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Correlation of the Weather and Crops

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JOURNAL

OF THE ROYAL STATISTICAL SOCIETY.

MARCH, 1907.

CORRELATION *of the* WEATHER *and* CROPS.

By R. H. HOOKER, F.R.Met.S.

[Read before the Royal Statistical Society, 15th January, 1907.
SIR RICHARD B. MARTIN, Bart., President, in the Chair.]

IN his paper upon "Seasons in the British Isles from 1878,"* read in 1905 before this Society, Dr. W. N. Shaw drew attention to the great importance of the rainfall during autumn to the yield of wheat in the following summer. In the subsequent discussion upon this paper, Mr. D. A. Thomas† thought that the relation was not so close as Dr. Shaw seemed to think, and questioned whether the autumn rainfall were the dominant factor: to me, however, it appeared that Dr. Shaw had shown it to be of more importance than had hitherto been supposed. It occurred to me that the method of correlation might quite possibly enable us to determine whether the meteorological conditions during autumn were or were not the predominant factor in our wheat supply.

The method, although somewhat laborious, is in theory exceedingly simple and obvious. The correlation coefficients between the yield of wheat and the rainfall of various periods are calculated in the usual way, and it is then assumed that the maximum coefficient indicates the period of greatest influence. The primary problem suggested by the discussion on Dr. Shaw's paper is, therefore, to ascertain whether the correlation coefficient between the wheat yield and rainfall is higher during autumn than at any other period of the year.

It occurred to me also that it was worth while extending the scope of this inquiry to include other crops, and, in addition, to

* *Journal of the Royal Statistical Society*, vol. lxviii, part ii, p. 285. See also "Proc. Roy. Soc.," 1905, p. 552, and 1906, A, p. 70; and "Report of the "Meteorological Committee, 1905-06," p. 20-22.

† *Journal*, 1905, p. 315.

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ascertain similarly the effect of variations in temperature. The tables at the end of this paper therefore comprise the correlation coefficients for successive periods of the year between (*a*) rainfall, (*b*) temperature, and the following ten crops:—wheat, barley, oats beans, peas, potatoes, turnips and swedes, mangolds, hay from clover and rotation grasses, and hay from permanent grass.*

It will be observed that the treatment of such a subject presupposes a knowledge of the conditions of plant growth, practical agriculture, and of statistics, far beyond what I possess, more particularly in the case of the two former; and my grateful thanks are accordingly due to Sir William Thiselton-Dyer, F.R.S., Dr. W. Somerville, and Mr. G. U. Yule, for much information on fundamental elementary points in connection with these subjects. I hope it will be recognised that I have done my best to supplement my ignorance, by securing the help of the best authorities in their respective branches of science.

The first consideration is the selection of a suitable tract of country. Climatic conditions differ so materially in England and Scotland, and even in different parts of England, that it is necessary to select an area sufficiently small to ensure reasonable uniformity of climate over the whole of it. That is to say, that, if one portion is experiencing heavy rain, we want to be pretty certain that the remainder is also receiving an excess of precipitation. On the other hand, the area must not be too small, since it is necessary, in order to attribute any results to the weather, to be fairly safe in assuming that other possible factors more or less balance each other. It is quite conceivable, for instance, that a given rainfall may have a different effect upon a crop grown on a limestone soil to what it has upon one grown on alluvium or granite; hence the area should, if possible, be of sufficient size to comprise various geological formations, &c. It should, moreover, include a considerable amount of each of the crops under investigation. The area must therefore be somewhat of the nature of a compromise, and should be as large as is compatible with reasonable uniformity of climatic conditions.

These desiderata seem to me best secured in the district known in our Agricultural Returns as "Division I: England, east and "north-east." From this I have, however, omitted the East Riding of York (as being rather too far north), Middlesex and London; and the selected area thus consists of the counties of Lincoln, Huntingdon, Cambridge, Norfolk, Suffolk, Essex, Bedford, and Hertford. I shall call this area Eastern England. The average area under each of these crops in the last two decades is shown in

* For brevity, I shall describe these two classes of hay as "seeds' hay" and "meadow hay," respectively.

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Table II. It may be pointed out, as evidence of the importance of this district in this connection, that it includes the county with the largest acreage under each of the ten crops named, except only permanent grass: it may therefore not inaptly be described as comprising the centre of production of each crop.* The yield per acre of each crop (see Tables II and III) is of course calculated from the figures of area and production given for each county in the Annual Agricultural Returns during the twenty-one years 1885-1905 (1886-1905 only in the case of the two classes of hay).

The district is also very uniform as regards climate. My data are taken from the weekly returns of the Meteorological Office, and represent the average rainfall, accumulated temperature above 42°, and accumulated temperature below 42°, in each of the periods under consideration, of the following eight stations: Hillington, Yarmouth, Geldeston, Cambridge, Felixstowe, Clacton-on-Sea, Rothamsted, Shoeburyness.† These are the stations comprised in the Meteorological District known as "England East," and are all within the agricultural area specified above, which latter, however, includes Lincolnshire. This county is so important from an agricultural point of view, that I could not omit it; there are situated within it two meteorological stations, but the data for them do not materially affect the averages I have taken.

As regards the periods of the year selected, Dr. Shaw took the usual quarters. It seemed conceivable, however, that the critical period for a crop might be a shorter time than three months: comparison with autumn rainfall indicated that conditions at the time of sowing wheat are of importance, possibly therefore a single month might prove the dominant period. On the other hand, farming operations, and the period of growth of a plant, may be delayed (for a limited length of time, doubtless varying with the crop); and consequently on an average of many years the limits of the dominant period may be more extended and ill-defined. For instance, among the problems to which an answer might be expected from this inquiry is: Is the weather at time of sowing important for turnips? If it is, then June will be important in an

* Potatoes may possibly be regarded as an exception. Lincoln has, on the average, the greatest area, but owing to the higher yield per acre, Lancaster frequently surpasses it in total production.

† These averages are calculated from the data published in the "Weekly "Weather Report," but I have been saved the considerable trouble of actually working them out, as the Meteorological Office have allowed me to copy the weekly averages for the district from their books. It should be mentioned that the 53rd week, when it occurs, has been ignored: I satisfied myself that in no case was the weather in this week abnormal, and that the general average was representative of it.

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early year, and possibly July in a late year; hence we must choose a period sufficiently long to cover all reasonable delays. Eight weeks seem sufficient for this in the majority of cases. The periods tested are therefore successive (and overlapping) periods of eight weeks.

I anticipated that the 33rd—40th weeks (approximately second half of August to first week in October) would be the earliest period to affect the earliest sown crop (wheat). When these calculations were practically completed, however, I found that the autumn seemed to have an important influence upon certain crops that were not sown until after the succeeding winter. I suppose a practical agriculturist might have anticipated this. I accordingly carried the calculations back for a further six months. I end with the 37th–44th weeks of the harvest year itself (approximately mid-September to early November) as being probably the last to affect the latest harvested crops (roots). I have thus examined the effect, upon each crop, of the weather during a period extending over twenty months, viz., from the 9th week (beginning of March) until the 44th week (beginning of November) of the following year. I have also taken the seasons (autumn,* winter, spring and summer), and the approximate cereal year (36th week to 35th week of the following year) as a whole, with a view to seeing whether the average of the whole year, or a three-monthly period, were more important than any particular eight weeks.

As regards the meteorological statistics, the actual rainfall figures were naturally taken. But as regards temperature, it seemed to me that the variations in the number of degrees Fahrenheit between one year and another were hardly sufficiently large to bring out the differences with sufficient clearness. I have therefore utilised the accumulated temperatures above 42° F.; that is to say the total number of day-degrees† above 42° in each period. The selection of 42° as a base temperature below which it is assumed that plants make (practically) no growth is, I believe, due to A. de Candolle, but I do not know how far it is supposed to apply to all plants alike. In any case, it forms the accepted base-line, and is quite convenient for the present purpose. I have also correlated the crops with the accumulated temperatures below 42°; but these rarely appear to yield any significant information (beyond what

* These terms will throughout be used to denote approximately the three calendar months, viz., autumn = September, October, November, &c. Strictly speaking, they are periods of thirteen weeks: autumn is taken as including the 36th–48th weeks, &c.

† See, *e.g.*, Dr. Shaw's paper (*Journal*, 1905, p. 265) for an explanation of accumulated temperatures, also regarding the base temperature of 42° F.

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may be learnt from the accumulated temperatures above 42°, with which they are of course closely correlated), and I have not as a rule discussed them.

Some explanation is perhaps desirable concerning the correlation coefficients. I have in the first place formed the ordinary coefficient* $r = \frac{\Sigma(xy)}{\sqrt{n\sigma_1\sigma_2}}$, between the crop and (*a*) rainfall, (*b*) accumulated temperature above 42°. But rainfall and temperature are themselves correlated; hence an apparent influence of, say, rainfall upon a crop may really be due to the rainfall conditions being dependent upon temperature, or *vice versâ*. Hence it seemed desirable to calculate the *partial* or *net* correlation coefficients, *i.e.* (following the notation given in Mr. Yule's paper of 1897).†

$$\rho_{12} = \frac{r_{12} - r_{13}\,r_{23}}{\sqrt{(1 - r_{13}^2)(1 - r_{23}^2)}},\quad \rho_{13} = \frac{r_{13} - r_{12}\,r_{23}}{\sqrt{(1 - r_{12}^2)(1 - r_{23}^2)}}.$$

This partial coefficient (ρ) may be regarded as a truer indication of the connection between the crop and each factor alone, inasmuch as, speaking approximately, we may say that the effect of the other factor is eliminated. It may be observed, moreover, that the relative influence of rainfall and temperature upon the crop is given by $\frac{\rho_{12}}{\rho_{13}}$; or, more accurately, this fraction measures the relative effect of changes equal in amount to their respective standard deviations in the rainfall and temperature.‡ In discussing the figures in the tables I shall accordingly utilise the partial correlation coefficients rather than the others. Finally, I have worked out what Mr. Yule calls the coefficient of double correlation§ between the crop and rainfall and accumulated temperature above 42°, $R = \sqrt{\frac{r_{12}^2 + r_{13}^2 - 2r_{12}\,r_{23}\,r_{13}}{1 - r_{23}^2}}$, or as it may also be written, $R = \sqrt{1 - (1 - r_{12}^2)(1 - \rho_{13}^2)}$, a form which is quicker to calculate. This may be regarded as a measure of the joint influence of the rainfall and temperature upon the crop. For the sake of brevity, I shall speak of R as measuring the effect of the

* See, *e.g.*, Yule "On the Theory of Correlation" (*Journal*, vol. lxi. 1897, p. 812, *et seq.*, or Bowley, "Elements of Statistics."

† *Journal*, 1897, p. 833.

‡ *Cf.* Hooker and Yule, "Note on Estimating the Relative Influence of Two "Variables upon a Third" (*Journal*, 1906, p. 197). In that paper we gave a method of estimating the relative influence of equal *percentage* changes in two factors, the fraction there given being equivalent to $\frac{\rho_{12}}{\rho_{13}} \cdot \frac{\sigma_2}{\sigma_3}$.

§ *Journal*, 1906, p. 199; also 1897, p. 833.

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"weather," using this term in the strictly limited sense of consisting only of these two factors.

Before discussing the actual results of the calculations, several cautions are necessary. In the first place, what value of the correlation coefficient may we safely regard as significant of a causal connection between the crops and rainfall or temperature? Clearly, with the very small number of observations at our command, a very small coefficient can no more be regarded as absolute evidence of such than, say, 3 successive throws of sixes with a die can be taken as proof positive that the die is loaded. In this case, we have records of the yield of crops for only 21 years, *i.e.*, we have but 21 observations. Mr. Bowley suggests* that when the correlation coefficient (r) is greater than six times its probable error we may be practically certain that two phenomena are not independent of each other. Now the probable error of the correlation coefficient $= 0{\cdot}67\,\dfrac{1-r^2}{\sqrt{n}}$; on this assumption, then, the correlation coefficient may be regarded as satisfactory evidence of causal connection when $r = 6 \times 0{\cdot}67\,\dfrac{1-r^2}{\sqrt{n}}$ or more, *i.e.*, when $r = 0{\cdot}58$. With a large number of observations, such a coefficient would be a very high one; but in the present instance we must ignore many values that would generally be regarded as significant. The chance that there is no real connection when the coefficient is as high as six times its probable error is, I believe, something like one in 15,000, and I think we shall be fairly safe in assuming a real connection whenever the coefficient is over 0·5. It must be observed, however, that with lower coefficients the probability of there being interdependence is still very great; we should for instance only be wrong once in about seven times by assuming connection when the correlation coefficient is 0·3 (probable error = 0·135). I propose accordingly to regard a coefficient between 0·3 and 0·5 as *suggestive* of dependence. Values below 0·3 I shall, as a rule, ignore, in the absence of any corroborative evidence. Perhaps I may remark that I believe that some statisticians would consider themselves justified in drawing deductions from lower coefficients than those I have adopted as my limits.

The probable error of ρ, Mr. Yule informs me, is similar to that of r, viz., $0{\cdot}67\,\dfrac{1-\rho^2}{\sqrt{n}}$. I, therefore, take the same limits as above indicated, namely, 0·5 and 0·3 as satisfactory evidence, and as suggestive, of causal connection respectively.

* "Elements of Statistics" (1st edition), p. 320.

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The double correlation coefficient (R) is not so simple. This value can of course never fall below 0, and the square root of the mean square of all accidental values should theoretically (Mr. Yule estimates) be 0·31 in the present instance, corresponding to a somewhat lower arithmetic mean value of about 0·25, if the variables were really independent. The probable error would seem to be less, rather than greater, than the value of

$$0{\cdot}67\frac{1 - R^2}{\sqrt{n}}.$$

I may perhaps here usefully call attention to some calculations, in reality based upon a false assumption, that I had made with a view to ascertaining approximately, from the observations, the limiting values of r, ρ, and R, that might be regarded as satisfactory evidence of dependence. I assumed that all coefficients obtained by correlating a crop with a period after it had been harvested, or before the seed had been put in the ground, were purely accidental: hence all such coefficients should be less than the required limiting values, and, being chance observations, should follow the normal law of error. Tabulating 116 such values of r, 84 values of ρ, and 42 values of R, I found, as was to be expected, that the average of r and ρ was practically 0; that of R was 0·265. Now in a normal distribution, practically the whole of the observations should fall within a value of three times the standard deviation on either side of the average. For r the standard deviation worked out at $\sigma = 0{\cdot}22$; this gave a critical value of 0·66 as the practical end of the range of all chance values, *i.e.*, rather higher than the 0·58 found above. As a matter of fact, all the 116 coefficients lay between $\pm$ 0·5; which confirmed me in my supposition that I was safe in taking this quantity as my limiting value. The 84 partial coefficients yielded almost identically the same σ (viz., 0·21), with a range slightly smaller, for they all lay between $\pm$ 0·45. Hence I had already concluded that, for practical purposes, the probable error of ρ might be treated as the same as that of r, a supposition which Mr. Yule afterwards proved theoretically. The standard deviation of the coefficient of double correlation worked out at 0·15. As subsequent investigation showed that all periods prior to sowing the crop cannot be regarded as without influence, the above calculations can hardly be accepted as really throwing much light upon the point. I may remark, however, that it is precisely the largest of these coefficients that fall at periods when the seed is likely to be affected, and which can, therefore, be regarded as highly significant. This consideration is consequently a further confirmation of my opinion that the limiting values I have adopted are ample.

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It will be remembered that the main problem of this paper is to determine the highest coefficients between each crop and the weather. But each coefficient, it must not be forgotten, is qualified by its probable error. I have not worked these out, because they can be so easily deduced from the formula; but they must not be overlooked. Any given correlation coefficient must only be regarded as the most probable value of that coefficient; and in making comparisons between any two the higher is as a rule in reality only more or less probably greater than the other. The degree of probability varies considerably: where the difference is slight, the probability is small, but it always exists. The paucity of observations is again unfortunate, as the probable error is so large that I am seldom able to state emphatically that any particular period is the most important. As an illustration, the probability that a coefficient of 0·6 really represents a degree of dependence greater than 0·5 is something like 3 to 1. With this reservation, which applies throughout, that period which yields the highest coefficient may be regarded as exercising the most influence* upon a crop. And it is always true to say that the actual coefficient found is an accurate measure of the amount of coincidence between the crop and the weather during the particular period under review; or that the difference between two coefficients measures the actual difference between the coincidences of the two periods in these years. The relationship found is therefore the relationship that has really existed during that period; but we are usually in a position to say only that the same relationship *probably* holds generally.

Two or three further cautions must be given concerning the data. First as regards the meteorological. All the calculations, and therefore all the deductions therefrom, relate solely to differences from the average. Differences from the average, however, may indicate very different meteorological conditions. A fall of 2 inches of rain in June, for instance, may be made up by a dull rather drizzly month, or it may be a single thunderstorm followed by a four weeks' drought. The effect upon a crop of these two sets of almost diametrically opposite conditions is probably entirely different. But I have perforce had to ignore such phenomena. Mere differences from averages, therefore, cannot tell the whole story of weather influences; all I have aimed at ascertaining is what story these do tell. The work on this has been very considerable, and I must, in regard to any other factor, adopt the ancient motto of this Society: *aliis exterendum* (let somebody else thresh it out).

* It would in many cases be truer to say that that period is more frequently than any other the dominant factor.

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Secondly, as regards the crops, it must be borne in mind that the correlation coefficients relate solely to the quantity harvested, not the quality of the crop. I have unexpectedly, however, found evidence of the influence of the weather upon one quality of the seed. Finding, as already stated, that in certain cases some periods prior to sowing were important, it seemed possible that this might be due to the weather of the preceding harvest (or other) time having affected the ripening of the seed. This turned out to be the case, and it will be seen that a factor of great importance in some crops is the condition of the seed as harvested in the previous year. The figures have thus yielded evidence of the influence of the weather upon at least one quality of the seed. I shall use the word "condition" to denote this particular quality, and the term must be understood to mean solely "power of producing a bulky crop next season" (of grain, roots, &c., as the case may be): in fact, quality from the seed merchant's point of view. The correlation coefficients with the *previous* growing season are therefore indicative of the conditions requisite for "condition" of a crop, and not quantity (except, of course, in the case of hay). I have no information regarding what is usually known as quality, from the consumer's point of view.

This distinction must be carefully borne in mind if some of my results appear unexpected. Indeed, I suspect that many of the factors required for quantity are injurious to quality (using the term in its ordinary sense, *i.e.*, milling, feeding, malting, &c., value). It does not therefore follow that the period which is most critical for the quantity of a crop is also the most critical so far as regards total value (quantity × quality). This is probably more especially the case as regards ripening of fruits, and perhaps also grain, for which sunlight (and consequently high temperature) during summer is generally regarded as necessary. For instance, I do not find a single crop that wants a hot summer to give a bulky yield; yet the quality of many kinds of produce is injuriously affected by a cold wet summer. Sugar-beet, for instance, though possibly giving roots of large size in a wet season, would contain little sugar, and the feeding quality of mangolds is doubtless similarly affected. Having, therefore, no statistics of quality for consumptive purposes, this point is also *aliis exterendum;* and nothing that follows can be taken as suggesting opinions contrary to those usually held upon this subject.

A consideration which may usefully be borne in mind is that, in investigations such as the present, a correlation coefficient zero is not necessarily an indication that there is no connection between the crop and the weather. The coefficient only tells us the degree

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of correspondence of the differences of the two variables from their respective averages (with a linear law). Imagine, for instance, a crop for which the average rainfall of the east of England is actually the most suitable; then any deviation, whether above or below, from this average should be the more detrimental according to the amount of the excess or deficiency, and the correlation coefficient would be, theoretically, zero. Similarly, if the optimum weather conditions were nearly, but not quite, the average, we should only have a small correlation coefficient. It is only when the optimum conditions differ materially from that of the district under review that we may expect to find significant coefficients, and be enabled to say that the crop does better in a different climate, or to specify the meteorological conditions that suit it. Hence, when we find no correlation between the weather and a crop, it by no means follows that the crop is indifferent to the weather. The correlation of data under such conditions is a very complex matter, and the question of whether a crop is indifferent to the meteorological changes or whether the actual meteorological conditions are the optimum, must be determined by other methods; the method of correlation is not adapted to this particular problem. I shall, however, have something to say in this connection later on.

It must further be remarked that the deductions drawn from coefficients other than the highest are qualified by the possibility of correlation between the weather of the two periods. How far the weather of one part of the year depends upon that of another is a big question that cannot be discussed within the limits of this paper. I am satisfied, however, that twenty-one years is much too short a period to allow of our ignoring random correlation (whether apparent or real). For instance, the average autumn rainfall in the first decade is much greater than in the second. I do not suppose the autumn is really getting dryer, but merely that the period is not long enough to yield a stable average. I have not had time to examine this possible connection except in one or two instances where the coincidence appeared striking. If there be correlation of the weather at any two periods, it may have the effect of reducing the coefficient between the crop and one (or possibly both) periods below the critical value. But the higher of the two coefficients, after this allowance has been made, will still remain the higher.

These cautions and limitations being premised, I now proceed to discuss the figures obtained for each of the individual crops.

Wheat (Seed gathered, August. Sown, mid-October to mid-November. Crop harvested, August).—The highest partial coefficient I have found for any eight-week period is — 0·62 with rain in the 37th—44th weeks—*i.e.*, at and just before the sowing period.

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Absence of rain in September and October is therefore more important to the wheat crop than rain or temperature at any other period of the year. This is therefore the answer to the primary question arising out of the discussion on Dr. Shaw's paper, and may, I think, be accepted as strong evidence in favour of his contention. I observe, moreover, that the partial coefficient between wheat and *autumn* rain is only $-0{\cdot}53$: it would therefore seem that the most critical period for wheat is shorter than three months. Of course, it is possible that a yet higher coefficient might be obtained by taking a slightly different eight weeks, or a somewhat longer or shorter period than that chosen.

The highest coefficient of all is $-0{\cdot}69$ for the cereal year as a whole. Naturally, the rainfall of the year is dependent upon that of the different seasons, but I think this means that a dry twelve months is (in so far as stress can be laid upon the difference between 0·69 and 0·62) rather more important than a dry autumn alone. But among the seasons a dry September-October ranks first among the wheat's requirements.

The most surprising feature at first sight, however, is its requirement of a dry warm winter. For the first eight weeks of the year $R = 0{\cdot}68$, or just more than in the 37th—44th weeks ($R = 0{\cdot}65$). The combined effect of rain and temperature in winter seems, therefore, at least as great as the autumn rainfall alone. The partial coefficient for rain in these first eight weeks is $-0{\cdot}55$; but this is largely due to the fact that the rainfall of 1st—8th weeks is highly correlated ($r = +0{\cdot}60$) with the rainfall of the 37th—44th weeks. So large a coefficient indicates a real interdependence between the winter and autumn rainfall; still, even if the connection were accidental and due to insufficiency of the number of observations, its effect on the figures must be taken into account. Estimating the partial correlation coefficients between crop and rainfall of the two periods, we have $-0{\cdot}48$ for the autumnal eight weeks and $-0{\cdot}31$ only for the winter weeks (whereas r was $-0{\cdot}66$ and $-0{\cdot}58$ respectively). Hence the winter coefficient would seem to be partly adventitious, and the main connection to be with the autumn.

It is interesting to observe that Gilbert and Lawes noticed the detrimental effect of a wet winter* (November to February), but the importance of a dry seeding-time appears to have escaped them. My calculations indicate that this dependence upon a wet winter is largely due to correlation between the autumn and winter rainfalls; but I have not the figures to enable me to determine whether the wheat

* Hall: "An Account of the Rothamsted Experiments," p. 60; also Gilbert and Lawes, Journal of the Royal Agricultural Society (1880), vol. xli, p. 173, *et seq.*

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crops obtained at Rothamsted were correlated with the seed-time to the same degree as during the last two decades. Gilbert and Lawes dealt with a period almost immediately preceding mine; hence, if there were correlation between crop and autumn rainfall, there would seem to have also probably [but by no means necessarily] been correlation between rainfall in winter and autumn. This would enormously increase the probability of a real connection between autumn and winter rain. Gilbert and Lawes concluded that the most critical period of the wheat's growth lay in the first four months, when the foundation of roots was being laid.* My calculations point to the foundation having been laid in a much shorter time, and I think a great deal of light could be thrown on the point if the Rothamsted figures were correlated for the much longer period at their disposal.

As regards the temperature, the matter is, I think, different. We find $\rho = +0{\cdot}57$ for the whole winter, indicating that wheat likes a mild winter. This is perhaps a little unexpected, but is, I think, borne out by a consideration of the experience of North America. In Great Britain, wheat is sown in autumn, and passes the winter in the ground; but in Canada and the northern wheat-growing districts of the United States, wheat is mostly a spring corn, comparatively little "fall wheat" being sown. In the southern portion of the wheat belt, and on the mild Pacific coast, on the other hand, the varieties grown are chiefly winter wheat. In other words, wheat is sown in America in the autumn in those States which have a relatively less rigorous winter. It would seem that experience has shown that a cold winter is detrimental.

No other partial coefficient during the period of growth amounts to 0·5; but there are two distinctly suggestive coefficients: the first ($-0{\cdot}44$ in the 17th—24th weeks) indicating that wheat likes a cold spring; the second ($-0{\cdot}46$ in the 25th—32nd weeks) pointing to a dry July.

As regards condition of the seed, we find two other important periods during the preceding year's growth. Partial coefficients of $-0{\cdot}49$ during the 21st—28th weeks (say about June) and of $+0{\cdot}51$ during the 29th—36th weeks (covering August) indicate that absence of rain during the flowering period, and warmth at harvest time are wanted for good germinating seed. It seems clear, therefore, that in the case of wheat the condition of the seed is a very important factor, perhaps second only to the weather at the time of sowing, and during winter.

It would seem also that the temperature conditions during the summer affect the bulk and condition of the seed differently. All

* Hall: "An Account of the Rothamsted Experiments," p. 62.

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through spring and summer of the harvest year there are a series of negative coefficients with bulk. They do not quite attain, except in two instances, my criterion of suggestiveness, but I think the sequence is in itself suggestive that cool weather is a desideratum for a heavy yield. For condition, on the other hand, the preceding summer should be warm. Hence we might expect that the seed of a bulky crop would not usually be of good quality. This consideration suggests a simple explanation of a phenomenon frequently observed, viz.: that a good crop is often succeeded by a poor one.

It may be said that farmers have always been quite aware that a wet autumn means a bad seed-bed for wheat. In evidence of this I have correlated the rainfall of the 37—44th weeks with the area sown with wheat each year. The coefficient works out to − 0·41,* thus showing that less land is put under wheat in a wet than in a dry autumn. Further striking evidence of this will be found in a diagram in the Agricultural Statistics (Part I, p. 11) for 1906. This gives the area under wheat, barley and oats since 1867; and inspection will show that a fall in the wheat area is practically invariably followed by an increase in barley and oats, and *vice versâ*. I have correlated the successive annual changes in the figures in that diagram, and find that the coefficient between the wheat and barley areas of England is − 0·59, while that between the wheat and oat areas is as much as − 0·86, and between the wheat area and the whole area under barley or oats − 0·88. This is an exceedingly high coefficient, indicating that the joint barley and oat area in any particular year is almost entirely dependent upon the area put under wheat five months earlier, and not upon the weather at the time of sowing. In other words, the farmer proposes to devote a certain area to corn, and if the autumn prove too wet for wheat, he leaves a certain portion of that area unsown till the spring, when he puts in barley or oats. Whether the farmer really knows that he is not likely to get a heavy yield with a wet seed-bed, as I believe is generally the case, or whether he merely refrains from tilling the land at that season on account of the mechanical difficulty of the operation, the result is the same: his practice agrees with what these statistics show to be the best. It may be thought that farmers might take greater advantage of the variations in the seasons, but this is not always possible; they may want a certain amount of wheat straw, or a serious disturbance in the rotation might nullify any saving in this direction by loss on subsequent crops.

* Since the area under wheat has fallen largely during the period, I have correlated successive annual changes in the wheat area and the rainfall (*cf.* *Journal*, vol. lxviii, p. 696).

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Before leaving the subject of the effect of autumn rainfall upon the wheat crop, mention may be made of another important factor pointed out by Dr. Shaw.* This is the periodicity in the yield of wheat. Dr. Shaw showed that there has been a very remarkable periodicity in the yield during the past twenty years, and has found an eleven year period; the actual harvests, as recorded by the Board of Agriculture, being in remarkable agreement with the results obtained from calculations based upon this theory. It so happens that 1906 forms, to a certain extent, a test of the relative importance of the autumn rainfall and periodicity factors. The autumn rainfall in 1905 was deficient, amounting to but 6·05 inches, and according to the formula given by Dr. Shaw as best applicable to the east of England,† $W = 46 - 2{\cdot}2\ R$, a yield of 32·7 bushels per acre, or well above the average, might be anticipated. On the other hand, the probable figure indicated for 1906 by the periodic curve is practically equal to a yield as low as any during the past twenty years—say about 27 bushels per acre. Hence the two factors are, for almost the first time in twenty years, in direct opposition, and it is accordingly of peculiar interest to see which wins. The yield actually recorded is 34·3 bushels per acre, which is in fair agreement with that forecasted from a study of the autumn rainfall. That it is 1½ bushels higher is due to practically all the other seasons being also favourable; the previous harvest time was very warm, the winter was warm: April to June was cool, and July and August were dry.‡ I observe that 1895-96 is mentioned by

* "Proc. Roy. Soc." A. vol. 78, 1906, p. 69.

† Proc. Roy. Soc. A. 1906, p. 76. Dr. Shaw's district is not absolutely identical with mine, but the difference is not sufficiently great to materially modify the formula.

‡ It is of some interest to compare Dr. Shaw's equation with the regression equation given by my data for the 37—44th weeks. The formula for this is $w = r\dfrac{\sigma_w}{\sigma_i}i$ where w and i are the differences of the wheat yield and of the rainfall from their means, and σ_w and σ_i are the standard deviations of these two variables. The yield deduced for 1906 by this equation from the rainfall of the 37—44th week is therefore—

$$w = -0{\cdot}66 \times \frac{3{\cdot}04}{1{\cdot}90} \times (-0{\cdot}61) = +0{\cdot}64 \text{ bushels above average,}$$

indicating a total yield of 32·05 bushels per acre. But the autumn, although favourable, was not exceptionally so, and other factors have affected the crop of 1906 to a greater degree, particularly the period when the seed of the 1905 crop was being harvested. Forming the regression equation with the accumulated temperature of the 29—36th week of the preceding year, we get—

$$w = +0{\cdot}52 \times \frac{3{\cdot}04}{89{\cdot}0} \times 100 = 1{\cdot}78 \text{ bushels above the average,}$$

corresponding to a yield of 33·19 bushels per acre. The bountiful wheat harvest of 1906 appears, in fact, to be mainly attributable to the condition of

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Dr. Shaw as a nodal period, perhaps he can tell us whether we ought to have anticipated that at the next nodal period (eleven years later, *i.e.*, 1906-07) the forecast might not be reliable?

Barley (Seed gathered, August. Sown, mid-March to mid-April. Crop harvested, August).—The chief, and very important, requisite for the barley crop appears to be a cool summer. No less than four successive (overlapping) periods show a coefficient greater than – 0·5 with temperature, indicating cool weather from May till the commencement of September, apparently from the time of flowering till harvest; the highest coefficient of all being – 0·70 in the 25—32nd weeks (say mid-June to mid-August). At this period also there is a large negative coefficient (– 0·55) with rain; barley would therefore seem to prefer the somewhat unusual combination of a cool dry summer. There is also a suggestive coefficient indicating dry weather in January and February. This is perhaps in accordance with *à priori* expectations; it is well known that barley seed should be sown in a fine tilth, and this can hardly be secured with a wet clogged soil. A rainfall above the average does not seem to be a necessity at any time. The preceding season also does not seem to have any very marked effect upon the condition of the seed; a warm dry summer is probably preferable, for though none of the coefficients are large, the long sequence of positive coefficients with warmth, and of negative with rain, may be significant.

In connection with barley, it may be as well to recall that my figures can take no account of consumptive quality, whether for brewing or feeding. Brewing quality in this crop is, practically, recognised to be closely connected with early sowing; and it is pretty generally known that, at the Brewers' Exhibitions, the prize samples of malting barley prove to be the earliest sown.* Barley is essentially a crop of which the profits depend on quality—the difference in price between a malting and a feeding sample being exceedingly great. I am afraid that my figures can therefore be of no assistance in determining what weather conditions most affect the profitableness of the crop.

the seed. There is probably some correlation between the figures measuring the weather at these two periods; but if it were permissible to ignore this, we could say, with some degree of approximation, that the seed-time and condition of the seed together accounted for some 2·4 bushels (it is of course really something less) of the total observed increase of 2·9 above the average. Some smaller additions are, as above noticed, due to the favourable weather at other periods of the year. As the coefficients for the various periods of the year show, there are several seasons which exercise an important influence on the wheat crop; still, as might be expected, a better forecast is obtained by taking account of more than one season than by utilising only the principal period.

* *Cf.* Journal of the Board of Agriculture, vol. iii, p. 394.

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Attention may perhaps be called to the different deductions which might be drawn from the total and partial correlation coefficients. The total coefficients are suggestive of the desirability of rain in the spring, but they are largely reduced when the connection between rain and temperature is taken into account; and their relative largeness becomes more apparent than real. On the other hand, in the 25—32nd week r is nearly 0, whereas the effect of rain is at that time really considerable, judged by ρ.

Oats (Seed gathered, August. Sown, mid-March to mid-April. Crop harvested, August).—Oats are similar to barley inasmuch as they urgently require a cool summer: the partial coefficients between oats and temperature being almost identical with those of barley in the 17—36th weeks. But they differ from barley in requiring rain in the spring; in fact for the spring (season) the coefficient with rainfall (+ 0·70) is just above the summer coefficient with temperature (− 0·69). Before harvest (25—32nd week), however, they would seem to like dry weather. There are some suggestive negative coefficients with rainfall during autumn; can they mean that oat seed does not keep well during a damp autumn? The coefficients with the preceding summer all seem insignificant.

Comparing the three cereals, it is noteworthy that with barley and oats spring and summer are of preponderating importance, seed-time being relatively unimportant: with wheat, on the other hand, there are several different periods which may materially affect the crop, the seed-time being the most influential.

Beans (Seed gathered, mid-September to mid-October. Sown mid-October to mid-November.* Crop harvested, mid-September to mid-October).—These very much resemble wheat in their requirements. They want a dry seed-time, but the coefficients are not quite so high as with the cereal. It would also seem that they like the temperature then to be low, whereas there was no such indication with wheat. The most important point with beans, however, would seem to be the condition of the seed sown, for I find the highest coefficient in the 33rd—40th weeks, covering the period of the previous season's harvest. We may therefore infer that a previous dry summer, with warmth during the latest ripening period, is of more importance to the subsequent bean crop than the weather at sowing time.† With wheat, on the other hand, the reverse seemed to hold.

* The bulk of the crop in the eastern counties may be taken to be winter beans.

† This is of course subject to the qualification, to which attention has already been generally directed, that the probability of this coefficient ($R = 0·57$) being really higher than the next ($R = 0·56$ in the 17—24th weeks) is very small.

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Of the other periods of the year, the figures suggest that beans like a warm winter, a wet spring and summer (the coefficients, though small, are worth a certain weight on account of their persistence), and cold weather about May. It must be borne in mind that considerable quantities of beans are sown in the spring: hence if the spring crop is affected by conditions to which the winter crop is indifferent, we might get a correlation coefficient (probably small) at that time without our being able to say which of the two crops was affected. It may be surmised, however, that the wet spring is required chiefly for the main (autumn-sown) crop, since we found that crop to prefer a dry seeding-time.

Peas (Seed gathered, August. Sown, mid-February to mid-March. Crop harvested, August).—Like beans, the chief factor (coefficient − 0·47) suggested is condition of the seed: for this the previous summer should be dry, and apparently not hot. There are also suggestions of a cool time about May in the season of growth; and the condition of the seed is perhaps favoured by a wet spring. The calculations with this crop (like the next) have yielded hardly any coefficients of importance, and their chief interest is the confirmation they give to the deductions regarding the other leguminous crop. The balance in favour of the condition of the seed being more important for beans than the seed time was, as we saw, slight; but the evidence of the peas lends additional force to the argument that this is the principal factor with these two allied plants.

Potatoes ("Seed" gathered, mid-August to mid-September. "Sown," March—April. Crop harvested, mid-August to mid-September).—Here also I get comparatively little information; as with peas, no coefficient reaches 0·5. A dry summer, from about May to August, seems to be required, and possibly a dry spell just before planting. Whether the dry summer would be directly required for a great weight of tubers in healthy conditions may possibly be doubted; it is very likely on account of drought retarding potato disease, which fungus spreads most rapidly in warm wet weather and is detrimental to the size of the tubers. As regards the condition of the "seed" (sets), also, but little information is forthcoming, though possibly the fact that the coefficients with temperature are all negative may indicate a preference for cool weather. (See also the footnote on p. 22.)

Turnips and **Swedes** (Seed gathered, second half of July. Sown, June—July. Crop harvested, November).—The highest coefficient, + 0·55, indicates rain in June and July, *i.e.*, the sowing season, as the chief necessity. This is no doubt, partly at least, required on account of the turnip fly, which, as is well known, will eat off

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a young crop as soon as it shows above ground in a dry season, to such an extent that a turnip field is frequently re-sown more than once. Oddly enough, after this period I find no significant correlation with rainfall, the partial coefficients indicating that the real connection is with a cool temperature from Midsummer to Michaelmas. In other words, rainy weather appears to suit turnips because such weather is cool. The coefficient with rainfall for the year as a whole is, curiously, higher than for any particular period (except the eight weeks already mentioned), although not equal to that with temperature. This latter coefficient for the whole cereal year is also larger than that for any shorter period, but this is natural in view of the whole series of negative coefficients throughout absolutely the entire twelve months.

The absence of any large coefficients with rainfall in the late summer seems rather remarkable; indeed in the 33rd—44th weeks (say mid-August to October) the coefficient is actually just negative. Considering how farmers look to rain at this period to swell out the roots when a dry summer has left them backward, such coefficients are unexpected. I take the explanation to be partly that the English climate usually furnishes a sufficiency of wet at some time or another of the plant's growth. Autumn rainfall in fact is perhaps only useful if the earlier part of the season has been dry. Nevertheless, it may almost be doubted whether a wet summer is vital for roots; there are certainly some striking exceptions: the exceedingly wet year of 1903 gave a turnip crop below the average, while the dry season of 1906 has given practically an average yield.

There are a remarkable series of suggestive coefficients in the autumn, pointing to the desirability of cool weather throughout the whole autumn and winter previous to sowing. None of the coefficients attain the critical 0·5, but the regularity of the sequence of figures cannot be ignored. It would almost seem that, as with oats, we have here another case of the keeping quality of the seed being affected, but in this case the requirement seems to be cold. The winter coefficients may indicate the desirability of frosty weather to secure a good tilth, but this explanation can hardly apply to the coefficients in the early autumn. The highest of these negative coefficients occur after the seed harvest, which would be covered by the 25th—32nd weekly period.

Altogether, the connection between the turnips and the weather seems the most curious, and most difficult to interpret.

Mangold (Seed gathered, end of August to beginning of September. Sown, mid-April to mid-May. Crop harvested, October).—This seems to require a cold spell from at least the beginning of March to the end of June, and probably throughout

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the summer. A rainfall above average also seems desirable in the spring. Mangolds require a fine tilth, and the explanation of the high coefficient with the temperature of the late winter —long before the seed is sown—may perhaps be that frosts are desirable for the proper mellowing of a good seed bed. The whole of the preceding summer should be dry, indicating that condition of the seed may be nearly as important as weather conditions during the season of growth.

Attention may perhaps be drawn to the comparatively high (negative) coefficient with accumulated temperature below 42° in the 37—44th week. A similar coefficient is found with turnips and swedes, and also with one or two other crops of which the harvest is completed by that date, so that too much stress cannot be laid upon these suggestive figures, especially as they have not been taken into account in calculating the more reliable partial coefficients. But it is well known that mangolds are seriously injured by frosts, and in the case of roots the figures may therefore be significant. They do not, I presume, mean that cold weather reduces the size of the roots, but that if cold weather sets in early the roots are lifted at once instead of being left to grow a little longer, as may occur in a warmer season.

Hay.—With this crop we get the highest coefficients of all; the essential requirement being, as will appear strange to no one, a heavy precipitation during spring.

In the case of hay from clover and rotation grasses,* which I shall abbreviate to "seeds' hay," the partial correlation coefficient reaches its maximum, + 0·76 with the spring rainfall, the double coefficient, with "weather," being 0·80. Consideration of the eight-weekly periods shows that the critical period is much shorter than with most other crops, from mid-April to mid-June at latest evidently being the extreme limits for useful rains. There are also indications of the desirability of cool weather (irrespective of rain) in spring and summer. Unexpectedly high coefficients may be noticed in the autumn after sowing, indicating dry cool weather from August to October as desirable, the coefficient with temperature being as much as − 0·54, and with rain − 0·5. I am not sure how to translate this, perhaps I may venture to suggest that removal of the corn crop, and consequent exposure of the young crop to the heavens may in some way affect it. Probably the shelter it has enjoyed from hot

* Clover seed is gathered in September, grass seed in July. It is sown with the corn crop in the following spring (mid-March to mid-April) and the crop is harvested in June of the following year. My figures in the case of this crop, therefore, go back only as far as seed-time. A large proportion of the clovers and rotation grasses are, however, left down for two or three years.

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sun is beneficial and the plant misses it at first; cool weather mitigating the shock which the young plants experience on the removal of the cereal crop that has previously nursed them. The crop perhaps also likes a dry winter.

Another unexpectedly high coefficient is the +0·51 found with the rainfall of the 9—16th weeks of the preceding season. Rain is evidently desirable then—probably with warmth—but is not required again until twelve months afterwards. The 9—16th weeks cover exactly the period of sowing. It may be remembered that neither barley nor oats, with which the clovers are usually sown, showed any special predilection for rain at this time.

The hay from permanent grass, or meadow hay (harvested mid-June to mid-July), exhibits some small differences from the seeds' hay which may nevertheless have a meaning. The coefficient with spring rainfall is slightly lower (+ 0·71). But the coefficients with temperature are all suggestive that the meadow hay requires cool weather throughout the spring and summer (the latest month doubtless affecting the second cut). I do not know whether these results indicate so much a real difference between the two classes of hay, as that a larger proportion of the permanent grass is low-lying, on damper land less suitable for arable culture, and in many cases irrigated. Such portions being rather better supplied with water, may be rather more indifferent to precipitation, and hence the correlation of the whole crop with the rainfall may be smaller, while the effects of temperature are able to show themselves. It is conceivable that the smaller demand of the seeds' hay for cooler weather is more apparent than real, and that its requirements in this respect are masked by the more urgent necessity for moisture.

With the permanent grass also there is some evidence that cool dry weather in the preceding autumn is an advantage; though the coefficients are not quite so high as in the case of the seeds' hay. This may indicate that my suggestion—that the removal of the sheltering crops is of importance—is wrong, or that permanent grass also really requires the same conditions at that period, and should not make too much growth. It is, however, quite likely that the connection may be only apparent, since the yields of the two kinds of hay are themselves so very closely correlated that, if one is connected with the autumn, the other will also show some correlation with it. Similarly, I imagine that the apparent requirements of the permanent grass, in the way of rain, in the 9—16th weeks of the preceding year are due to the correlation between the two hay crops. I may call attention to the fact that, although the differences in the coefficients for the two

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classes of hay are comparatively slight, they are all remarkably consistent in bearing out the suggestions I give as regards the behaviour of these crops.

The desirability of a cool spring before hay-making was hardly to be expected. Generally, farmers look to warm wet weather at this time of the year to bring the crops along, more especially grass: indeed, with warm rains, we can almost "see the plants "growing." But according to these figures such warmth is not wanted: cold rains seem to suit grass better than warm ones.

Regarding more generally the influence of the weather upon the crops, the statistics in most cases tell us little that we did not know before. But one feature stands out with—to me—quite unexpected prominence, and that is the advantage of cool weather during spring and summer for the great majority of the crops. Indeed, there is no coefficient, with the exception of those with potatoes, that even seems to suggest the possibility of warmth at that period being other than detrimental. The coefficients do not in all cases reach the critical 0·5 which I have adopted as the index to practical certainty, but potatoes and turnips are the only two that do not show at least a suggestive figure between April and June. Taking the 17th—24th weeks, or say the period from the end of April to mid-June, we have the following five partial correlation coefficients between temperature and the corn and pulse crops: $-0·44$, $-0·51$, $-0·60$, $-0·45$, and $-0·40$; and this cool weather should in most cases last considerably longer, generally throughout the summer. What is to be noticed more particularly, however, is that it is not because cool weather usually accompanies a wet May and June: the calculations I have made practically eliminate the influence of the rain, and show that it is really with cool weather, irrespective of rain, that the relationship exists. If rain comes also, it is as a rule acceptable, and in the case of oats especially rain is required, more particularly somewhat earlier.

The interpretation of this result I must leave to botanists, but to one who has no knowledge of that science it may perhaps be permitted to ask whether it means that, to secure a bulky yield, the grain should mature slowly. As already mentioned, other conditions may be desired for quality. In this connection the different behaviour of the grass crop may be noticed. Consideration of the coefficients prior to April point to the desirability of weather conditions which do not allow it to make much progress before then (once the seeds have had a good start), and the greatest bulk seemed to be secured when the grass can respond with sudden growth to the spring rains.

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Root crops also appear to want cool weather throughout the summer—not rain: they want rain in the late spring and early summer only. In their case the evidence, although the different crops corroborate each other, is not so strong as with cereals; still it seems probable that a good start, and cool weather to follow (? to allow of persistent uninterrupted growth), are the optimum conditions.

With hay, on the other hand, moisture is overwhelmingly important, temperature taking a secondary place. This is also, no doubt, as is generally known from practical observation, the case with the stalks and foliage of the cereal crops (straw) and of roots.

The second important point, which is perhaps only clearly realised among the more educated farmers, is that the condition of the seed sown may be quite as important as the weather during any period of growth. With the pulse crops, the figures indicate that it is the primary factor, while it is also a very weighty consideration in the case of wheat, mangolds, and possibly other roots.

This raises a nice point of practical importance. With many crops it is a not infrequent practice to import seed from a different part of the country. "Change of seed," as it is called, is often looked upon with favour. There seems for instance to be a growing practice among certain English farmers to import potato seed from Scotland; while large quantities of clover and grass seed are imported from abroad, notably from warmer climates where it may be assumed to have ripened better (from the seedsman's point of view). My figures indicate—though feebly—cool weather as desirable for condition in potato seed: is this a theoretical reason (besides exhaustion of the stock) why Scotch seed, coming from a cooler climate, should be better than English grown?* Dr. Somerville also informs me that much of the wheat and barley sown in Scotland and the north of England is not home-grown: my figures decidedly support this practice by showing the greater production from seed

* Since this was written, I have come across a booklet entitled "Potato Demonstration," by Messrs. Sutton. Experiments have been conducted by them which seem to answer this question in the affirmative, as Scotch and Irish seed yielded much better than English, particularly south English. They conclude that the chief requirement for the production of good seed potatoes is an equable climate, so that the plants can develop and the tubers form gradually without check, spells of hot dry weather being prejudicial. But another experiment in the same booklet is also of great interest, as indicating (what my statistics could not possibly show) that the Scotch and Irish seed is more productive *because* it is immature, not because the Scotch climate enables the seed to mature better. *Cf.* "Why potatoes vary in cropping power," by D. A. Gilchrist ("Journal of the Newcastle Farmers' Club," 1906); also Cambridge University, "Farmers' Bulletin, No. 4" (1905) and "Guide to Experiments" (1905 and 1906).

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which has ripened under warmer skies. He also adds that clover and mangold seed are practically never saved in Scotland or the north of England; turnip and rye grass, on the other hand, are. I have not been able to carry my figures back to the harvest period of the grass and clover seeds; but the coefficients with the root crops suggest that the practice with both is correct in so far as they are dependent on the weather (unless the coefficient + 0·25 between turnips and temperature be as a matter of fact significant). If any practical deductions may be drawn under this head, it would seem that it is to the pulse seeds that most attention should be given: they should apparently be drawn from the driest districts of England. Possibly this is the case now.

The preparation of this paper has necessitated the use of a considerable amount of statistical material, and the calculation of some quantities to which but little attention has hitherto been devoted. It seemed to me a pity to leave these data unexplored in various directions when a few further simple calculations only were required to elicit certain points of interest. I make, therefore, no further apology for travelling beyond the original scope of the paper, and discussing briefly as a sort of addendum a few questions for which these figures form the necessary basis.

A question of economic interest is: What practical progress has been made during recent years in raising more produce from the land? We have now reliable data of the amount extracted from a given area of land since 1885. Of recent years considerable endeavours have been made to encourage the spread of agricultural education: County Council instruction in agriculture, now provided in some form or other, and in greater or less degree, in almost every county of England, has been a growth entirely since that date. Has there been any increased yield? It is doubtless too early to expect it, but I have in Table II taken out the average yield of each crop—in the district under review—for the first and last ten of the twenty years 1886-1905. I have also taken out similar figures for Scotland for comparison. [I had at first thought of comparing the earliest ten years (1885-94) with the latest, but the yields of 1885 were markedly high in the case of corn, and very bad indeed in the case of pulse; in fact, the crops of that year were on the whole considerably more abnormal than those of 1895, which comes in in its place.]

Before commenting upon these figures, a few of the exceptionally abnormal crops may be mentioned, as influencing the averages for the decades. In Eastern England 1893 and 1904 were both bad years for cereals, particularly the former; these, however, tend to

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balance each other in a comparison of the two decades, except as regards oats, for which 1893 was by far the worse. The comparison as regards beans is completely vitiated by there being two bad years (1891 and 1892, with deficiencies from the average of 8 bushels per acre) in the first decade; the apparent increase here is therefore quite illusory. Peas had only one abnormally bad year (1885, as also beans) which fortunately does not come into account. 1893 was, moreover, an abnormally bad year for mangolds and both classes of hay, and in these cases also the changes noted are somewhat discounted. It will not escape notice that, apart from the wheat and barley, these exceptional years all fall in the first of the two decades. In Scotland there do not appear to have been so many abnormal years to vitiate comparisons, but very low yields of beans and peas were recorded in 1888, and distinctly poor yields of hay in 1891 and 1895. These again are in the first decade, but on the whole they were not so extremely deficient as the years named in England, and I think the Scottish comparison rather the more trustworthy of the two. I have not had time to work out any Scottish weather statistics, so am unable to give any meteorological explanations in their case.

In Eastern England, only five crops show an increase, chief among them being wheat and beans. But both these are largely dependent upon autumn rain. Considering the 37th—44th weeks, which are the most important period for wheat, I find that the average rainfall in the first decade was as much as 5·0 inches; in the second only 3·8 inches. Hence the conditions have been much more favourable during the second decade, and so great a difference is much more than sufficient to account for the comparatively small increase found. Dr. Shaw gave the formula $W = 46 - 2{\cdot}2\ R$ as applicable for ascertaining approximately the yield of wheat in the east of England, where R is the autumn rainfall. This amounted to 7·7 and 6·1 inches respectively; hence the average yields of wheat should be approximately 29·1 and 32·6 bushels in the two decades, an increase of $3\frac{1}{2}$ bushels. The same factor has also affected beans. Hence, when weather is taken into account, the two material increases are transformed into decreases. I regret to conclude therefore that there has been no progress, but rather the reverse, in extracting more produce from the soil during the past twenty years in this district of England.

Very probably the twenty years under review are insufficient to justify any conclusions as to causes; the only cause that suggests itself to me is, that, arable land being relatively so unprofitable that much of it has been turned into pasture, less attention has been given to it than formerly, and, with

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the increase in dairying, more attention has been paid to the stock. In connection with this it is just possibly significant, although the changes are exceedingly slight, that the yield of seeds' hay (arable) is smaller and that of meadow hay larger. [The average rainfall during the most closely correlated period—spring—was 4·9 inches in both decades.] It does not follow, however, that the efficiency of the British farmer has diminished, for, if there has been no increase in the production, the labour expended thereon, and the cost of production generally—doubtless owing to the commoner use of machinery—has been much less. There are some very interesting diagrams in a report recently issued by the Board of Agriculture on the Decline in the Agricultural Population,* showing that the number of labourers on the land (in England as a whole) has decreased very much more rapidly than the arable land. Hence it is extremely probable that the production per person engaged in farming has increased during the twenty years.

Looking at the Scottish figures, a complete contrast is presented. The yield of the whole ten crops is greater in the second decade. As already mentioned I am quite unable to say whether any or all of these increases are due to the meteorological conditions. But we have seen that there were fewer abnormal years during the earlier decade, so I do not think it likely, or at least not to the same extent as in England. This result may lend a little support to the suggestion that the increase in stock raising has rendered the farmer of Eastern England somewhat apathetic towards his arable land. Turning again to the diagrams in the Report on the Decline of the Agricultural Population, it will be seen that Scotland has nearly maintained its arable area, and that the increase in stock is comparatively slight. Possibly, the Scotchman still continues therefore to devote most of his attention to the arable side of his farm. But, as already indicated, the probability is that the time has not been long enough to permit of any theories in this connection.

This possible connection between a diminished yield per acre from a diminished area leads directly to another point of economic interest. It is often said, for instance, that the high yield per acre of wheat in Scotland and Holland is due to the small area placed under the crop, and that districts can be found of equal area in England yielding an equal amount, since, theoretically, so small a proportion being placed under the crop, farmers select the land most suited to it. This is no doubt largely true, as in Scotland the great bulk of the wheat is grown in a very few counties where the soil and climate are specially favourable, and probably the same holds with the rich alluvial lands of Holland. It had occurred to me

* [Cd -3273], p. 12.

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accordingly that the considerable reductions in the areas under certain crops during the past twenty years might have resulted in improved yields, apart from other causes. The figures already referred to, however, show no evidence in favour of such a theory: it may possibly be counterbalanced by relative indolence towards the less profitable crops where the difference in proportionate area is one of time and not of geography. It is to be remembered, moreover, that in any case it is not necessarily the most unsuitable area of the district which would go out of cultivation, but only the most unsuitable portions of each farm; considerations of rotation, &c., keeping much land under wheat that a farmer might otherwise wish to put under a more intrinsically profitable crop.

Another addendum which may perhaps find a place here is the actual change that has taken place in the utilisation of the land of these Eastern Counties as a district. The wheat area has been reduced from 863,152 acres in 1885 to 736,969 acres in 1905, with a minimum of 573,036 acres in the preceding year. Barley has fallen off rather more than wheat, viz., from 837,984 to 679,374 acres, or by 169,296 acres. The yield per acre has also been somewhat reduced, but the most important period of the year has been less favourable. Oats have increased their acreage from 299,296 to 444,245 acres (the area was 500,473 acres in 1904); the diminution in their yield is the same in amount (but less in percentage) as barley, in spite of less favourable conditions. Beans and peas have also reduced their acreage.

The potato area has largely increased, viz., from 89,358 to 156,286 acres, and the yield per acre has considerably diminished. As found above, it is not easy to decide which is the most important period of the year. Possibly the decline may be due to the planting of unsuitable lands, but possibly also exhaustion of the stock has something to do with it. The area of turnips has declined, that of mangolds shows no change.

Rotation hay has fallen off somewhat—by 28,722 acres from the 444,638 of 1886, while the area of meadow hay was identical in 1905 and 1886. Grass, naturally, is cut on the better lands, and frequently a meadow intended for cutting is left for grazing if the season prove dry; the hay figures thus hardly lend themselves to comparison.

Which is the most variable crop? The test of variability I take to be the standard deviation*; and in Table III I have given the average, the maximum, and the minimum, yield per acre, and the standard deviation, of each crop for the twenty-one years 1885-1905.

* Though, from the pecuniary point of view, it is quite arguable that the mean deviation is the better guide in practice.

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There is one other crop the production of which is recorded in our Annual Returns, namely, hops. And this is, as is well known, the most uncertain and speculative of all our English crops. None, however, are grown in the district under review, and I have therefore inserted in this table similar particulars regarding the Kentish hop crop for comparison. It will be observed that the produce of this per acre has varied from 4·63 to 14·47 cwts. per acre (much lower yields have been noted in earlier years), with a standard deviation of as much as 27·8 per cent. of the average.

Apart from hops, the most uncertain are hay and beans—thanks mainly as regards the latter to the three very low years already mentioned. It may be remarked, however, that 1906, by giving a record yield per acre of beans, has still further increased its standard deviation. Meadow hay, as appears from the figures, has an even larger standard deviation (compared with the average), and the seeds' hay somewhat less. I suspect, moreover, that these figures under-estimate the real variability of this crop, inasmuch as, when the season is bad, considerable areas of the poorer grass are left for pasture, hence the yield of the portions cut in such years is somewhat higher than would otherwise be the case.* Other crops of course do not lend themselves to such treatment in poor seasons. This great variability of the grass crop is unfortunate when it is remembered that its total value is greater than that of any other crop in Great Britain.

The least variable crop is oats, followed closely by barley. The roots are more variable than the corn crops, and peas are very little more uncertain than wheat.

In Table III I have included similar data for Scotland, and, so far as the statistics permit, for France. The possibility of these being useful occurred to me in connection with the point raised on pp. 9 and 10, viz., that we could not expect to obtain significant correlation coefficients where a crop was grown in a country presenting the optimum weather conditions. If, therefore, the average temperature of Eastern England were very suitable for, let us say, potatoes, we might expect to find the correlation coefficient between temperature and potatoes to be nearly zero; but to obtain a negative coefficient in a warmer district like France, and a positive coefficient in a colder country like Scotland. To work out these coefficients would, of course, take just as long as the English figures; moreover, France is too large an area for such a purpose.

* The correlation coefficient between the area of permanent grass cut for hay and the yield per acre, in Eastern England, during the twenty years 1886-1905, is as much as $+0·52$.

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But another comparison occurred to me. If a climate is suitable for a plant, and the plant does not mind moderate deviations from the average, we might, other things being equal, expect theoretically to find that the yield per acre was greatest in that district, and the standard deviation least. Now we can, owing to differences of soil, methods of cultivation, individual energy, variety of seed sown, &c., not expect to find the average production growing less according as we move further from the district of optimum climate; as between Scotland, England, and France, the other causes indicated are probably of much greater importance than the difference in climate. But I do not quite see why the standard deviation ought not to be a guide: this should only depend upon changes within the country. I hoped accordingly that this would admit of a practical application. Wheat we found to be highly correlated with dryness: might we not then expect to find the standard deviation of wheat to be less in France than in England? Oats are correlated with rain and cold; may we not then expect to find a smaller standard deviation in Scotland? And as regards crops which have not yielded significant coefficients, might we not assume that that country is most suitable which shows the smallest standard deviation? This was a theoretical consideration which seemed worth testing to the small extent that I have indicated.

Examination of Table III shows that it is useless for the purpose. With the single exception of potatoes, the whole of the crops are less variable—in most cases largely so—in Scotland than in Eastern England; while the mangold (*betterave fourragère*) and the hay crops alone are less variable in France than in England. I doubt whether France as an entity, however, could be considered as a reliable guide in this connection, the area is so large that the crops vary much from one district to another; the hay crops, moreover, are hardly comparable with ours.

Although the table has not yielded the information I desired, I have let the figures stand, as they present some points of interest. It will be observed that the majority of the crops show a heavier yield in Scotland than in Eastern England. To some extent this may be due to Scotchmen being better farmers than their southern brethren; to some extent to the above-mentioned greater apathy towards crops that are going out of cultivation (it has already been observed that the arable area in Scotland has diminished but little, as compared with the English), and to some extent to the fact that the great bulk of the crops in Scotland are grown in counties peculiarly suited to them. One great exception may be noted, and that is oats, the staple cereal of Scotland, and grown wherever a cereal is wanted. Of this the Englishman

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produces over 25 per cent. more than the Scotchman, in spite of the climate, judging by the correlation coefficients, being more favourable in the north. In this connection, however, the straw is of importance; the Scotch farmer puts far more value on the straw of the oat crop than does the English. As regards the hay crops, these are favoured by the rainier north, but different farmers may have entirely different notions as to whether a given quantity of grass in an area is worth saving as hay or not, and I think no comparisons can be made regarding this crop. On the whole, I am inclined to think that the main reason of the larger crops is probably the more suitable soil on which the bulk of the crops is grown, combined with the lower temperatures which we found to be so significant a factor with many of the crops, more especially as the Scotch appear to take care not to use home-grown seed in the case of those crops which mature their seeds best in a warmer climate.

That the standard deviations should practically throughout be less is also possibly due to similar reasons. In so far as the temperature affects each crop, the cooler districts of the north would tend to lower the standard deviation, and the same would apply as regards such crops as prefer a greater rainfall. But this does not explain why the standard deviation should be less in the case of wheat, unless it be that it is only grown in such suitable soil as to render it less dependent on the rainfall. Nor is it easy to understand why potatoes alone should be a more variable crop in Scotland; the average production, it will be noticed, is identical in the two districts.

Finally, I have not given the standard deviations, &c., of the various meteorological data. Useful as these would be for many purposes, the twenty-one years under review are insufficient to give more than an approximation to the true values. Many more years' data are available, and a nearer approach to the reality should be made by calculating such data from as long a series of observations as possible. For the particular purpose of this paper I have been obliged to use exactly the same period as for the crops; and I have given in Table IV the actual correlation coefficients required for this paper between rainfall and accumulated temperature above 42° F. These values, however, apply solely to the particular years specified, and should not be quoted as necessarily holding generally, since a more accurate guide to the interdependence of rain and temperature can be obtained from a longer series of years. Doubtless the same objection holds as regards these latter; but there is this difference, that with the meteorological statistics more accurate measures are obtainable; the produce statistics, on the other hand, are the best we have got, and so I have done my best with them.

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Explanatory Note to Table I.

In Table I, r at the head of the first three columns denotes the *total* correlation coefficient between the crop and the meteorological data, ρ the *partial* coefficient, and R the double coefficient.

The suffixes to r and ρ denote the particular data correlated; the first is the initial of the crop named at the head of the table, while r = rainfall, a = accumulated temperature above 42° F., b = accumulated temperature below 42° F.

The double coefficient represents the joint effect on the crop of rainfall and accumulated temperature above 42° F.

The actual calculations of the partial coefficients were performed by using three places of decimals and a slide-rule. If calculated from the two places here given, slightly different figures may possibly be obtained.

TABLE I.—CORRELATION COEFFICIENTS BETWEEN WEATHER AND CROPS.

(*a*) **Wheat.**

	Period.	r_{wr}.	r_{wa}.	r_{wb}.	ρ_{wr}.	ρ_{wa}.	R.
Previous year.	9—16th weeks	+0·02	+0·00	−0·18	+0·02	+0·01	+0·02
	13—20th ,, ...	− ·21	+ ·12	− ·22	− ·17	+ ·01	+ ·21
	17—24th ,, ...	− ·27	+ ·23	− ·13	− ·22	+ ·13	+ ·31
	21—28th ,, ...	− ·49	+ ·12	....	− ·49	− ·11	+ ·50
	25—32nd ,, ...	− ·23	+ ·31	....	− ·07	+ ·22	+ ·31
	29—36th ,, ...	− ·15	+ ·52	....	+ ·08	+ ·51	+ ·53
	33—40th ,, ...	− ·55	+ ·42	....	− ·44	+ ·21	+ ·56
	37—44th ,, ...	− ·66	+ ·36	−0·07	− ·62	− ·00	+ ·66
	41—48th ,, ...	− ·47	+ ·20	+ ·01	− ·44	+ ·09	+ ·47
	45—52nd ,, ...	+ ·21	+ ·24	− ·07	+ ·19	+ ·22	+ ·31
	49— 4th ,, ...	+ ·01	+ ·46	− ·32	− ·01	+ ·46	+ ·46
	1— 8th ,, ...	− ·58	+ ·52	− ·39	− ·55	+ ·49	+ ·68
	5—12th ,, ...	− ·30	+ ·17	− ·24	− ·31	+ ·18	+ ·34
	9—16th ,, ...	+ ·32	− ·12	− ·15	+ ·32	+ ·01	+ ·32
	13—20th ,, ...	+ ·36	− ·41	+ ·10	+ ·19	− ·28	+ ·45
	17—24th ,, ...	+ ·26	− ·49	+ ·26	+ ·09	− ·44	+ ·50
	21—28th ,, ...	+ ·01	− ·16	....	− ·04	− ·16	+ ·16
	25—32nd ,, ...	− ·37	− ·01	....	− ·46	− ·30	+ ·47
	29—36th ,, ...	− ·31	− ·07	....	− ·39	− ·25	+ ·39
	33—40th ,, ...	+ ·01	+ ·02	....	+ ·03	+ ·03	+ ·03
	37—44th ,, ...	+ ·19	− ·05	+ ·21	+ ·19	+ ·06	+ ·20
Seasons :—							
	Previous Spring........	− ·25	+ ·14	− ·27	− ·21	− ·00	+ ·25
	,, Summer	− ·34	+ ·37	....	− ·15	+ ·21	+ ·39
	,, Autumn....	− ·61	+ ·36	− ·01	− ·53	+ ·14	+ ·61
	Winter	− ·38	+ ·53	− ·39	− ·44	+ ·57	+ ·67
	Spring......................	+ ·52	− ·51	+ ·02	+ ·32	− ·30	+ ·59
	Summer	− ·28	− ·06	....	− ·40	− ·31	+ ·40
	Cereal year..................	− ·65	+ ·10	− ·30	− ·69	− ·33	+ ·69

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TABLE I (*Contd.*).—(*b*) **Barley.**

	Period.	r_{br}.	r_{ba}.	r_{bb}.	ρ_{br}.	ρ_{ba}.	R.
Previous year.	9—16th weeks	−0·17	+0·07	−0·33	−0·16	−0·01	+0.17
	13—20th „	− ·12	+ ·09	− ·12	− ·09	+ ·03	+ ·13
	17—24th „	− ·04	+ ·25	− ·10	+ ·06	+ ·26	+ ·26
	21—28th „	− ·37	+ ·28	....	− ·29	+ ·16	+ ·39
	25—32nd „	− ·29	+ ·32	....	− ·15	+ ·19	+ ·35
	29—36th „	− ·11	+ ·22	....	− ·02	+ ·20	+ ·23
	33—40th „	− ·23	+ ·19	....	− ·16	+ ·09	+ ·25
	37—44th „	− ·30	+ ·09	+ ·00	− ·30	− ·10	+ ·31
	41—48th „	− ·12	− ·18	+ ·37	− ·18	− ·23	+ ·25
	45—52nd „	+ ·22	− ·08	+ ·19	+ ·23	− ·11	+ ·24
	49—4th „	− ·00	+ ·27	− ·06	− ·02	+ ·27	+ ·27
	1—8th „	− ·41	+ ·31	− ·13	− ·35	+ ·24	+ ·45
	5—12th „	− ·16	− ·04	+ ·01	− ·15	− ·03	+ ·16
	9—16th „	+ ·27	− ·24	+ ·20	+ ·20	− ·16	+ ·25
	13—20th „	+ ·30	− ·40	+ ·30	+ ·12	− ·30	+ ·42
	17—24th „	+ ·27	− ·57	+ ·58	+ ·06	− ·51	+ ·57
	21—28th „	+ ·32	− ·55	....	+ ·19	− ·50	+ ·57
	25—32nd „	− ·07	− ·52	....	− ·55	− ·70	+ ·70
	29—36th „	− ·02	− ·49	....	− ·32	− ·56	+ ·56
	33—40th „	+ ·29	− ·14	....	+ ·26	+ ·02	+ ·29
	37—44th „	+ ·40	− ·07	+ ·16	+ ·41	+ ·15	+ ·41
	Seasons :—						
	Previous Spring........	− ·09	+ ·11	− ·29	− ·03	+ ·08	+ ·12
	„ Summer	− ·33	+ ·30	....	− ·19	+ ·12	+ ·35
	„ Autumn	− ·20	+ ·04	+ ·34	− ·21	+ ·05	+ ·21
	Winter	− ·30	+ ·28	− ·10	− ·31	+ ·29	+ ·41
	Spring	+ ·53	− ·49	+ ·34	+ ·35	− ·26	+ ·57
	Summer	+ ·06	− ·57	....	− ·43	− ·67	+ ·67
	Cereal year	− ·04	− ·38	+ ·10	− ·29	− ·46	+ ·52

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TABLE I (*Contd.*).—(*c*) **Oats.**

Period.	r_{or}.	r_{oa}.	r_{ob}.	ρ_{or}.	ρ_{oa}.	R.
Previous year: 9—16th weeks	+0·13	−0·03	−0·35	+0·13	+0·04	+0·13
13—20th „	− ·00	− ·11	+ ·07	− ·06	− ·12	+ ·12
17—24th „	+ ·03	+ ·15	+ ·05	+ ·10	+ ·18	+ ·18
21—28th „	− ·18	+ ·16	....	− ·13	+ ·10	+ ·20
25—32nd „	− ·29	+ ·25	....	− ·19	+ ·10	+ ·29
29—36th „	− ·20	+ ·07	....	− ·19	− ·09	+ ·20
33—40th „	− ·23	− ·05	....	− ·29	− ·20	+ ·30
37—44th „	− ·32	+ ·04	− ·04	− ·36	− ·17	+ ·36
41—48th „	− ·29	− ·12	+ ·28	− ·34	− ·22	+ ·36
45—52nd „	+ ·08	− ·11	+ ·14	+ ·09	− ·12	+ ·14
49— 4th „	− ·06	+ ·33	− ·15	− ·08	+ ·33	+ ·33
1— 8th „	− ·40	+ ·36	− ·19	− ·35	+ ·29	+ ·49
5—12th „	− ·20	− ·06	+ ·02	− ·20	− ·06	+ ·21
9—16th „	+ ·13	− ·32	+ ·23	+ ·01	− ·29	+ ·32
13—20th „	+ ·64	− ·52	+ ·25	+ ·52	− ·27	+ ·68
17—24th „	+ ·62	− ·68	+ ·46	+ ·52	− ·60	+ ·78
21—28th „	+ ·53	− ·65	....	+ ·45	− ·60	+ ·73
25—32nd „	+ ·09	− ·59	....	− ·41	− ·68	+ ·68
29—36th „	+ ·13	− ·53	....	− ·15	− ·53	+ ·54
33—40th „	+ ·17	− ·16	....	+ ·10	− ·08	+ ·18
37—44th „	+ ·22	+ ·07	− ·24	+ ·30	+ ·24	+ ·30
Seasons :—						
Previous Spring	+ ·05	− ·02	− ·26	+ ·04	+ ·00	+ ·05
„ Summer	− ·26	+ ·13	....	− ·24	− ·05	+ ·27
„ Autumn	− ·23	− ·04	+ ·32	− ·33	− ·18	+ ·33
Winter	− ·28	+ ·31	− ·16	− ·29	+ ·32	+ ·41
Spring	+ ·74	− ·52	+ ·29	+ ·70	− ·17	+ ·79
Summer	+ ·27	− ·70	....	− ·24	− ·69	+ ·72
Cereal year	+ ·10	− ·49	+ ·04	− ·19	− ·52	+ ·52

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TABLE I (*Contd.*).—(*d*) **Beans.**

	Period.	r_{br}.	r_{ba}.	r_{bb}.	ρ_{br}.	ρ_{ba}.	R.
Previous year.	9—16th weeks....	+0·17	+0·06	−0·15	+0·22	+0·15	+0·23
	13—20th „	− ·02	+ ·11	− ·25	+ ·04	+ ·11	+ ·11
	17—24th „	− ·04	+ ·33	− ·32	+ ·09	+ ·34	+ ·34
	21—28th „	− ·17	+ ·25	....	− ·08	+ ·20	+ ·26
	25—32nd „	− ·33	+ ·26	....	− ·23	+ ·09	+ ·34
	29—36th „	− ·52	+ ·25	....	− ·48	+ ·05	+ ·52
	33—40th „	− ·39	− ·17	....	− ·56	− ·46	+ ·57
	37—44th „	− ·30	− ·16	+ ·09	− ·47	− ·39	+ ·49
	41—48th „	− ·47	+ ·06	+ ·16	− ·48	− ·10	+ ·48
	45—52nd „	− ·21	− ·02	+ ·11	− ·20	+ ·01	+ ·20
	49—4th „	− ·17	+ ·38	− ·26	− ·20	+ ·39	+ ·42
	1—8th „	− ·36	+ ·44	− ·37	− ·30	+ ·40	+ ·52
	5—12th „	− ·13	+ ·09	− ·13	− ·14	+ ·12	+ ·17
	9—16th „	+ ·39	− ·10	− ·28	+ ·39	+ ·06	+ ·40
	13—20th „	+ ·43	− ·31	− ·23	+ ·32	− ·11	+ ·44
	17—24th „	+ ·38	− ·54	− ·06	+ ·22	− ·45	+ ·56
	21—28th „	+ ·32	− ·35	....	+ ·23	− ·28	+ ·41
	25—32nd „	+ ·20	− ·01	....	+ ·24	+ ·13	+ ·24
	29—36th „	+ ·25	− ·02	....	+ ·27	+ ·12	+ ·27
	33—40th „	− ·21	+ ·14	....	− ·17	+ ·04	+ ·22
	37—44th „	− ·40	+ ·35	− ·18	− ·27	+ ·20	+ ·43
	Seasons :—						
	Previous Spring	+ ·07	+ ·12	− ·27	+ ·17	+ ·19	+ ·20
	„ Summer	− ·39	+ ·23	....	− ·33	− ·03	+ ·49
	„ Autumn	− ·45	− ·08	+ ·18	− ·53	− ·33	+ ·54
	Winter	− ·36	+ ·27	− ·22	− ·37	+ ·29	+ ·45
	Spring	+ ·46	− ·31	− ·30	+ ·37	− ·06	+ ·46
	Summer	+ ·37	− ·16	....	+ ·34	+ ·07	+ ·38
	Cereal year	− ·05	− ·17	− ·22	− ·15	− ·22	+ ·22

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TABLE I (*Contd.*).—(*e*) **Peas.**

Period.	r_{pr}.	r_{pa}.	r_{pb}.	ρ_{pr}.	ρ_{pa}.	R.
Previous year.						
9—16th weeks	+0·31	−0·28	+0·15	+0·21	−0·17	+0·34
13—20th „	+ ·20	− ·24	+ ·08	+ ·09	− ·16	+ ·26
17—24th „	+ ·16	+ ·22	+ ·26	+ ·27	+ ·31	+ ·35
21—28th „	+ ·07	+ ·11	....	+ ·12	+ ·15	+ ·16
25—32nd „	− ·15	− ·12	....	− ·27	− ·26	+ ·30
29—36th „	− ·40	− ·07	....	− ·47	− ·28	+ ·47
33—40th „	− ·13	− ·13	....	− ·22	− ·22	+ ·26
37—44th „	+ ·14	− ·10	+ ·10	+ ·10	− ·03	+ ·14
41—48th „	− ·02	− ·04	+ ·02	− ·03	− ·05	+ ·05
45—52nd „	− ·12	− ·03	+ ·16	− ·12	− ·02	+ ·14
49—4th „	− ·18	+ ·22	− ·07	− ·19	+ ·23	+ ·29
1—8th „	− ·29	+ ·18	− ·13	− ·26	+ ·12	+ ·31
5—12th „	− ·20	− ·22	+ ·16	− ·20	− ·22	+ ·30
9—16th „	+ ·24	− ·10	+ ·09	+ ·22	− ·01	+ ·24
13—24th „	+ ·21	− ·16	− ·11	+ ·15	− ·06	+ ·22
17—20th „	− ·05	− ·35	+ ·06	− ·21	− ·40	+ ·40
21—28th „	+ ·06	− ·24	....	− ·03	− ·23	+ ·24
25—32nd „	+ ·24	− ·11	....	+ ·22	+ ·04	+ ·24
29—36th „	+ ·14	+ ·07	....	+ ·19	+ ·15	+ ·21
33—40th „	− ·18	+ ·31	....	− ·02	+ ·25	+ ·31
37—44th „	− ·39	+ ·49	− ·34	− ·20	+ ·38	+ ·52
Seasons :—						
Previous Spring........	+ ·42	− ·21	+ ·13	+ ·38	+ ·03	+ ·42
„ Summer	− ·18	− ·11	....	− ·32	− ·29	+ ·34
„ Autumn	− ·04	− ·01	+ ·03	− ·05	− ·03	+ ·05
Winter	− ·34	+ ·03	+ ·03	− ·34	+ ·03	+ ·34
Spring........................	+ ·17	− ·16	+ ·00	+ ·10	− ·07	+ ·19
Summer	+ ·22	− ·13	....	+ ·19	+ ·01	+ ·22
Cereal year....................	+ ·04	− ·12	+ ·03	− ·02	− ·12	+ ·13

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TABLE I (*Contd.*).—(*f*) **Potatoes.**

Period.		r_{pr}.	r_{pa}.	r_{pb}.	ρ_{pr}.	ρ_{pa}.	R.
Previous year	9—16th weeks	−0·17	+0·06	+0·10	−0·16	−0·02	+0·16
	13—20th „	− ·18	+ ·10	+ ·12	− ·15	− ·00	+ ·18
	17—24th „	+ ·14	− ·10	+ ·21	+ ·11	− ·05	+ ·14
	21—28th „	+ ·24	− ·31	....	+ ·13	− ·24	+ ·33
	25—32nd „	+ ·24	− ·35	....	+ ·05	− ·27	+ ·35
	29—36th „	+ ·28	− ·25	....	+ ·20	− ·16	+ ·31
	33—40th „	+ ·03	+ ·07	....	+ ·08	+ ·10	+ ·10
	37—44th „	+ ·05	+ ·12	+0·04	+ ·14	+ ·17	+ ·18
	41—48th „	+ ·38	+ ·03	− ·20	+ ·41	+ ·16	+ ·41
	45—52nd „	+ ·24	+ ·29	− ·21	+ ·22	+ ·27	+ ·36
	49—4th „	+ ·06	+ ·04	+ ·18	+ ·06	+ ·03	+ ·08
	1—8th „	− ·02	− ·26	+ ·38	− ·09	− ·27	+ ·27
	5—12th „	− ·34	− ·07	+ ·32	− ·34	− ·07	+ ·35
	9—16th „	− ·22	+ ·14	+ ·30	− ·18	+ ·05	+ ·22
	13—20th „	− ·18	+ ·40	− ·05	+ ·04	+ ·36	+ ·40
	17—24th „	− ·41	+ ·33	− ·04	− ·32	+ ·19	+ ·45
	21—28th „	− ·43	+ ·09	....	− ·42	− ·05	+ ·43
	25—32nd „	− ·13	− ·07	....	− ·21	− ·18	+ ·22
	29—36th „	− ·32	+ ·19	....	− ·26	+ ·05	+ ·32
	33—40th „	+ ·00	+ ·27	....	+ ·18	+ ·32	+ ·32
	37—44th „	+ ·36	− ·10	+ ·31	+ ·36	+ ·09	+ ·37
Seasons :—							
	Previous Spring	− ·04	+ ·04	+ ·14	− ·02	+ ·02	+ ·06
	„ Summer	+ ·27	− ·25	....	+ ·15	− ·10	+ ·29
	„ Autumn	+ ·23	+ ·08	− ·21	+ ·29	+ ·20	+ ·30
	Winter	− ·12	− ·00	+ ·25	− ·12	− ·00	+ ·12
	Spring	− ·15	+ ·21	+ ·27	− ·04	+ ·15	+ ·22
	Summer	− ·46	+ ·13	....	− ·48	− ·18	+ ·49
	Cereal year	− ·29	+ ·19	+ ·23	− ·23	+ ·05	+ ·29

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TABLE I (*Contd.*).—(*g*) **Turnips** and **Swedes.**

	Period.	r_{tr}.	r_{ta}.	r .	ρ_{tr}.	ρ_{ta}.	R.
Previous year.	9—16th weeks	+0·24	−0·06	−0·05	+0·24	+0·06	+0·25
	13—20th „	− ·15	+ ·07	+ ·07	− ·14	− ·02	+ ·15
	17—24th „	− ·30	+ ·36	− ·11	− ·19	+ ·25	+ ·40
	21—28th „	− ·10	+ ·25	....	− ·01	+ ·23	+ 26
	25—32nd „	− ·06	+ ·19	....	+ ·06	+ ·19	+ ·20
	29—36th „	− ·18	− ·12	....	− ·25	− ·22	+ ·28
	33—40th „	+ ·26	− ·38	....	+ ·08	− ·30	+ ·39
	37—44th „	+ ·25	− ·45	+0·46	+ ·00	− ·39	+ ·45
	41—48th „	+ ·09	− ·46	+ ·48	− ·04	− ·45	+ ·46
	45—52nd „	− ·12	− ·41	+ ·42	− ·09	− ·40	+ ·42
	49— 4th „	− ·26	− ·29	+ ·30	− ·26	− ·29	+ ·38
	1— 8th „	+ ·03	− ·31	+ ·28	− ·05	− ·31	+ ·31
	5—12th „	+ ·16	− ·26	+ ·21	+ ·17	− ·27	+ ·29
	9—16th „	+ ·08	− ·11	+ ·04	+ ·04	− ·09	+ ·12
	13—20th „	− ·06	− ·10	+ ·18	− ·13	− ·16	+ ·17
	17—24th „	+ ·25	− ·13	+ ·35	+ ·21	− ·04	+ ·25
	21—28th „	+ ·60	− ·32	....	+ ·55	− ·17	+ ·61
	25—32nd „	+ ·39	− ·49	....	+ ·14	− ·36	+ ·50
	29—36th „	+ ·34	− ·47	....	+ ·16	− ·37	+ ·49
	33—40th „	+ ·03	− ·09	....	− ·02	− ·09	+ ·10
	37—44th „	− ·13	+ ·20	− ·32	− ·04	+ ·16	+ ·20
Seasons :—							
	Previous Spring	− ·08	+ ·03	+ ·01	− ·07	− ·02	+ ·08
	„ Summer	− ·14	+ 0·7	....	− ·12	− ·02	+ ·14
	„ Autumn	+ ·23	− ·44	+ ·53	+ ·06	− ·39	+ ·45
	Winter	− ·10	− ·41	+ ·39	− ·11	− ·41	+ ·42
	Spring	+ ·18	− ·04	+ ·07	+ ·19	+ ·07	+ ·19
	Summer	+ ·50	− ·52	....	+ ·28	− ·32	+ ·57
	Cereal year	+ ·57	− ·62	+ ·44	+ ·39	− ·47	+ ·69

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TABLE I (*Contd.*).—(*h*) **Mangolds.**

	Period.	r_{mr}.	r_{ma}.	r_{mb}.	ρ_{mr}.	ρ_{ma}.	R.
Previous year.	9—16th weeks	+0·21	−0·12	−0·27	+0·18	−0·02	+0·21
	13—20th ,, ...	+ ·03	− ·10	− ·12	− ·03	− ·10	+ ·10
	17—24th ,, ...	− ·16	+ ·09	− ·18	− ·14	+ ·03	+ ·16
	21—28th ,, ...	− ·34	+ ·07	....	− ·33	− ·07	+ ·34
	25—32nd ,, ...	− ·38	+ ·44	....	− ·17	+ ·30	+ ·47
	29—36th ,, ...	− ·43	+ ·28	....	− ·37	+ ·12	+ ·45
	33—40th ,, ...	− ·22	− ·05	....	− ·25	− ·19	+ ·26
	37—44th ,, ...	− ·12	+ ·04	+ ·01	− ·12	− ·03	+ ·13
	41—48th ,, ...	− ·09	− ·03	+ ·17	− ·11	− ·06	+ ·11
	45—52nd ,, ...	+ ·12	− ·11	+ ·13	+ ·13	− ·12	+ ·17
	49— 4th ,, ...	+ ·06	+ ·09	− ·08	+ ·06	+ ·09	+ ·11
	1— 8th ,, ...	− ·09	− ·10	+ ·08	− ·12	− ·13	+ ·15
	5—12th ,, ...	− ·13	− ·45	+ ·27	− ·13	− ·45	+ ·47
	9—16th ,, ...	+ ·26	− ·47	+ ·16	+ ·09	− ·41	+ ·47
	13—20th ,, ...	+ ·50	− ·59	+ ·14	+ ·28	− ·45	+ ·63
	17—24th ,, ...	+ ·37	− ·56	+ ·44	+ ·20	− ·49	+ ·59
	21—28th ,, ...	+ ·36	− ·34	....	+ ·28	− ·26	+ ·52
	25—32nd ,, ...	+ ·01	− ·25	....	− ·19	− ·32	+ ·32
	29—36th ,, ...	+ ·05	− ·18	....	− ·04	− ·18	+ ·19
	33—40th ,, ...	− ·01	+ ·05	....	+ ·02	+ ·05	+ ·07
	37—44th ,, ...	− ·09	+ ·21	− ·34	+ ·01	+ ·17	+ ·21
	Seasons :—						
	Previous Spring	+ ·04	− ·21	− ·19	− ·10	− ·23	+ ·24
	,, Summer	− ·48	+ ·28	....	− ·41	− ·03	+ ·48
	,, Autumn	− ·08	+ ·01	+ ·20	− ·08	− ·02	+ ·08
	Winter	− ·06	− ·09	+ ·09	− ·06	− ·09	+ ·10
	Spring	+ ·60	− ·59	+ ·23	+ ·39	− ·38	+ ·67
	Summer	+ ·14	− ·36	....	− ·10	− ·34	+ ·37
	Cereal year	+ ·25	− ·54	+ ·18	− ·02	− ·49	+ ·54

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TABLE I (*Contd.*).—(*i*) **Hay** from **Clover** and **Rotation Grass.**

Period.	r_{hr}.	r_{ha}.	r_{hb}.	ρ_{hr}.	ρ_{ha}.	R.
Previous year. 9—16th weeks	+0·44	+0·05	−0·41	+0·51	+0·30	+0·51
13—20th „	+ ·07	− ·06	− ·09	+ ·05	− ·03	+ ·08
17—24th „	+ ·11	− ·09	+ ·01	+ ·08	− ·05	+ ·12
21—28th „	+ ·05	− ·23	....	− ·05	− ·23	+ ·23
25—32nd „	− ·11	+ ·08	....	− ·09	+ ·02	+ ·12
29—36th „	− ·06	− ·11	....	− ·12	− ·15	+ ·16
33—40th „	− ·23	− ·32	....	− ·50	− ·54	+ ·57
37—44th „	− ·39	+ ·00	− ·01	− ·45	− ·26	+ ·45
41—48th „	− ·32	+ ·16	− ·03	− ·29	+ ·08	+ ·32
45—52nd „	+ ·12	+ ·08	− ·10	+ ·11	+ ·06	+ ·14
49—4th „	+ ·00	+ ·16	− ·20	− ·05	+ ·16	+ ·16
1—8th „	− ·31	+ ·13	− ·00	− ·29	+ ·05	+ ·32
5—12th „	− ·32	− ·14	+ ·19	− ·32	− ·15	+ ·35
9—16th „	+ ·04	− ·38	+ ·15	− ·14	− ·40	+ ·40
13—20th „	+ ·78	− ·48	− ·03	+ ·70	− ·13	+ ·78
17—24th „	+ ·73	− ·41	+ ·04	+ ·68	− ·19	+ ·75
21—28th „	+ ·37	− ·31	....	+ ·30	− ·22	+ ·42
25—32nd „	+ ·09	− ·35	....	− ·22	− ·40	+ ·41
29—36th „	+ ·29	− ·27	....	+ ·17	− ·16	+ ·32
Seasons :—						
Previous Spring........	+ ·18	− ·06	− ·36	+ ·18	+ ·05	+ ·18
„ Summer	− ·04	− ·13	....	− ·16	− ·20	+ ·21
„ Autumn	− ·29	− ·01	+ ·08	− ·32	− ·15	+ ·32
Winter	− ·24	+ ·09	− ·04	− ·24	− ·07	+ ·25
Spring........................	+ ·80	− ·40	+ ·04	+ ·76	+ ·10	+ ·80
Summer	+ ·31	− ·42	....	+ ·03	− ·30	+ ·42
Cereal year....................	+ ·20	− ·34	+ ·00	+ ·03	− ·28	+ ·35

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TABLE I (*Contd.*).—(*j*) **Hay** from **Permanent Grass.**

	Period.	r_{hr}.	r_{ha}.	r_{hb}.	ρ_{hr}.	ρ_{ha}.	R.
Previous year.	9–16th weeks	+0·36	+0·04	−0·33	+0·42	+0·22	+0·42
	13—20th ,, ...	+ ·06	− ·11	− ·01	− ·00	− ·09	+ ·11
	17—24th ,, ...	+ ·05	+ ·04	+ ·02	+ ·08	+ ·07	+ ·09
	21—28th ,, ...	− ·18	+ ·04	....	− ·17	− 03	+ ·18
	25—32nd ,, ...	− ·33	+ ·21	....	− ·27	+ ·04	+ ·34
	29—36th ,, ...	− ·21	+ ·08	....	− ·19	− ·01	+ ·21
	33—40th ,, ...	− ·16	− ·30	....	− ·40	− ·45	+ ·49
	37—44th ,, ...	− ·25	− ·17	+ ·15	− ·40	− ·36	+ ·43
	41—48th ,, ...	− ·29	− ·07	+ ·24	− ·32	− ·16	+ ·33
	45—52nd ,, ...	+ ·01	− ·15	+ ·04	+ ·02	− ·15	+ ·15
	49—4th ,, ...	− ·08	+ ·13	− ·12	− ·09	+ ·14	+ ·17
	1—8th ,, ...	− ·28	+ ·20	− ·17	− ·24	+ ·14	+ ·31
	5—12th ,, ...	− ·14	− ·14	+ ·09	− ·11	− ·11	+ ·20
	9—16th ,, ...	+ ·15	− ·38	+ ·16	− ·01	− ·35	+ ·38
	13—20th ,, ...	+ ·74	− ·50	− ·03	+ ·64	− ·19	+ ·75
	17—24th ,, ...	+ ·68	− ·54	+ ·15	+ ·61	− ·41	+ ·74
	21—28th ,, ...	+ ·42	− ·49	....	+ ·31	− ·42	+ ·56
	25—32nd ,, ...	+ ·13	− ·38	....	− ·21	− ·41	+ ·43
	29—36th ,, ...	+ ·25	− ·31	....	+ ·10	− ·22	+ ·33
	Seasons :—						
	Previous Spring	+ ·12	− ·05	− ·27	+ ·11	+ ·02	+ ·12
	,, Summer	− ·26	+ ·07	....	− ·26	− ·12	+ ·27
	,, Autumn	− ·21	− ·17	+ ·32	− ·31	− ·29	+ ·35
	Winter	− ·23	+ ·09	− ·13	− ·22	+ ·06	+ ·23
	Spring	+ ·79	− ·49	+ ·07	+ ·71	− ·09	+ ·79
	Summer	+ ·33	− ·49	....	− ·03	− ·38	+ ·48
	Cereal year	+ ·27	− ·49	− ·01	+ ·03	− ·43	+ ·50

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TABLE II.—AVERAGE ACREAGE AND YIELD OF CROPS, 1886–95 AND 1896-1905.

(*a*) **Eastern England** (*as defined on p.* 2).

Crop.	Area.		Yield per Acre.		
	1896–1905.	1896–1905.	1886–95.	1896–1905.	Increase or Decrease.
	Acres.	Acres.	Bushels.	Bushels.	Bushels.
Wheat	845,136	713,219	30·4	32·1	+ 1·7
Barley	801,346	749,306	33·6	33·1	– 0·5
Oats	340,750	410,948	46·5	46·0	– 0·5
Beans	149,579	128,670	27·3	29·1	+ 1·8
Peas	95,979	82,341	26·9	27·2	+ 0·3
			Tons.	Tons.	Tons.
Potatoes	100,267	134,524	6·0	5·5	– 0·5
Turnips and swedes	397,164	346,489	12·0	11·3	– 0·7
Mangolds	161,348	162,749	16·9	17·3	+ 0·4
			Cwts.	Cwts.	Cwts.
Seeds' hay	450,209	463,528	28·1	27·9	– 0·2
Meadow hay	516,631	476,003	22·6	22·7	+ 0·1

(*b*) **Scotland.**

	Acres.	Acres.	Bushels.	Bushels.	Bushels.
Wheat	53,404	45,044	35·2	38·7	+ 3·5
Barley	217,116	226,120	35·3	36·1	+ 0·8
Oats	1,020,811	966,707	36·0	36·5	+ 0·5
Beans	15,544	12,354	30·4	33·8	+ 3·4
Peas	1,229	1,046	23·6	25·8	+ 2·2
			Tons.	Tons.	Tons.
Potatoes	143,392	130,751	5·7	6·0	+ 0·3
Turnips and swedes	481,037	462,116	15·0	15·2	+ 0·2
Mangolds	1,208	2,476	16·4	17·4	+ 1·0
			Cwts.	Cwts.	Cwts.
Seeds' hay	411,073	409,600	30·2	32·2	+ 2·0
Meadow hay	157,238	139,280	28·2	29·4	+ 1·2

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TABLE III.—AVERAGE RANGE, AND STANDARD DEVIATION OF CERTAIN CROPS IN EASTERN ENGLAND, SCOTLAND AND FRANCE, 1885–1905.

Crop and District.	Period.	Average Yield per Acre.	Range. Maximum.	Range. Minimum.	Standard Deviation. Actual per Acre.	Standard Deviation. Per Cent. of Average Yield.
		Bushels.	Bushels.	Bushels.	Bushels.	
Wheat, E. England	1885–1905	31·41	36·84	25·86	3·04	9·7
„ Scotland	„	36·81	42·47	31·12	2·67	7·3
„ France	„	18·20	22·05	14·68	1·93	10·6
Barley, E. England	„	33·57	38·17	27·77	2·57	7·7
„ Scotland	„	35·63	39·07	33·29	1·37	3·8
„ France	„	21·09	24·39	15·57	1·85	8·8
Oats, E. England	„	46·48	50·94	36·99	3·48	7·5
„ Scotland	„	36·05	39·43	31·93	1·63	4·5
„ France	„	25·88	30·64	18·12	2·62	10·1
Beans, E. England	„	27·78	33·58	19·38	4·48	16·1
„ Scotland	„	32·04	36·76	24·31	2·85	8·9
Peas, E. England	„	26·66	30·67	17·36	2·80	10·5
„ Scotland	„	24·54	27·16	18·79	1·99	8·1
		Tons.	Tons.	Tons.	Tons.	
Potatoes, E. England	„	5·81	7·06	4·63	0·69	11·9
„ Scotland	„	5·81	7·13	4·54	0·79	13·6
„ France	1885–1904	3·15	3·58	2·86	0·54	17·1
Turnips and swedes, E. England	1885–1905	11·59	13·77	7·82	1·70	14·7
Turnips and swedes, Scotland	„	15·05	17·25	12·23	1·35	9·0
Mangold, E. England	„	17·14	21·16	14·83	2·03	11·8
„ Scotland	„	16·83	20·95	13·21	1·82	10·8
„ France*	1885–1904	9·92	12·29	7·89	0·89	9·0
		Cwts.	Cwts.	Cwts.	Cwts.	
Hay from clover and rotation grass, E. England	1886–1905	28·02	36·74	14·97	4·42	15·8
Hay from clover and rotation grass, Scotland	„	31·22	35·14	25·55	2·64	8·5
Clover hay, France	1885–1904	29·88	35·00	14·80	4·22	14·1
Hay from permanent grass, E. England	1886–1905	22·68	28·77	9·89	4·46	19·7
Hay from permanent grass, Scotland	„	28·84	31·65	22·61	2·34	8·1
Hay from permanent grass, France	1885–1904	25·05	28·80	11·20	3·93	15·7
Hops, Kent	1885–1905	8·84	14·47	4·63	2·46	27·8

* Betteraves fourragères.

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TABLE IV.—CORRELATION COEFFICIENTS BETWEEN RAINFALL AND ACCUMULATED TEMPERATURE ABOVE 42° F.

Period.	Twenty-one Years. 1884-1904.	Twenty-one Years. 1885-1905.	Twenty Years. 1885-1904.	Twenty Years. 1886-1905.
1—8th weeks	....	−0·24	....	−0·25
5 "	....	+ ·02	....	− ·00
9 "	−0·46	− ·41	−0·43	− ·42
13 "	− ·53	− ·53	− ·53	− ·53
17 "	− ·38	− ·39	− ·39	− ·39
21 "	− ·39	− ·31	− ·40	− ·32
25 "	− ·57	− ·59	− ·54	− ·70
29 "	− ·40	− ·46	− ·44	− ·56
33 "	− ·50	− ·54	− ·54	....
37 "	− ·54	− ·48	− ·53	....
41 "	− ·29	....	− ·27	....
45 "	+ ·10	....	+ ·11	....
49—4th "	+ ·05	....	+ ·05	....
Seasons:—				
Winter	....	− ·06	....	− ·11
Spring	− ·57	− ·57	− ·57	− ·56
Summer	− ·63	− ·59	− ·63	− ·71
Autumn	− ·42	....	− ·42	....
Cereal year	....	− ·50	....	− ·51

DISCUSSION *on* MR. R. H. HOOKER'S PAPER.

DR. SHAW said they were much indebted to Mr. Hooker for the great labour he had bestowed on calculating the correlation coefficients between the rainfall and warmth at different times of the year and the various crops. The relation between the crops and those conditions was in this way formulated for those who were acquainted with the matter practically. It was a great advantage to have these results put into a numerical form, because they were very much shorter than the practical expression of the memory of practical man, and much more easy to put into a table. He would suggest that in the discussion they might have a pronouncement from some one acquainted with correlation coefficients and their application to phenomena of different kinds, as to the meaning which could be attached to correlation coefficients of comparatively small values. There was no doubt that if you got them between 0·75 and 1, the indication of association was very close; but if it fell below 0·75 or below 0·5, the precise application of the correlation coefficients was more dubious. And he should like to have from some expert illustrations of the extent to which such a matter could be regarded as indicating a definite relation. For instance, in the table relating to peas there was a correlation coefficient of 0·49 between the crop of peas and the warmth of the subsequent autumn. No doubt there might be or must be some correlation between the crop and what happened afterwards—it

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might be between the subsequent accumulated temperatures and the crop of peas. And that being so, whether 0·5 was the proper critical point was worth examination. That particular correlation suggested to his mind an old-fashioned method of forecasting the weather, which he thought had rather gone out of fashion, namely, that if you got a large crop of hips and haws you would have a cold winter. Mr. Hooker had not touched on that particular correlation coefficient, but between the peas and the subsequent autumn he had given at least a suggestive coefficient which rehabilitated to a certain extent the possibilities of such a method; and it added force to the conclusion that the question of correlation between different seasons was extraordinarily interesting. It was so particularly in connection with wheat. In a paper which he (the speaker) contributed lately to the *Cambridge Agricultural Journal*, he put in a table showing the accumulated temperatures and the rainfall for the different seasons corresponding to the yield of wheat for the last twenty years; and, to his great astonishment—he would not say that there was a correlation—there was an indication of a relation of the following kind. In sixteen years out of twenty-one years a wet autumn had a winter with a rainfall above the average; or *vice versâ*, when it was below the average in one case it was below in the other. The two seasons ran parallel in 16 cases out of 21; but between the autumn and the spring they ran opposite. This did not show that the correlation coefficient would come very high, because there was no sort of proportionality between the amounts by which the autumn rainfall was increased or decreased, and the amount by which the corresponding spring rainfall was in defect or excess. As long as Mr. Hooker was speaking of the correlation coefficients he dealt with them strictly, taking them for better or worse, as he thought himself bound to do; but in the latter part of the paper, where he proceeded to some speculations not based on the strict method of correlation coefficients, he referred to abnormal seasons, and he seemed to indicate that under certain circumstances he might reject data as having somehow or another gone wrong. He took it that in calculating the correlation coefficients you did not reject anything, but took them for better or worse. In a matter of this kind it did not seem to him to be necessarily an advantage to find correlation coefficients always between the "brut" data and the crop. For example, if you set out to find the correlation coefficient between the yield of wheat and the accumulated temperature in the year, as a rule you had to deal with a small variation in the one corresponding with a small variation in the other. But there was one year, 1879, when there really was not enough warmth to grow a wheat crop at all in this country. Practically, the experiment failed, and to bring in a failure of that kind, when the accumulated temperature was only numerically low, into association with other data where there was more or less proportionality, seemed to require a certain amount of justification. Therefore, he should once more like to ask experts whether it would be feasible in computing the coefficients to leave out of account some of the specially exceptional cases, as Mr. Hooker seemed disposed to do in the last few

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paragraphs. A very high coefficient of correlation, obtained for all years with one or two exceptions, might have a very definite meaning. Again, he should like to ask whether, if one calculated the combined correlation coefficient between the crop and several elements of the weather, say the spring rainfall and the autumn rainfall, or other different elements for which the partial correlation coefficients were high, one would get a very high correlation coefficient which would be an obvious indication of a close relationship. If that could be done it might be possible to get an indication for some crops of what in combination were the vitally important elements.

There was one little criticism he might venture to offer. Mr. Hooker had compiled a fresh district in the British Isles in order to find the relation between one thing and another. His impression was that there were already too many different groupings into districts. Probably it was not a matter of vital importance whether you included Lincolnshire when dealing with a question of this kind. As regards the relation between the yield of wheat and the rainfall, it was closer for the whole of England than for the Eastern counties taken as a district. He thought it would not be desirable not to introduce another scheme for classification of English counties into districts.

Mr. Hooker had challenged him to say something about the triumph of the autumn rainfall over the indication of the eleven-year periodicity. He had not yet seen the crop values for the individual counties, and he did not know whether the Board of Agriculture had yet issued them; but, supposing the triumph was as complete as it appeared to be, he might reply to Mr. Hooker that the occurrence of a node gave no particular reason for the relation kicking up its heels and bolting. A node was not specially the point where one would expect such things to occur.

Professor EDGEWORTH remarked that the statisticians who dealt with meteorology in relation to agriculture were fortunate in the stability of their subject. "O fortunatos!" he would say, if he might add "sua si *mala* norint;" for the condition of success in such investigations was to be aware of their difficulty. Mr. Hooker gave us confidence in his results by making ample allowance for the unavoidable deficiencies in his data. Not only was the number of observations, viz., 21, rather small, but also, as Mr. Hooker intimated when speaking of cycles in crops, there might be some correlation between those observations. Accordingly, in the computation of probable errors, the denominator proper to the case of independent observations, viz., $\sqrt{21}$, must be taken *cum grano*. The error to be apprehended might really be a little greater than appeared. He hoped that Mr. Hooker would confirm his theories by dealing with additional materials. Some trouble might perhaps be saved by a slight variation in the procedure. He referred to the "coefficients of double correlation" which Mr. Hooker had employed to exhibit the correlation between abundance of crop on the one hand, and on the other hand a pair of (mutually correlated)

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attributes, temperature and (deficiency of) rainfall—the pair happily subsumed by Mr. Hooker under the description "weather." To form the combination of temperature and rainfall constituting "weather," it would be agreed that the compound attribute, say z, should be related in the simplest manner to the two components, say x_1 and x_2; that z should be a linear function of x_1 and x_2. But there might be a difference of opinion as to the proper species of this genus. Mr. Yule, whom Mr. Hooker had followed, would determine the linear function by the condition that the correlation between the third attribute x_1, and the compound of x_1 and x_2, should be a maximum. It was as if we suspected complicity between an accused pair and a third party, and it was thought best to employ that form of trial or ordeal which would make the complicity appear greatest. He (Professor Edgeworth) thought that the purpose of an impartial inquiry might perhaps be as well served by some other arrangement. He would therefore propose as a variant method for coupling x_1 and x_2 the plan which he had suggested in the *Journal of the Royal Statistical Society** for the identification of criminals in cases where two attributes used for this purpose proved to be highly correlated. Take as the unit, in terms of which x_1 is measured, the corresponding *standards deviation*, and let x_1 be likewise measured by σ_2; then put $z = \frac{1}{\sqrt{2}}(x_1 + x_2)$; x_1 and x_2 being positively correlated. Thus, if each couple of concurrent observations of the type x'_1, x'_2 is represented by a dot on the plane of x_1, x_2, these dots being disposed in (a series of concentric and coaxal) elliptical rings —curves of equal probability—then z is to be measured along (a parallel) to the major axis of the ellipse (from the minor axis). The "weather" thus defined would be independent of the crop with which it was compared. The correlation between z thus defined and any third attribute x_1 might be used as a coefficient of double correlation. Its form was very simple. It was such as to become negative if there proved to be a negative coefficient of correlation—a repugnancy—between the "weather" at any period and the abundance of a certain crop.

Major CRAIGIE said he had listened to the paper with great interest, because he thought it was the beginning of a series of papers in which the practical knowledge of agriculturalists and the theoretical methods of arithmetical expression might be brought together. The agriculturalist had a storehouse of information; and a great many farmers if they examined the results of Mr. Hooker's conclusions would be, no doubt, somewhat startled. He was himself a little alarmed at the conclusion drawn as to the effect of the weather at certain periods on permanent grass; and he was very much surprised at certain figures. He hoped he was too much of a statistician to say that the figures were wrong, but, at any rate, they gave cause for thought. He did not feel quite sure whether the results were not obtained from possibly insufficient data. He must

* Vol. lix, 1896, "Supplementary Notes on Statistics," IV, p. 534 *sqq.*

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join in congratulating Mr. Hooker on the first paper he had produced in his new position he held as Head of the Statistical Branch of the Board of Agriculture. The connection of mathematical knowledge and agricultural data promised a great deal in the future, for they were now only making a beginning. He was not sure that it might not be worth the consideration of the Council at some future time whether a mixed Committee should be formed of practical agriculturists and statisticians to go into some of these points, which apparently wanted thrashing out across the table rather than in a public discussion.

He should like, again, to consider what was the real meaning of the want of progress to which Mr. Hooker pointed very forcibly in the latter part of his paper. Why was it that, as regards England, there was no progress, but rather the reverse, in the yield per acre of crops since the great depression set in? In a paper read in 1883 he had dealt with the older records of production, somewhat scattered as they were, and his conclusion was that there had been a distinct tendency to progress since 1883, as the area of wheat had been reduced. But how was it with regard to other crops? The area under oats, for instance, had extended, but whether, with all the advantages of the further knowledge, they were obtaining better results than before, was a serious question, and he only hoped it could be answered satisfactorily.

He agreed with Dr. Shaw that there were certain abnormal years, such as 1879, that one always felt inclined to omit, as having gone so far beyond the ordinary swing of the pendulum as to be like a cataclysm of nature, which they could not expect to recur. It was evident that this paper, and the previous one of Dr. Shaw, were the opening of a new and very promising field of investigation.

Mr. YULE said that generally when a speaker rose late in a discussion the majority of his points had been already dealt with; but, during the present discussion, a large number of additional points had been raised, and he found himself in some difficulty in dealing both with the points of the paper and those raised by previous speakers, particularly as he had been so interested in listening to the remarks that he had not made any notes.

As to the question of probable errors raised by Dr. Shaw, and the meaning to be attached to very small correlation coefficients, one could not lay down any definite law. If you wrote down certain numbers at random on tickets, and drew them by pairs out of a bag, and treated the pairs as representing the wheat record and the rainfall record, there ought not to be any connection at all between the two numbers; but, inevitably, you would find greater or less correlation coefficients, sometimes positive, sometimes negative, and sometimes nearly zero. The values of the correlation coefficients so obtained would fluctuate round zero, and large figures of either sign would be very rare—but there was no absolute or definite limit. Mr. Hooker had taken a fairly high limit, beyond which he considered the coefficient as being significant of a definite physical relationship. A more rash statistician might have taken a

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lower limit; but it was largely a point of personal taste what limit one would take in any actual case.

As Mr. Hooker had referred to him in connection with the question of the probable error of the partial coefficient, he should say that he hoped to justify the formula given (p. 6) very shortly. The coefficient of double correlation, R, on which Mr. Hooker and himself presented a short note recently (*Journal*, 1906), was, however, a very troublesome quantity as regarded the effect of errors of sampling. It was not only subject to fluctuation round the true value, but was also subject to biassed error. In the formula for R, the positive sign was always to be attached to the square root, and, consequently, if the two coefficients, r_{12} and ρ_{13}, had any values whatever, due to fluctuations of sampling or otherwise, R would have a positive value. On averaging, consequently, a series of values of R obtained from cases where the variables were really independent, the mean would not approximate to zero, but to a sensible value which he estimated at $\sqrt{(v-1)/N}$ for the root-mean-square average, v being the number of variables and N the number of observations. This formula gave the value 0·31 cited by Mr. Hooker.

Passing to another point, also raised by Dr. Shaw, the question as to the form of relationship between the weather and the crop, and its influence on the coefficient of correlation, the value of r was most easily interpreted when there was a linear relation between the average value of the crop and the weather. If the relationship was of the kind which could only be expressed by a curve, say of such a kind that the greatest value of the crop corresponded with certain optimum weather conditions and was less for a deviation in either direction, you would obtain much lower values of the correlation. Unfortunately, with so small a number of observations it would be very difficult to be certain whether there were a relationship of that kind or no, unless it were extremely well marked.

He would like to emphasize two points which seemed to him to be of great importance in the conclusions which Mr. Hooker had reached. First, with regard to the importance of a cool spring and summer: if one looked through the signs of the partial correlation coefficients between the crops and the temperature in all the tables, during the period between the ninth and twenty-eighth weeks (which included four correlations), they were *all* negative in the cases of barley, oats, peas, turnips and swedes, mangolds, and both the hay crops. That was an extraordinarily sweeping uniformity of sign. In the case of wheat there was only one positive coefficient; and in beans only one. Potatoes was the only crop in which there were three positive coefficients to one negative. This conclusion, it seemed to him, was one of considerable practical importance. The second very important point was the apparent opposition indicated between the conditions requisite for good seed-quality and the conditions requisite for a bulky crop. He had tried to summarise Mr. Hooker's figures somewhat hastily in a different way in order to see if such opposition was more clearly

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indicated thereby. He found in the case of temperature that in all the weeks of the year between the ninth and the thirty-sixth (from early spring to early autumn) there were, out of six coefficients, with wheat, one positive in the harvest year, and five positive in the year in which the seeds were grown. In the case of barley it was the same thing: there were no positive coefficients in the harvest year, but five in the seed year. With oats, again, there were no positive coefficients in the harvest year, and four in the seed year. In the case of the rainfall, the opposition was not quite so marked. For wheat there were three positives in the harvest year to two in the seed year. But for barley there were four positives in the harvest year, and only one positive in the seed year. For oats, four positive in the harvest year, and two in the seed year. In the case of beans, again, there was a somewhat similar opposition. In all these cases of "seed crops," in which the seed was not only used as such but also for the food, there was a marked opposition between conditions requisite for the two qualities, good seed and a bulky crop. This fact bore on that curious tendency to alternation of good and bad crops to which Dr. Shaw had alluded. That tendency was well marked in the case of the years 1885 to 1905; they gave fourteen pairs of years in which a deviation of the crop in one direction from the average was followed by a deviation of the other sign; and only six pairs of years in which a deviation of one sign was followed again the next year by a deviation of the same sign. If the crop were above the average one year, the odds were therefore 7 to 3 that it would deviate in the other direction the next year.

As a corollary to the conclusions respecting the opposition between good seed qualities and bulky crop, he would like to raise the question whether there ought not to be greater specialization in growing a crop for seed and a crop for food, specialization either in districts or in the mode of growth, manuring, &c.? In the case of potatoes there did seem to be some such specialization; and he would like to know how far it was recognised as desirable, from a practical standpoint, in the case of other crops. He would like, in conclusion, to point out, as one who knew something of the matter, what an enormous labour must have been devoted by the author to his paper. Most statisticians knew the amount of calculation needed even to obtain many averages; but to calculate a correlation coefficient required a great deal more, and in the present paper there were something like 700 total correlation coefficients, together with the partial correlations calculated therefrom by a not very handy formula. However, the labour had been well repaid, as it led to many conclusions and speculations of a far-reaching and important kind.

Mr. SYDNEY YOUNG said he would like to say a word or two on the practical side of the question. It had been said that an abundant harvest was most likely to produce bad seed. But he should say that an abundant harvest produced good seed, but was often followed by a poor harvest owing to the fact that although the seed was good it was put into the ground in bad weather; he

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thought that was really the reason why they sometimes got first a good crop and then a bad one—not that they got bad seed from a full harvest. It had also been said that the most critical time for the farmer in wheat harvest was the seed time. But wheat seed was very hardy indeed; it would stand a very large amount of rough treatment, so long as it was sown in dry weather. When the farmer had to sow it in wet weather, there was no doubt the chances were that he would get a bad result. In his opinion, the most critical time was the flowering time, which was about June. According to a great French scientist, M. Bidard, for a period of about fourteen days in the month of June the wheat was prepared to flower; and, as long as the temperature was within the region of 70° F. there would be a good flowering season, provided there was no rain or wind. If there were rain or wind, the flowers were spoilt; or directly they flowered the bloom withered. When you saw the withered flower you could tell whether you were going to get a good or a bad harvest as regards quantity. At other times you could only form an uncertain estimate. As long as the wheat germinated in the ground it did not matter whether it was frozen off or eaten off at a certain time, it would still grow up and produce good straw; and from that you would get a harvest; but the flowering time was the most important. With regard to the period of eleven years of cycle good and bad crops, he could not see that that was borne out by the statistics; the averages had remained between 26 and 34 bushels for a great number of years; but they did not go regularly from 34 downwards, or from 26 upwards and then down again; they were very irregular in sequence, and therefore he did not think there was that periodicity of good and bad crops which had been suggested.

Mr. Rew said that if he wished to criticise this paper he had other opportunities of doing so, while if he eulogised it, it might possibly be thought that he was not altogether disinterested. He should, however, like to say that it was of the greatest importance and interest from the point of view of the Society that questions of this sort should be taken up by statisticians of the ability, industry and thoroughness of Mr. Hooker. Everyone must realise the enormous amount of work which had been put into this paper, and although Mr. Hooker had perhaps left one or two of his conclusions at rather a loose end, they would well repay further consideration. He had done work of great value to those interested in agricultural subjects in having opened a new field—or in extending the area of investigation which Dr. Shaw had opened up—in regard to the actual relationship between the weather and the crops. He hoped the suggestions made in the paper would be further followed up.

The Chairman conveyed to Mr. Hooker the cordial thanks of the meeting for his paper.

Mr. R. H. Hooker, in reply, said that he was glad to find, from Professor Edgeworth's and Mr. Yule's remarks, that they regarded his critical value of 0·5 as sufficiently safe to justify conclusions

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being drawn from it. He would refer Dr. Shaw to p. 7 *sqq.* of his paper, in which he had dealt at some length with the theoretical considerations that led him to adopt this figure. As mentioned, the odds against there being no dependence, when such a coefficient was obtained with 21 observations, were something like 1 in 15,000 —of course, there was that one odd chance that the twenty-one years were so peculiar that the connection was adventitious. He had himself noted the coefficient of 0·49 between peas and temperature after harvest, and had concluded that it was a chance value, because the weather then could have no obvious connection with the crop. He would observe two things as regards this value: first, that by correcting for rainfall the net coefficient was reduced to 0·38; and, secondly, that he had specifically treated coefficients between 0·3 and 0·5, as suggestive only, not as proof, of dependency; in fact, this particular coefficient—the largest of all those between any crop and a period with which it could apparently have no connection—had largely guided him in determining what might safely be regarded as the lowest limit of "proof." There was also the possibility that the weather after harvest was correlated with the weather of some other period that did affect the crop.

Dr. Shaw had mentioned the importance of correlation between one part of a year and another as affecting the figures: this was discussed on p. 3, and, with regard to autumn and winter rainfall in particular, on p. 11. Dr. Shaw found 16 cases in which the rainfall of these two periods corresponded in direction, and 5 when it did not, but that the amounts did not seem to correspond. The amounts for the eight weekly periods compared on p. 12 seemed to correspond to a considerable degree (in the last twenty-one years), and the big coefficient there given indicated a real connection between those two periods. He hoped accordingly that Dr. Shaw and his assistants would investigate possible connections between various seasons from the longer series of data at their disposal.

Dr. Shaw asked whether he could combine the effects of two seasons upon a crop so as to estimate their total effect. He saw no reason why the net and double correlation coefficients should not be formed between a crop and any two seasons, in exactly the same way as he had formed them for two other factors, viz., rainfall and temperature at one season. To find the joint effect of more than two seasons was much more complicated: correlation of three variables such as he had performed was comparatively simple, but with four variables the work, although similar in theory, became very complex, and with more than four the labour would be enormous, if not prohibitive.

Dr. Shaw also asked why abnormal seasons were not rejected. Simply because he was dealing solely with averages. He was not quite sure that the nature of the problem dealt with was clearly grasped. He (Mr. Hooker) was trying to obtain some idea of the *average* effect of deviations from the mean rainfall and temperature upon the crops. Dr. Shaw seemed inclined to think that a peculiar year like 1879 ought to be omitted. But it ought not, any more than Dr. Shaw should omit it in estimating, say, the average rainfall

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of 1870-1900. He wished he had the yields of 1879 in order that the effect of the weather of that year might be taken into account, and its relative influence on our crops in a long series of years estimated. When, however, he (Mr. Hooker) got to his little excursus at the end, he mentioned the abnormal years, because here he was no longer comparing crops with the weather affecting them, but the crops of different years *inter se*, and abnormal years would very seriously affect the average of so small a number as ten years. A crop 10 per cent. below the average, for instance, would lower the average of the decade by 1 per cent. The distribution of the crops during the period, in fact, and doubtless the weather also, was not normal; and sufficient time had not elapsed to nullify the effect of abnormal years on the average. It is, on the other hand, quite permissible to correlate variables of which the distribution is not normal.[2]

Dr. Shaw had seemed rather to reproach him for including Lincolnshire. It would no doubt have been easier to take simply one recognised agricultural district, but Lincolnshire was the most important county for certain crops, and he could hardly omit it without largely reducing the acreage of these. He was not, of course, suggesting that his district should be taken for any other purpose, or by anybody else.

On the question of the frequent alternation of a good and bad wheat crop, he still thought this was due partly to the summer weather having a different effect upon the bulk and condition of the seed. It must be remembered that the summer weather was not the primary factor in the wheat yield; other times were more important, hence a heavy crop, due, say, to a previous favourable seedtime, might sometimes give good seed, the summer, while favouring the quality, not being sufficiently detrimental to quantity as to overbalance previous development of the bulk. As regards a hot June being necessary for wheat, of course, other factors besides the weather affected the crop, but so far as regarded the differences from the averages, the figures clearly showed that, during the past twenty-one years, good crops had resulted when the temperature at that period was below the mean, not when the weather was hot.

Mr. Yule had asked whether growers specialised for seed: he believed that was largely done, more particularly by seed merchants. He had recently made some inquiries regarding the time of the harvest, and with regard to the dates mentioned for wheat on p. 12, one correspondent mentioned a much narrower period, viz., seed gathered in 19–25th August; crop harvested 9–12th August. In eastern England, therefore, the wheat intended for seed was left standing for ten days or a fortnight later than that intended for consumption. Attention to the same point was, he had no doubt, generally paid in the case of other crops.

The following were elected Fellows of the Society:—

Andersson, Thor Erik Engelbrekt. | Gemmill, William.
Simon, André L.

[2] See "Proceedings of the Royal Society," vol. 60, p. 477.

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