerable, and the contrast between their situations is almost as great as will be met with in England south of the Pennines and east of the Welsh Border. It is quite likely, therefore, that satisfactory estimation over distances of more than a hundred miles is possible if it is only required to estimate slowly changing quantities such as the values Q used in this paper.

Summary

It is proposed shortly to analyse the effect of temperature on the Rothamsted crop-yields. For this purpose we require the mean Q_0 and quantities Q_1, ..., Q_5 proportional to the regression coefficients of a fifth degree polynomial fitted to the weekly mean temperature of each crop year. Rothamsted's temperature record did not commence until 1878, whereas yields for most of the classical experiments are available from 1852. The

required values for the period 1852–3 to 1877–8 must be estimated from the longer records of Oxford and Greenwich. As a first step, the quantities Q were evaluated for a period of years (1878–9 to 1907–8) during which the three stations were concurrent, and the means, variances and covariances of each set of Q's were calculated.

Greenwich appears to have had a slightly more extreme climate than Oxford or Rothamsted, but this may have been due in part to the unorthodox exposure of the thermometers there. A significant increase in mean temperature over the period was noted, amounting to about 0·05° F. a year. Changes in the seasonal distribution of temperature were not significant. The variance of Rothamsted temperature was significantly smaller than that of Oxford or Greenwich, both from week to week, and from year to year. This noteworthy difference was doubtless due to the more upland situation of Rothamsted.

The linear regressions of the Q's for Rothamsted on the corresponding values for Oxford and Greenwich were evaluated, taking the two stations individually and simultaneously. Oxford gave a better fit than Greenwich in every case, and the partial regression on the two stations was little better than the regression on Oxford alone. The fit was very good for the regression of Rothamsted or Oxford, the residual variance in no case exceeding 5 %.

We may therefore obtain an extremely satisfactory prediction of the mean annual temperature (the standard error being reducible to $\pm 0{\cdot}14°$ F.) and of the regression coefficients up to the 5th degree for Rothamsted from those of Oxford only. At the same time differences of surprising magnitude have been revealed in the variability of weekly and annual temperature at Rothamsted as compared with Oxford and Greenwich.

In conclusion, the author wishes to acknowledge the help he has received from Dr Yates, Head of the Statistical Department, Rothamsted Experimental Station. He is also indebted to Dr Glasspoole and to the Librarian of the Meteorological Office, who facilitated the abstraction of the temperature data used in this paper. The data was taken mainly from the *Weekly Weather Report* of the Meteorological Office, but the earlier years of the Greenwich record were abstracted from the Registrar-General's *Reports*.

APPENDIX

The values $Q_0, Q_1, \ldots, Q_5$ *for Rothamsted, Oxford and Greenwich* (1878–9 *to* 1907–8).

The values of λ and of $\Sigma(\xi_1'^2) \ldots \Sigma(\xi_5'^2)$ are given below to permit the calculation of the actual regression coefficients from the Q's (from *Statistical Tables* (Fisher & Yates)).

	Q_1	Q_2	Q_3	Q_4	Q_5
λ	2	1	$\frac{2}{3}$	$\frac{1}{24}$	$\frac{1}{20}$
$(\Sigma\xi_p'^2)$	46,852	2,108,340	162,342,180	108,228,120	26,358,466,680

Year	Q_0			$Q_1/10^1$		
	Rothamsted	Oxford	Greenwich	Rothamsted	Oxford	Greenwich
1878–9	45·59	46·18	46·64	+666	+670	+616
1879–80	46·86	47·70	47·99	+885	+858	+853
1880–1	47·60	48·47	49·07	+651	+656	+666
1881–2	48·52	49·94	49·71	+704	+666	+672
1882–3	47·76	49·01	49·10	+707	+682	+694
1883–4	48·93	50·16	50·63	+660	+678	+733
1884–5	47·55	48·69	49·33	+533	+546	+591
1885–6	46·15	47·45	47·88	+762	+779	+788
1886–7	47·46	48·20	49·09	+597	+592	+621
1887–8	45·32	45·87	46·66	+758	+769	+764
1888–9	47·71	48·54	49·12	+749	+736	+759
1889–90	47·32	48·38	49·02	+642	+642	+632
1890–1	46·05	46·65	47·37	+615	+596	+637
1891–2	47·06	47·85	48·98	+612	+625	+651
1892–3	48·59	49·70	50·51	+992	+1040	+1050
1893–4	47·99	48·91	49·71	+630	+625	+648
1894–5	47·26	48·17	49·18	+763	+781	+826
1895–6	49·04	50·24	51·12	+614	+647	+655
1896–7	47·65	48·71	49·49	+877	+883	+947
1897–8	48·33	49·44	50·22	+660	+680	+701
1898–9	50·19	51·46	51·92	+571	+610	+576
1899–1900	47·90	49·00	49·65	+724	+735	+730
1900–1	48·48	49·67	50·18	+619	+631	+639
1901–2	47·04	48·19	48·73	+537	+584	+555
1902–3	48·07	49·24	49·79	+502	+512	+535
1903–4	48·16	49·22	49·80	+706	+703	+762
1904–5	48·40	49·09	50·00	+765	+814	+790
1905–6	47·76	48·81	49·31	+822	+854	+889
1906–7	47·59	48·71	49·06	+438	+442	+500
1907–8	47·88	49·05	49·97	+582	+593	+639
Total	1430·21	1460·70	1479·23	+20,343	+20,629	+21,119

Year	$Q_2/10^2$			$Q_3/10^3$		
	Rothamsted	Oxford	Greenwich	Rothamsted	Oxford	Greenwich
1878–9	+802	+805	+814	−364	−367	−335
1879–80	+727	+697	+746	−344	−353	−354
1880–1	+784	+745	+796	−380	−390	−371
1881–2	+490	+484	+494	−241	−251	−256
1882–3	+604	+570	+642	−229	−211	−204
1883–4	+603	+599	+645	−172	−175	−171
1884–5	+655	+652	+705	−305	−311	−310
1885–6	+754	+733	+760	−281	−277	−276
1886–7	+863	+875	+951	−305	−300	−298
1887–8	+623	+614	+653	−276	−283	−294
1888–9	+609	+590	+628	−286	−278	−297
1889–90	+582	+594	+604	−264	−278	−296
1890–1	+792	+807	+824	−381	−396	−412
1891–2	+720	+701	+735	−328	−310	−347
1892–3	+583	+568	+597	−365	−372	−389
1893–4	+578	+560	+593	−289	−294	−315
1894–5	+747	+733	+753	−284	−297	−302
1895–6	+627	+626	+664	−350	−363	−392
1896–7	+603	+589	+614	−362	−367	−371
1897–8	+608	+605	+640	−150	−141	−134
1898–9	+761	+752	+816	−197	−202	−204
1899–1900	+761	+749	+752	−279	−292	−284
1900–1	+737	+730	+757	−213	−228	−226
1901–2	+683	+663	+685	−257	−270	−253
1902–3	+539	+533	+547	−209	−216	−210
1903–4	+640	+638	+679	−290	−291	−289
1904–5	+579	+582	+603	−295	−296	−299
1905–6	+662	+652	+686	−187	−189	−190
1906–7	+690	+679	+709	−302	−305	−303
1907–8	+681	+699	+704	−272	−271	−275
Total	+20,087	+19,824	+20,796	−8457	−8574	−8657

Year	$Q_4/10^3$			$Q_5/10^4$		
	Rothamsted	Oxford	Greenwich	Rothamsted	Oxford	Greenwich
1878–9	− 51	− 57	− 60	+ 55	+ 34	+ 54
1879–80	+ 4	+ 2	− 15	+ 75	+110	+ 99
1880–1	−137	−125	−133	− 96	− 65	−143
1881–2	− 48	− 55	− 75	− 27	− 11	+ 5
1882–3	−110	− 84	−112	− 10	− 13	− 6
1883–4	− 68	− 59	− 77	− 97	−114	− 88
1884–5	− 99	− 96	−114	− 86	− 83	− 59
1885–6	−128	−109	−142	+ 49	+ 2	+ 3
1886–7	−151	−153	−172	− 18	− 22	− 65
1887–8	−111	−113	−128	− 46	− 29	− 41
1888–9	−169	−166	−192	+ 42	+ 43	+ 8
1889–90	− 89	− 83	− 87	− 80	− 71	− 68
1890–1	− 85	− 99	−115	+101	+111	+ 90
1891–2	−106	− 95	−110	+ 61	+ 45	+ 42
1892–3	− 66	− 46	− 68	+ 77	+ 74	+101
1893–4	− 46	− 36	− 41	− 2	− 6	0
1894–5	−221	−233	−254	+218	+208	+198
1895–6	− 94	− 88	−114	− 66	− 68	− 91
1896–7	− 43	− 48	− 78	−136	−136	−140
1897–8	− 99	−100	−103	− 27	− 30	− 18
1898–9	− 90	− 91	− 98	−149	−170	−176
1899–1900	−141	−122	−152	− 69	− 89	− 88
1900–1	−201	−205	−213	− 28	− 39	− 31
1901–2	− 84	− 71	− 87	+ 10	+ 13	− 13
1902–3	− 47	− 51	− 57	− 78	− 85	− 87
1903–4	−154	−154	−177	+ 48	+ 29	+ 21
1904–5	−117	−114	−139	− 57	− 68	− 59
1905–6	− 29	− 20	− 35	−143	−123	−145
1906–7	− 76	− 64	− 60	+ 85	+ 59	+ 57
1907–8	−145	−147	−157	+ 20	− 5	+ 28
Total	−3001	−2882	−3365	−374	−499	−612

REFERENCES

W. Ellis (1891). "On the comparison of thermometrical observations made in a Stevenson screen with corresponding observations made on the revolving stand at the Royal Observatory, Greenwich." *Quart. J.R. Met. Soc.* **17**, 240–7.

R. A. Fisher (1924). "The influence of rainfall on the yield of wheat at Rothamsted." *Philos. Trans.* B, **213**, 89–142.

R. A. Fisher & F. Yates (1938). *Statistical Tables*, p. 60.

Meteorological Office (1919). *The Book of Normals.*

—— (1936). *Averages of Temperature for periods ending* 1935.

J. Wishart (1930). "On the secular variation of rainfall at Rothamsted." *Mem. R. Met. Soc.* **3**, no. 27.