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WHEAT STUDIES

of the FOOD RESEARCH INSTITUTE

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INTERREGIONAL CORRELATIONS IN WHEAT YIELDS AND OUTPUTS

V. P. Timoshenko

Correlation analysis is here applied to numerous series of wheat yields and outputs, for the major wheat regions of the world and for some of their smaller subdivisions.

Variations in world wheat production, region by region, display less regularity and uniformity than is sometimes assumed or asserted. Variations in wheat yields in remote regions of the several continents are very little related among themselves. The correlation between yields is not close even in far-distant regions of the same continents, as, for instance, in the wheat regions of North America. Fairly close correlations among regional wheat yields and outputs exist only for relatively limited areas, the weather developments within which are controlled by similar meteorological factors.

Variations in wheat outputs in the wheat-exporting countries dispersed throughout the world are particularly diverse and practically independent. Such variations happen, however, to be more or less compensatory. This results in a considerable approach to stability of world wheat production, and in the total supply of wheat on the world wheat markets, as compared with production or supplies in individual exporting countries.

Still less correlation than in wheat-yield variations should be expected among variations in yields of different crops in regions remote one from another. Consequently, world crop production should be essentially stable, if the trend of growth is disregarded. Only a slight portion of the variability of total crop production should depend on factors common to most crops in most of the regions. Hence, it is probable that small variations in the total world crop production are less responsible for disturbances of the world's business than are great variations in crops in some of the leading countries that play an important role in world trade in agricultural products.

STANFORD UNIVERSITY, CALIFORNIA

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Announcement of

CHANGE IN RESEARCH AND PUBLICATION POLICY

Readers of *Wheat Studies:*

Twenty years ago *Wheat Studies* made its first appearance. With the July 1944 number this series is being terminated. Henceforth the results of our research on grains will be presented in new forms, and our research program itself will have a somewhat different emphasis.

During two decades of continuous publication, *Wheat Studies* came to enjoy a world-wide reputation for its authoritative contributions on wheat in the world economy. Years of concentrated research on this great cereal, here and elsewhere, have by no means exhausted the subject. Yet probably more is known about wheat today than about any other foodstuff of widespread importance.

In a sense, *Wheat Studies* was a pioneering venture. In recent years, official publications and others originating with private agencies in several parts of the world, while not seeming to fill its place, have gone far toward meeting deficiencies that were so apparent at the close of World War I. World War II is revealing other important tasks that lie ahead of the Food Research Institute.

The discontinuance of *Wheat Studies* will permit the Institute's limited staff to give fuller attention to commodities that have been less intensively investigated and to broader issues of national and international policy. While in part the accumulated experience of our staff will be used on other subjects, certain features of *Wheat Studies* will be carried forward in book and pamphlet forms.

In the next few years, our research in grain economics will put less emphasis on short-run analysis. We do not expect to publish studies resembling the "Survey" issues of *Wheat Studies* which have appeared three times a year since early in 1925. We do plan, however, to continue studies having a longer-range emphasis.

An annual review of world wheat developments, broadened to give more attention to other grains, will be combined with a world grain outlook for the current crop year and beyond it. This book will contain charts and statistical tables similar to those which have appeared in *Wheat Studies,* and due consideration will be given to matters of agricultural and food policy. The first volume of the new type, under some such title as *World Grain Review and Outlook, 1944–45,* is planned for publication late in 1944, at a price of $3.00.

(over)

Other studies with wheat as the common focus which in the past have covered a wide range of economic, statistical, historical, and geographic subjects will hereafter appear less frequently than formerly. These will ordinarily be published in our *Grain Economics Series,* our *Commodity Policy Studies,* and our *War-Peace Pamphlets.* Announcements will be mailed to those interested as such studies become available for distribution.

Many subscribers and former readers have now accumulated from a few to twenty complete volumes of *Wheat Studies,* which they value for their wealth of information on wheat. Each year we receive orders for early volumes needed to complete sets. Although the supply is limited and certain issues are no longer available, we shall fill orders for missing numbers or volumes in so far as we are able to do so.

For those who use *Wheat Studies* for reference purposes, we have in an advanced stage of preparation a small volume that should greatly facilitate this use. Under some such title as *Wheat in the World Economy: A Guide to Wheat Studies of the Food Research Institute,* this book will contain a brief digest of the contents of each issue (except "Surveys") and an index to the twenty volumes of *Wheat Studies.* It will be priced at $2.00. This volume should prove indispensable to those who work with *Wheat Studies* regularly, and a great convenience to those having complete or semi-complete sets used less frequently. It is designed also to introduce *Wheat Studies* to those who have not hitherto used them.

We trust that the changes indicated above will meet with the approval of present subscribers. Those wishing to apply prepaid subscriptions toward the *World Grain Review and Outlook,* the *Guide to Wheat Studies,* or both, may do so. **Unless otherwise instructed, we shall assume that present subscribers will wish to receive at least the annual review, and we shall credit present prepaid subscriptions accordingly. Appropriate refunds will be made on request if this arrangement is not satisfactory.**

Finally, we wish to express our appreciation of the confidence in the Food Research Institute shown by subscribers to *Wheat Studies* over a long period of years. Wheat will continue to have a prominent place in our research program. By giving more attention to other grains, other foods, and food policies, we expect to increase the interest and usefulness of our publications.

FOOD RESEARCH INSTITUTE
STANFORD UNIVERSITY

Stanford University, California
July 25, 1944

INTERREGIONAL CORRELATIONS IN WHEAT YIELDS AND OUTPUTS

V. P. Timoshenko

I. INTRODUCTION

This study of correlations among concomitant variations in regional yields and production of wheat grew out of the present writer's two previous studies on "Variability in Wheat Yields and Outputs."[1] In these earlier studies our problem was to analyze variations in wheat yields (or outputs) in individual regions without regard to their relationship to concomitant variations in other regions. In the first, our principal interest was in the order of fluctuations in time, and the question to be answered was: Are fluctuations in wheat yields and production periodic, cyclical, or random in character? In the second study, an attempt was made to present certain measures of the average variability in regional yields and outputs of wheat and to explain regional differences in the degree of variability, so far as possible in terms of climatic and other characteristics of the regions.

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In the latter study it was established, however, that the variability of yields and outputs in wider areas, such as large countries or continental areas, depends to a considerable extent on the degree and character of correlations among the fluctuations in yields in the smaller subdivisions of these areas. When fluctuations of yields in the separate portions of a larger area are positively related among themselves, that is, when they tend to fluctuate systematically in the same direction, the variability of the average yield per acre in the larger area will seldom be smaller than it is in the separate portions of that area. On the contrary, when fluctuations of yields in the smaller subdivisions of a large area are unrelated among themselves, or are negatively correlated, that is, when yields in these subdivisions tend to fluctuate systematically in the opposite direction, the average yield for the area as a whole (or its total output) will be stabilized to a considerable degree in comparison with the variability of yields (or outputs) in the smaller subdivisions. The existence of correlation among variations of yields and the character of this correlation (positive or negative) are, thus, important factors in explaining the variability in regional yields and outputs of wheat.

For instance, variations in wheat yields in the principal wheat regions of Australia are fairly closely and positively correlated among themselves. This explains why the total wheat production in Australia fluctuates relatively much more than that in the United States. This is true in spite of the fact that in some individual wheat regions of the United States the variability of wheat yields is as high as or even higher than it is in the principal wheat regions of Australia. Lack of positive correlation among the variations in wheat yields of some of the major wheat regions of the United States, and significant negative correlation between wheat yields of some other regions, are responsible for this fact.

Similarly, the lack of correlation among variations in wheat yields and outputs of the principal wheat-exporting countries, dispersed over all the continents of the world, results in relative stability of the total wheat production of all the principal wheat-exporting countries. The total production of these

[1] "Part I. Cycles or Random Fluctuations," WHEAT STUDIES, April 1942, XVIII, 291–338, and "Part II. Regional Aspects of Variability," *ibid.*, March 1943, XIX, 151–202.

countries is not less stable than the total production of all the principal wheat-importing countries of Europe. This is true in spite of the fact that the variability of wheat yields and outputs in most of the wheat-exporting countries is much larger than in individual wheat-importing countries of Europe. In the European wheat-importing countries, variations of wheat yields and outputs are small, but they are fairly closely and positively related among themselves.[2]

It appears, thus, that a study of interregional correlations in wheat yields and outputs is of importance for a full understanding of many problems of the variability in wheat yields and outputs, if the study of variability is not limited to strictly local problems of small areas. But knowledge of the existence of correlations between the fluctuations of wheat yields and outputs of certain producing areas, as well as knowledge of the character and closeness of these correlations, is of importance for many other problems of market analysis. Knowledge of the fact that wheat yields in the two North American wheat regions producing the best milling wheat—the Prairie Provinces of Canada and the United States Spring wheat belt—correlate positively and fairly closely (p. 225) is of considerable importance for the milling industry. Similarly it is important to know that the yield of hard winter wheat tends to fluctuate in the opposite direction from that of spring wheat in the Prairie Provinces, for this introduces a certain degree of stability in the total supply of the best milling wheats on the North American continent.

It may also be of some interest to know, for instance, that wheat production in French North Africa—a secondary wheat-exporting area—tends to fluctuate in the same direction as wheat production in France and Italy, the principal markets for North African wheat surpluses (see p. 242). This must contribute to the systematically repeated flooding and instability of those markets. On the contrary, wheat yields in Australia tend to fluctuate in the opposite direction from wheat yields in Northwestern Europe, including the British Isles, the principal market for Australian wheat (p. 222). Certainly this contributes to a certain stability of the market for Australian wheat.[3]

A thorough knowledge of interregional correlations in wheat yields in this country is of importance also for perfecting the actuarial basis for wheat-yield insurance, which is now under discussion for a second time. This knowledge must be more detailed, however, than that which is presented in one of the following sections of this study.

For these and many other problems, knowledge of correlations among the concomitant variations in yields and outputs of wheat of the principal wheat-producing regions of the world may be very useful. Our previous analysis of the variability in wheat yields and outputs has demonstrated that the properties of series on yield, and to a certain extent also of those on total production, are such that the standard correlation technique may be appropriately used in their analysis. Indeed, it was demonstrated in Part I of our study on variability in wheat yields and outputs that fluctuations in yields in the major wheat-producing areas of the world do not diverge significantly from fluctuations of random series. It is less clear that series on total production may be regarded as fully random series, since one of the components of production series—acreage—does not change from year to year at random, but tends to fluctuate in a cyclical manner. However, the variations of wheat-production series are dominated to such an extent by variations in yields that for practical purposes variations in production series also may be regarded as random variations, especially when the trend element in the series is eliminated in one way or another, and when variations about the trend are studied.[4]

Moreover, in Part II of the same study, it

[2] *Wheat Studies*, March 1943, XIX, 189. See also pp. 172–78.

[3] Although the negative correlation between wheat yields in Australia and in the British Isles is statistically significant, it is relatively small (see p. 222). It can hardly be relied upon before its existence is reasonably explained in terms of intercontinental weather correlations. At the present stage of knowledge of meteorological factors, it would be difficult to do this.

[4] For the random character of series on wheat yields and output, see WHEAT STUDIES, April 1942, XVIII, 305–07, 309–10.

was established also that the character of distributions of deviations of annual yields from the "normal" or average yield, grouped according to the size of these deviations, does not differ significantly from a so-called normal distribution.[5]

Hence, it is appropriate to apply the test of significance to the various measures of correlation between concomitant variations in yields and outputs established by correlation analysis. And these measures, when significant, may be regarded not only as measures of correlations existing in the past, but, under certain conditions, may be relied upon also for an appraisal of expectations in the future.

The following sections present results of the correlation analysis applied to numerous regional series on wheat yields and outputs for the major wheat regions of the world and for some of the smaller subdivisions of those regions. The regions and regional series used in this analysis are, unless specified otherwise, the same as those used in the earlier study on variability in wheat yields and outputs.[6]

In our correlation analysis we do not use original data for annual yields per acre (or total output) in the regions under consideration, but rather their deviations from the "normal" or average yield (or output) represented by the trends. The trends used in this study for both yield and output series are flexible curves represented by weighted moving averages of 9 years' duration.[7] Consequently, the correlation coefficients given in the following sections as measures of the closeness of the relationship between concomitant variations in yields and outputs measure the closeness of the relationship between short-term variations in yields (or outputs) about the trends, but not the relationship between the trends themselves. It is important to bear this in mind, particularly because of the type of trends chosen in this study. In many cases, they do not represent continuous growth or continuous decline in our regional series on yield (or output), but also show, in addition to some smaller irregular fluctuations, wave-like fluctuations of more or less long duration.[8]

The coefficients of correlation supplied in the following sections do not measure the relationship between these wave-like fluctuations. Hence, in many cases, when we conclude that there is no significant correlation between the concomitant variation in yields (or outputs) in the regions under consideration, because the coefficients of correlation are not sufficiently large, we mean only that there is no significant correlation between concomitant short-term variations about the trend. We do not mean, however, that no correlation exists between the trends (positive when both are rising or both declining, or negative when one rises and another declines) or between the long-term wave-like fluctuations of trends.

It is necessary to emphasize this, because the test for randomness of fluctuations in yields and outputs applied in Part I of the study on variability is not particularly sensitive to smooth cyclical fluctuations of long duration. Consequently, this does not exclude the possibility that cyclical fluctuations of this type may be present in the series on wheat yields and outputs used in our analysis, and that these fluctuations may be systematically related between some of the regions under consideration. However, the coefficients of correlation given in the following sections show nothing about these possible relationships, since they measure the closeness of the relationship only between short-term variations about the normal or average represented by the respective trends.

In our search for correlations among the concomitant variations in wheat yields and outputs, we centered our attention on the discovery of correlations among variations in regions relatively distant one from another. It was natural to begin with search for this type of correlations, since it is well known that fairly close positive correlations usually

[5] *Ibid.*, March 1943, XIX, 187–88.

[6] For definitions of regions and sources of statistics, see Appendix Note to Part I of the study on variability in wheat yields and outputs, *ibid.*, April 1942, XVIII, 331–33, and Appendix Tables to Part II, *ibid.*, March 1943, XIX, 197–200.

[7] They were obtained by taking 3-point averages of 7-point averages. The final averages gave weights of 1, 2, 3, 3, 3, 3, 3, 2, 1.

[8] For a sample of types of trends, see Charts 1 and 4 in WHEAT STUDIES, April 1942, XVIII, 299, 308.

exist among yields of neighboring localities. For this reason, more attention is given to correlations among yields averaged for major wheat regions than among yields in smaller subdivisions of these major regions.

It was particularly intriguing to answer the question: Are there significant correlations between the variations in yields averaged for large areas on different continents? Practically no important correlations of this kind were established by our analysis. The relationship between the variations in yields in far-distant areas located on different continents is characterized far more by diversity and randomness than by similarity and regularity. As will be shown, close correlations between the variations in yields are relatively rare even for distantly located areas on the same continents.

This result was to be expected in the light of our previous conclusions (obtained from the study of variability in individual regions) that variations in wheat yields do not differ significantly from random variations. If variations in regional yields are of a random character, the only possibility that correlations could exist between such variations for wide areas is that factors, which themselves vary at random, should affect yields in these wide areas in a uniform manner. Presumably these factors are mainly of a meteorological character, since meteorological phenomena are responsible for the greater part of the short-term variability in yields. But it is not very probable that meteorological factors should exert such a uniform influence over wide areas located on distant continents. At least, very few meteorological correlations of this type have been established as yet, and those that have been established are not close enough to produce significant correlations among variations in yields.

Generally speaking, at the present stage of knowledge of correlations among meteorological phenomena observed in far-distant areas and of the relationship between variations in local meteorological phenomena and in yields, it is not possible to give a full explanation of the interregional correlations in wheat yields established by our statistical analysis. Without question, the usefulness and reliability of correlations established in this study depend very much on whether they can be reasonably explained in terms of meteorological and other factors characteristic of respective regions. Statistically established correlations, although formally "significant," may be doubted so long as they are not explained on the basis of reasonable hypotheses. With full knowledge of this, we are obliged in most cases to leave such explanations out of our consideration. Hence, the results obtained in this research must be regarded as preliminary. The full understanding of many correlations established in this study would require much additional work by specialists competent in problems of meteorology and plant physiology. But it appears desirable to reveal these preliminary results, since they may be useful in analysis of other problems, mostly economic in character. Furthermore, these preliminary results may stimulate further research directed toward a better understanding of the correlations obtained.

II. INTERCONTINENTAL CORRELATIONS IN WHEAT YIELDS

As already noted, very little correlation is found among variations in wheat yields in far-distant areas located on different continents.[1] This conclusion is further substantiated (1) by comparison of variations in the average annual wheat yields computed for entire continental areas,[2] and (2) by compari-

[1] The relationship between variations in yields in French North Africa and in the near-by areas of the European coast on the Mediterranean Sea—Spain, southern France, and Italy—are not regarded here as intercontinental. As a matter of fact, French North Africa is considered in this study as a portion of the European area, comprising, together with the Iberian Peninsula, the Western Mediterranean wheat region.

[2] It must be remembered here that only three continents are represented fairly well by the statistics of wheat production used in this analysis—Europe, North America, and Australia. Statistics on wheat production for the relatively long periods, so necessary for study of variability in yields, are lacking for the wheat-producing regions of other continents, and this precluded a fairly complete representation. The only African wheat area included in this study—French North Africa—is treated as a portion of the European

sons of variations of wheat yields in specific regions of one continent with those in specific regions of another. Each method has its advantages and disadvantages.

One objection to the first method is that average wheat yields per acre for such wide wheat areas as North America and Europe ex-Russia are quite abstract values which are not representative of actual yields in any part of these wide wheat areas. However, variations of these average continental yields represent by far the largest component of the year-to-year variation in continental wheat outputs.[3] It is of interest, therefore, to know whether the variations in average yields for various continents are independent of each other, or, if they are related among themselves, what the extent of that relationship is.

From a comparison of the variability of the average "world" wheat yield with the variability of the average wheat yields for the continental areas, it was possible to conclude that variations in yields for different continents should be independent of each other, or, if there were significant correlations among them, some of these correlations should be positive and others negative.[4] Table 1 confirms the first of these alternatives, although it indicates also certain tendencies in the direction of the second alternative. These tendencies are, however, not strong enough to produce significant results. This table summarizes comparisons of variations in wheat yields, averaged for the continental areas by pairs of these areas.

The fourth figure in each "box" of the intersecting columns and rows is a coefficient of correlation (r) measuring the closeness of the relationship between the variation in yields in two areas, indicated by the designations of the respective columns and rows. The plus or minus sign preceding this figure indicates whether the relationship between variations in yields of the respective areas is direct or inverse.

TABLE 1.—INTERCONTINENTAL CORRELATIONS OF WHEAT YIELDS (DEVIATIONS FROM TRENDS)†

Region	Relationship[a]	North America 1889–1935	Europe ex-USSR 1889–1933	India 1889–1935	Australia 1864–1935
Europe ex-USSR 1889–1933	+	17			
	—	25			
	0	3			
	r	—.12			
India 1889–1935	+	22	21		
	—	23	22		
	0	2	2		
	r	..[b]	..[b]		
Australia 1864–1935	+	27	22	28	
	—	19	21	18	
	0	1	2	1	
	r	+.09	..[b]	+.29	
South America 1889–1935	+	18	28	28	22
	—	26	13	16	23
	0	3	4	3	2
	r	—.01	+.05	+.17	..[b]

† For definition of regions and sources of statistics, see footnote to Appendix Table I, WHEAT STUDIES, March 1943, XIX, 197. The periods for which correlation coefficients have been computed are indicated by the designations of the respective columns and rows. The shorter period of the two indicated by the respective designations determines the duration of the series used in computation.

[a] See accompanying text for explanation of relationships.

[b] Correlation coefficients were not computed, since the numbers of like signs sufficiently indicate that the correlation is not significant. See footnote 5, p. 218.

The three figures above the coefficient of correlation give another measure of the relationship between the variations in yields in the two areas. The first figure in each group, marked by a plus sign in the first column, indicates the number of years during the period under comparison in which the yields in both areas deviated in the same direction from the "normal" or average yield; that is how many times the yield was above the average in both areas or below it in both areas. The figure immediately below, in the rows designated by a minus sign, indicates the number of years that yields in the two areas deviated in opposite directions, being above

area, while Asia is represented by British India alone and South America by Argentina and Uruguay only. The principal wheat regions of European Russia are not included here in the European total, but their relationship to other wheat regions of Europe is discussed later.

[3] In all cases, the wheat yields per acre used in this study were obtained from total production for the respective regions divided by the total acreage. Thus, yields computed for the continental areas may be regarded as weighted averages of yields computed for the regions composing the respective continental areas, the regional acreages being used as weights.

[4] WHEAT STUDIES, March 1943, XIX, 178.

average in one and below it in the other. Finally, the third figure, immediately above the coefficient of correlation in the rows marked at the left with a zero sign, indicates the number of years in which annual yields did not deviate at all from the average in one or in both areas.

If the number of years in which yields in both areas deviated from the average in the same direction is substantially larger than a half of the total number of years in the period under consideration, this points to a positive or direct correlation between variations in yields in respective areas. A substantial preponderance of the number of years when annual yields in the two areas deviated in opposite directions from the average, being above the average in one and below it in the other, points to the existence of a negative or indirect correlation between the variations in yields in the two areas. On the contrary, when the number of years in these two groups are nearly equal, this may be regarded as an indication that variations in yields in the two areas are not related at all. Years in which the annual yield in one or in both of the two areas coincided with the average yield, the number of which is usually small, as the table indicates, may be regarded as neutral, not indicating either positive or negative correlation.

From an analysis of the table, it appears that in only four out of the ten possible paired combinations of 5 continental areas did the number of years with a plus sign nearly equal the number of years with a minus sign. This indicates that variations in yield in the respective areas are not related at all. In the other six cases, the difference between these numbers is substantial, thus pointing to a possible positive or negative correlation between the variations in yields in respective areas. However, in no one case is the number of years with like signs large enough to indicate a significant correlation among yields of respective areas.[5] The same is indicated by the six coefficients of correlation given in Table 1, none of which is significant. Although the numbers of years in which the wheat yield in North America deviated from the average in an inverse direction from that in Europe and from that in South America are substantially larger than the numbers of years when the deviations were in the same direction (25 against 17 in the first case and 26 against 18 in the second), these differences are not large enough to indicate significant negative correlations. The smallness of the coefficients of correlation in both cases (−.12 in one and −.01 in the other) also indicates that this tendency to inverse relationship is not systematic enough to be significant. The inverse variations in yields in such a number of cases of the total number of years under study could occur when fluctuations of yield in the two areas are random and independent.

[5] W. G. Cochran, in "The Efficiencies of the Binomial Series Tests of Significance of a Mean and of a Correlation Coefficient," *Journal of the Royal Statistical Society*, Vol. 100, Pt. I, 1937, pp. 69–73, supplies a tabulation showing the minimum number of like signs, out of a total number of pairs of observations from 6 to 50, required to indicate a significant correlation (at 5 per cent level of significance). According to this information, in the case of 45 pairs of observations, as in Table 1 for comparisons of Europe with other continents (1889–1933), the minimum number of like signs indicating significant correlation should be 30. In the case of 47 pairs of observations, as in the table for comparisons among other continents (1889–1935), the minimum number should be 31. In none of the ten intersections of Table 1 is the number of like signs large enough to indicate significant correlation, the largest being 28.

For cases in which the number of observed pairs (n) exceeds 50, Cochran gives the following formula for the determination of the minimum number of like signs indicating a significant correlation. This number is the smallest integer equal to or greater than the value computed from the expression $\frac{n}{2} + \sqrt{n}$. For instance, when $n = 64$, the number of like signs required to indicate a significant correlation is 40. Cochran adds, however, that the efficiency of the binomial series test of significance is relatively low; and, *consequently*, that the test must be used with caution in setting aside data on the grounds that there is no apparent correlation.

For this reason, in Table 1 as in several of the following tables, coefficients of correlation (more efficient indicators of the existence of correlation) were computed also for those cases in which the number of like signs, although smaller than the minimum required to indicate a significant correlation, is nevertheless considerably larger than the number of opposite signs. Such coefficients of correlation were computed thus in Table 1 for those six combinations of continental areas in which the number of like signs was equal to or exceeded 25. However, all these coefficients are too small to be significant. There was no reason to expect significant correlations in the other four cases, since the number of plus signs was nearly equal to the number of minus signs, and coefficients of correlation were not computed in these cases.

Likewise, the preponderance of the number of years with deviations of wheat yields in the same direction in South America compared with Europe (28 against 13) and with India (28 against 16), and in Australia compared with North America (27 against 19) and with India (28 against 18), is not strong enough to indicate significant positive correlation between fluctuations in yields in these areas. All four coefficients of correlation computed for these relationships, although positive, are too small to be significant. Only one of them, that between the wheat yields in Australia and in India, equal to +.286, closely approaches a significant level (+.2875).

It is of interest to notice, however, that the wheat crops in Australia and India, which tend to fluctuate in the same direction as far as yields per acre are concerned, are not harvested at the same time. Although they fall in the same calendar year, the Australian crop lags behind the Indian crop by about nine months. The latter, a winter crop, is harvested during February–April, depending on the location of the wheat region. The Australian crop is usually sown after most of the Indian crop has been harvested and is harvested mainly in November–December.

The principal factor in the variation of wheat yield in the most important wheat area of India (Punjab) is the October–December and January rainfall.[6] Similarly, a dominant factor for wheat crops in several Australian wheat regions is the August–September rainfall,[7] which comes some nine months later than the Indian rainfall of the preceding winter that is so important for wheat. The April–June rainfall is also important for Australian wheat, and this lags some six months after the Indian October–December rain.

Consequently, if the tendency for the Australian and Indian wheat crops to fluctuate in the same direction is a real and significant one, this correlation should find its explanation not in the correlation of concomitant weather elements in both areas but in the lag of Australian weather after Indian weather by 6–9 months. The persistence of weather characteristics from one quarter to the next was found to be strong in the area of the South Pacific and Indian Oceans, and Sir Gilbert Walker has established for this area significant relationships between quarterly averages for various weather elements such as barometric pressure, temperature, and rainfall.[8] Consequently the possibility is not excluded that a significant correlation may exist between the fluctuations of weather in Australia and in India with a lag of 6–9 months.

Furthermore, the practice of summer fallowing, which is used to accumulate soil moisture from precipitation during the preceding year, has become increasingly important in Australia. Consequently, the Australian wheat crop may be directly influenced by precipitation concomitant with the rainfall during the preceding October–November in India. However, without specific analysis substantiating this possible but highly complex relationship, we are inclined to think that the tendency of wheat crops in India and Australia to vary in the same direction may result from a chance coincidence of independent random fluctuations in wheat yields in these two areas.

There is still much less reason to expect a systematic direct relationship between the fluctuations in wheat yields in South America and those in India or in Europe ex-Russia. The same is true of wheat yields in North America and in Australia. Likewise, the observed tendency of wheat yields in North America to fluctuate in the opposite direction from those in Europe and in South America may be regarded as purely accidental.

The first method of analysis indicates, thus, that it is hardly possible to expect a systematic real relationship, direct or inverse, among the variations of average wheat yields computed for the continental areas. However, it would be premature to conclude that, because significant correlations among the variations of yields for these larger areas are lacking, significant correlations between variations in wheat yields in some specific regions of different continents also do not exist. An averaging of yields for wide continental areas may conceal these related variations in yield of limited regions of the respective continents.

[6] *Foreign Crops and Markets*, Mar. 14, 1927, p. 360.
[7] WHEAT STUDIES, March 1943, XIX, 169–70.
[8] *Ibid.*, April 1942, XVIII, 296.

It would be prohibitive, however, to undertake analysis of the relationship between variations in wheat yields in numerous wheat regions of one continent and in similar regions of all other continents. We made no attempt to do this also because, in the light of known facts about the relationship among various weather elements in far-distant areas, it is improbable that it would yield many significant correlations of this kind. Hence, we analyzed only a few of the relationships between regional yields in different continents, where there were some reasons to expect that significant correlations existed, or where we are interested for some other reasons.[9]

Thus, variations in wheat yields in the United States as a whole, and in some of its major wheat regions, were compared with variations in wheat yields in some of the European wheat regions. None of these comparisons revealed relationships between variations in wheat yields in the respective regions sufficiently systematic to indicate a significant correlation.

The wheat yield in the United States as a whole tended to fluctuate in the opposite direction from that in Italy, but this tendency was not strong enough to indicate a significant negative correlation, as is evident from the small negative coefficient of correlation (−.13) for the period 1889–1935. Still less correlation existed between variations in wheat yields in the United States and France: the coefficient of correlation for the period 1870–1935 was −.05.

For comparison of the regional wheat yields in the United States with those in western Europe, four United States regions were selected: two in the humid eastern part of the continent (the Eastern United States and the United States Soft Winter region) and two in the subhumid and semi-arid west (the United States Hard Winter and the United States Spring wheat regions). Wheat yields in the first two regions were compared with those in the British Isles and the Low Countries, and yields in the second two with yields in the British Isles, the Low Countries, and Scandinavia, called in our classification Northwestern Europe. All four comparisons were for the period 1879–1935.

Variations in yields in the Soft Winter and Hard Winter regions did not indicate any systematic relationship with variations of yields in the respective European regions: the number of years when yields in both of the regions compared departed in the same direction from respective trends was nearly equal to the number of years when they departed in opposite directions. More systematic tendencies appear in the case of the other two regions. Wheat yields in the Eastern United States fluctuated more frequently in the opposite direction from those in the British Isles and the Low Countries than they did in the same direction. This indicates an inverse relationship between yields in the two regions. However, the number of minus signs (30 out of 57) was substantially below the required minimum (36) to indicate a significant correlation.[10] Hence, we are inclined to question the significance of the coefficient of correlation between the variations in wheat yields in these two regions (it is −.33 for the period 1879–1935), although formally it is significant (at 5 per cent significance level). Moreover, a detailed analysis of this correlation reveals that nearly 30 per cent of the value of the correlation coefficient depends on the relationship between yields in one year (1931), when the record high wheat yield in the Eastern United States coincided with a relatively poor crop in the British Isles and the Low Countries. When this year is omitted from the comparison, the correlation coefficient becomes nonsignificant. The relationship, thus, is not systematic enough to be regarded as significant, and it should be considered rather as a chance coincidence. A correlation coefficient significant at 5 per cent significance level in one case out of twenty may result from such a chance coincidence.

Wheat yields in the United States Spring wheat region, on the other hand, tended to vary in the same direction as wheat yields in

[9] In some cases the interregional correlations in yields could be expected because significant correlations between regional wheat outputs were formally established, as shown in a later section. Correlations between outputs could be caused, however, by similarity in the variation of acreage and not of yields, as actually occurred in several cases.

[10] See footnote 5, p. 218.

Northwestern Europe. In 32 years out of 57, they moved in the same direction. But again the number of plus signs (32 out of 57) is not sufficiently large to indicate a significant direct correlation. The coefficient of correlation between the variation of wheat yields in these regions (+.18 for the period 1879–1935) is also too small to be significant. Thus it appears that variations of wheat yields in the United States are not systematically related to those in western Europe.

Similar comparisons of the variation of wheat yields in Canada, as a whole, with that in some European regions also failed to show significant correlations. Practically no relationship existed between the variations of wheat yields in Canada and in the British Isles. A tendency toward a direct relationship between variations in the Canadian and German wheat yields did exist, but it also was not systematic enough to be significant (the coefficient of correlation for the period 1889–1935 is +.08).[11]

Fluctuations in the Argentine wheat yield were compared with similar variations in yields in other wheat-exporting countries on other continents, as well as with those in several wheat-importing countries of Europe. Once more no significant correlation was established by these comparisons, in spite of the fact that significant positive correlations (5 per cent level of significance) were found between the variation of the output of wheat in Argentina and those in Canada and in Germany (pp. 253, 256). In this respect the most striking contrast between the relationship of variations in yields and in outputs was found for Argentina and Canada. Variations in wheat yields in these two countries were related very little, and showed a slight tendency to fluctuate in opposite directions, while there was found a significant positive correlation between the fluctuations in their wheat outputs (the coefficient of correlation for the period 1889–1935 is +.36). Further analysis indicated, however, that this formally significant coefficient of correlation was due mainly to strong concomitant variations in wheat outputs in these countries in four years—1923, 1924, 1928, and 1929. If these four years are omitted, the correlation coefficient would be zero. Under such circumstances, the significance of the correlation among variations in wheat outputs in these two countries may also be doubted.

A similar, though less striking, discrepancy appeared between the relationships of variations in yields and outputs for Argentina and the United States. Here too there was a tendency for yields in the two countries to fluctuate in opposite directions (the coefficient of correlation for the period 1889–1935 is −.06), while a small positive coefficient of correlation was found for the variations in wheat outputs in the two countries (the coefficient of correlation for the period 1889–1935 is +.08). However, both of these correlations are nonsignificant.

Better agreement between variations in wheat yields and outputs appeared when these variations for Argentina and Germany were compared. Both yields and outputs tended to fluctuate in the same direction in these two countries. The coefficients of correlation for both relationships were positive. The difference was that the coefficient of correlation between the variation of yields (+.16 for the period 1889–1935) was not significant, while that between fluctuations in outputs (+.29 for the period 1889–1935) was. A similar relationship was observed in the variations in wheat yields and outputs in Argentina and in France, with the difference, however, that both correlations were not significant. It may be added that, although wheat yields in Argentina and in India tend to fluctuate in the same direction, significant correlation between them was not established (the coefficient of correlation for the period 1889–1935 is +.15).

The last comparison of variations in wheat yields in far-distant areas given here is for the antipodean areas—the British Isles and Australia. The result of this comparison was rather surprising: wheat yields in these two areas appeared to fluctuate fairly systemati-

[11] A small but significant coefficient of correlation (5 per cent significance level) was established for variations in wheat outputs in Canada and in Germany (p. 256), but it also may be doubted since the application of the test of significance to the series on total production is less defensible than it is to the series on yield. The random character of the former is subject to more question (p. 252).

cally in opposite directions. The negative correlation between yields, although not close, appeared to be significant. The coefficient of correlation for the period 1864–1935 is −.24. Due to the long duration of the period covered, it is significant at the 5 per cent significance level. The relationship between total outputs of wheat in these two areas appeared similar, although less systematic than that between yields, and consequently not significant;[12] the coefficient of correlation for the same period is −.17.

The systematic inverse relationship between variations in wheat yields and outputs for such far-distant areas suggested some further analyses. Consequently, variations in wheat yields in the British Isles were compared with those in the principal wheat regions of Australia. The results are summarized in the following tabulation. It appears that the inverse

Relationship	New South Wales	Victoria	South Australia	Western Australia	Australia
+	25	33	32	26	29
−	42	33	35	40	39
0	5	6	5	6	4
r	−.23	..[a]	..[a]	−.44	−.24

[a] Coefficient of correlation not computed.

relationship between variations in wheat yields in the British Isles and in Australia is based on a similar relationship between yield variations in the British Isles and in two of the four wheat regions of Australia—New South Wales and Western Australia. Variations in yields in two other regions—Victoria and South Australia—appear to be little related to those in the British Isles.

Such results make the significance of the coefficient of correlation between yields in the British Isles and in Australia as a whole questionable; at least it is difficult to explain why wheat yields in these two groups of Australian wheat regions should relate differently to those in the British Isles. The difficulty in explaining the systematic inverse variation in wheat yields in the British Isles and in Australia is enhanced by the fact that the wheat harvest in Australia lags some three months behind the British. Consequently, the correlation in wheat yields may seem to imply a certain correlation between weather elements in Australia that lag behind those in the British Isles. However, if a positive correlation exists between concomitant rainfall in the two areas, this could supply some explanation of the inverse correlation between yields. Indeed, Australian wheat yields correlate directly with the amount of precipitation during most of the growing period, mainly during April–September and especially August–September. An abundance of precipitation during the preceding months, accumulated in the soil by the widespread practice of summer fallowing, should also be regarded as a factor increasing wheat yields in Australia. On the contrary, an excess of rain above the average in the British Isles is generally harmful for yields. Heavy rains during the autumn and winter are particularly disastrous for wheat yields in Great Britain, but the summer rains of June–August also have damaging effects.[13] Concomitant heavy rainfall in Australia and in Great Britain would thus affect wheat yields in Australia favorably and those in Great Britain unfavorably. The relationship is much more complex, however; and the existence of a positive correlation between rainfall in Australia and the British Isles has not been established as yet.

Consequently, before some reasonable explanation of the inverse variation in Australian and British wheat yields is given, we are inclined to believe that this tendency to a negative correlation may be explained by chance. Indeed, in one case out of twenty, a correlation coefficient of such magnitude could be obtained for two random series that vary independently.

[12] Variations in wheat outputs in Australia and Northwestern Europe (including the British Isles, Low Countries, and Scandinavia) showed somewhat better inverse correlation, which appeared to be significant for a shorter period, 1879–1935. In 37 out of 57 years, wheat outputs deviated from the trend in opposite directions in the two areas, and the coefficient of correlation for the same period was −.29 (p. 256).

[13] For analysis of factors affecting wheat yields in Great Britain, see John Percival, *Wheat in Great Britain* (London, 1934), p. 22; R. A. Fisher, "The Influence of Rainfall on the Yield of Wheat at Rothamsted," *Philosophical Transactions of the Royal Society of London*, Series B, Vol. 213, April 1925, pp. 89–142; W. N. Shaw, "The Law of Sequence in Yield of Wheat for Eastern England, 1885–1905," *Journal of Agricultural Science*, 1907–08, II, 17–28.

It appears, thus, that both of our approaches to the problem of the existence of intercontinental correlations in wheat yields fail to supply sufficient evidence for an affirmative conclusion. It is safer to conclude that variations in wheat yields in far-distant areas of different continents are independent. However, this negative conclusion should not discourage those who believe in interdependence among the elements of the world weather. The relationship between yields and weather elements is so complex, and it may be so different under conditions of different climates, that absence of intercontinental correlations in yields does not yet mean that there is no significant intercontinental correlation in weather elements. Several such correlations have already been established, and further studies in this direction may contribute to an explanation of those slight tendencies to intercontinental correlations in yields that were mentioned above. Furthermore, the correlations analyzed here are correlations among short-term variations in regional wheat yields, and indicate nothing about the possible relationship among variations of longer range. It is clear, however, that intercontinental correlations in yields cannot be close, even if it should eventually be established that some of them are real and attributable to a real relationship among variations in the weather elements of far-distant areas.

More numerous and much closer correlations among regional wheat yields were established, however, for regions of the same continents, even for noncontiguous and sometimes remote regions. These correlations for continents in which wheat cultivation is spread over wide areas are discussed in following sections.

III. CORRELATIONS AMONG REGIONAL WHEAT YIELDS IN NORTH AMERICA

Our principal interest in interregional correlations of wheat yields within continents, as also in correlations of yields between the various continents, lies in a search for correlations between variations in yields in relatively remote areas. Fairly close, direct correlations are normally expected to exist between yields of relatively small neighboring regions. In our search for such correlations in North America, it was decided, therefore, to compare variations of yields for all possible combinations of the major wheat regions, taken two at a time.

Of course, a more detailed picture would be obtained if such comparison were applied to a larger number of smaller subdivisions of the major wheat regions. However, seventeen such subregions were used for the North American continent in our study of the variability in wheat yields; and, if these subregions were used in our correlation analysis, it would be necessary to study 136 relationships among yields in these smaller subregions. This would require considerable work. The use of the less detailed but also less laborious procedure is justified by the fact that the major wheat regions used in this study were defined in such a way that each region is fairly homogeneous with regard to climate and type of wheat grown. The fact that a fairly close, direct relationship was established among variations in yields in the smaller subdivisions within practically all major wheat regions (see p. 238) indicates that the major wheat regions are sufficiently homogeneous.[1] Furthermore, the knowledge that correlations exist among variations in the wheat yields in such well-known regions as the United States Hard Winter wheat region, the United States Spring wheat region, the Pacific Northwest, and the Canadian Prairie Provinces has greater interest from the point of view of market analysis than the knowledge that correlations exist among smaller portions of these regions.

For these reasons, we limited our analysis of the relationships between yields in the smaller wheat subregions to a study of correlations among those within each major region. Only when correlations between variations in yields of some major wheat region presented special interest, or required special explanation, were the more detailed relationships be-

[1] As there was a lack of homogeneity between the Pacific Northwest and the Pacific Southwest within the Pacific region, these two subdivisions were treated as separate regions in the correlation analysis.

tween yields in a smaller subdivision of that region and yields in a smaller subdivision of another major region analyzed further. These more detailed relationships are discussed at a later stage.

General Discussion

Table 2 summarizes comparisons of variations in wheat yields for the seven major

Table 2.—Correlations between Wheat Yields (Deviations from Trends) in Specified Wheat Regions of North America†

Region	Relationship[a]	Pr. Prov. Canada[e] 1889-1935	U.S. Spring wheat[e] 1870-1935	Eastern U.S.[h] 1870-1935	U.S. Soft Winter[e] 1870-1935	U.S. Hard Winter[e] 1870-1935	Pacific Northwest[h] 1873-1935
U.S. Spring wheat[e] 1870–1935	+	33					
	—	13					
	0	1					
	r	+.54**					
Eastern U.S.[h] 1870–1935	+	19	26				
	—	24	37				
	0	4	3				
	r	..[b]	—.27*				
U.S. Soft Winter[e] 1870–1935	+	23	36	44			
	—	22	29	18			
	0	2	1	4			
	r	..[b]	+.02	+.55**			
U.S. Hard Winter[e] 1870–1935	+	17	36	36	41		
	—	27	28	26	22		
	0	3	2	4	3		
	r	—.26	+.12	+.41**	+.27*		
Pacific Northwest[h] 1873–1935	+	30	36	29	32	29	
	—	16	27	31	30	32	
	0	1	0	3	1	2	
	r	+.47**	+.07	..[b]	..[b]	..[b]	
Pacific Southwest[h] 1870–1935	+	33	32	32	36	29	33
	—	12	33	30	28	34	29
	0	2	1	4	2	3	1
	r	+.40**	..[b]	..[b]	—.05	..[b]	+.16

† See source footnote to Table 1, p. 217.
[a] See pp. 217–18 for explanation of relationships.
[b] It is assumed that the coefficients of correlation for the respective regions are insignificant.
[e] Wheat yields are computed on sown-acreage basis.
[h] Wheat yields computed on harvested-acreage basis.
* See accompanying text and footnote 3.
** See accompanying text and footnote 3.

wheat regions of North America.[2] It presents 21 interregional relationships, corresponding to the number of possible paired combinations of seven regions. Four figures in each intersection of the columns and rows characterize the relationship between variations in yields in the two regions indicated by the designations of the respective columns and rows. In general, the meaning of the figures is the same as in Table 1 (p. 217). One difference, however, must be mentioned. While no significant correlation was found to exist between variations in wheat yields averaged for continental areas, several significant correlations were established between regional wheat yields in North America. Such significant correlations not only characterize the relationships between regional wheat yields in the past, but, under certain conditions, may point to the expectation of similar relationships in the future. All significant correlation coefficients are indicated in Table 2 by asterisks at the right side of the respective correlation coefficient.[3]

It appears from Table 2 that in 7 cases out the 21 possible paired combinations of seven

[2] For the boundaries of the wheat regions in North America, see Chart 1, p. 229.

[3] One asterisk indicates significant correlations at 5 per cent significance level, and two asterisks indicate those at 1 per cent significance level. These last correlation coefficients, we shall call, according to usual custom, highly significant, since there is only one chance out of a hundred that coefficients of such magnitude could be obtained for independent random variations of two variables (deviations of yields from respective trends in two regions in this case).

From Table 2 it appears that only four significant correlations among variations in regional wheat yields are indicated by the number of like signs; and all these correlations are positive, since they all indicate the minimum required number of plus signs. There were established, on the other hand, seven significant correlation coefficients, five of which are highly significant, according to the test of significance on the basis of R. A. Fisher, *Statistical Methods for Research Workers* (4th ed., Edinburgh, 1932), Table V. *A*, p. 188. It was natural to expect this, as the efficiency of Cochran's test of significance applied in the first preliminary method of establishing correlations is smaller than the efficiency of the test of significance of a coefficient of correlation (see footnote 5, p. 218). Correlation coefficients were computed not only in four cases for which the number of like signs indicated significant correlations among variations in regional yields, but also in those cases in which the number of like signs, although smaller than the minimum required to indicate a significant correlation, substantially exceeded a half of the total number of pairs of observations. In three of these cases the coefficients of correlation obtained are significant, one of them being negative. When the number of plus signs differs only slightly from the number of minus signs, correlation coefficients have not been computed, since the probability is very small that the coefficients of correlation would be significant in these cases. The significant correlations discussed in the text are those indicated by significant correlation coefficients.

regions, significant correlations were established among variations of regional wheat yields. Six of these are positive, indicating that yields in the respective regions vary systematically in the same direction (from the respective trends), and one is negative, pointing to an inverse variation in yields. This last correlation is significant but relatively small (the coefficient of correlation is −.27). It indicates a systematic inverse variation of wheat yields in the United States Spring wheat region and in the wheat regions of the Eastern United States.

Of the six positive correlations, five are substantially closer than the one negative correlation, and they are "highly significant." However, even these highly significant positive correlations are not very close. The largest coefficient of correlation (+.55) was established between variations in wheat yields in the two neighboring wheat regions east of the Missouri–Mississippi Valley, namely in the Eastern United States and in the United States Soft Winter region. Both of these regions have similar climatic characteristics—at least in respect to humidity—for both belong to the eastern humid part of the United States. The next largest positive correlation coefficient (+.54) was established between variations of spring wheat yields in the United States Spring wheat region and in the Prairie Provinces of Canada. In this case both regions also belong to an area that has similar climatic characteristics, though divided into two parts by the political boundary between the United States and Canada. Most of the area of these two regions is characterized by a dry subhumid climate in the eastern portion and a semi-arid climate in the western.

Of the four other positive significant correlation coefficients, all of which are substantially smaller than the two just mentioned, the smallest (+.27) characterizes the relationship between variations in wheat yields in two neighboring regions but with different climatic characteristics—the United States Soft Winter wheat region and the United States Hard Winter wheat region. The other three coefficients characterize relationships between wheat yields in noncontiguous and relatively remote regions.

The principal climatic difference between the United States Soft Winter and the United States Hard Winter regions is that the first has the humid climate characteristic of the eastern part of the United States, while the second has mostly the subhumid and locally even semi-arid climate characteristic of the Great Plains. The humid climate is peculiar only to the eastern fringe of the second region. Because of this difference, similar variations in weather may sometimes result in opposite effects upon wheat yields. Seasons more humid than usual are, generally speaking, beneficial for wheat yields in the region with subhumid climate, while, under certain conditions, they may be harmful for wheat in the humid region. On the other hand, seasons drier than the average are usually harmful for wheat yields in the regions with a subhumid climate, but they may result in a better than average yield in the humid region. It is not necessary that similar variations in weather in these two regions have opposite effects on wheat yields always and in all parts of the regions. But frequently it is possible, and consequently the similarity in weather variations in the two regions, caused by their proximity, may not result in a positive correlation in their wheat yields. This perhaps is responsible for the fact that the positive correlation between variations in wheat yields in the United States Soft Winter region and in the United States Hard Winter region is substantially smaller than that between wheat yields in the United States Soft Winter region and the Eastern United States wheat region to the east of it.

It is of interest to notice that the positive correlation between variations in wheat yields in the two noncontiguous[3a] winter wheat regions with different climatic characteristics—the Eastern United States and the United States Hard Winter region—is highly significant and substantially closer than that between yields of winter wheat in the two contiguous regions—the United States Soft Winter and the United States Hard Winter regions. This is not easily explained. There are, however, indications that, in certain seasons, rain-

[3a] Very little wheat is cultivated in that part of the Eastern United States wheat region that is contiguous to the United States Hard Winter region.

fall in these noncontiguous regions with different climatic characteristics tends to vary in the opposite rather than in the same direction. We shall return to this problem.

The two other highly significant correlation coefficients between variations in wheat yields in noncontiguous regions are also difficult to explain. Both correlations indicate that wheat yields in the Canadian Prairie Provinces vary systematically in the same direction as wheat yields in the Pacific Northwest and in the Pacific Southwest. An explanation of the last correlation is particularly difficult. The yield of spring wheat in the Prairie Provinces, the only type of wheat cultivated there, depends mainly on the spring and summer rainfall (April–July) and also, to some extent, on the rainfall in the preceding fall (August–October) and on the temperature during the growing season.[4] In the Pacific Southwest only winter wheat is cultivated, and the yield depends mainly on winter rainfall. Consequently, the significant positive correlation between variations in wheat yields in these two regions can hardly depend on a correlation between variations of concomitant weather elements in the two regions, but rather on a correlation of weather that in the Prairie Provinces lags several months behind that in the Pacific Southwest. The fact that the harvesting of Canadian spring wheat lags about two months behind the harvesting of California wheat tends to substantiate this. This makes the correlation between wheat yields in the Prairie Provinces and in the Pacific Southwest ($r = +.40$) of particular interest as an aid to forecasting the Canadian crop. In view of this, we shall show later some more details in this relationship (pp. 237–38).

A more direct relationship may exist between simultaneous variations in weather factors influencing wheat yields in the Prairie Provinces and the Pacific Northwest, two regions that are nearly contiguous. In the Pacific Northwest, spring wheat is extensively cultivated, although it fluctuates in importance from year to year, and the wheat-growing season in the Prairie Provinces does not lag so much behind that in the Pacific Northwest as is the case with the Pacific Southwest. It is puzzling, however, that no significant correlation exists between variations in wheat yields in the Pacific Northwest and in the contiguous United States Spring wheat region (the coefficient of correlation, given in Table 2, is +.07), although wheat-growing conditions in these two regions should be more similar than in the case of the Pacific Northwest and the Prairie Provinces of Canada.[5]

Aside from the seven significant correlations between regional wheat yields just discussed, no significant correlation was established for other interregional relations. In eight out of the fourteen remaining cases, correlation coefficients were not computed, since the numbers of plus signs and of minus signs were so nearly equal that it was improbable that significant correlations would be found to exist. In the other six cases, when the number of one sign substantially exceeded the number of the opposite sign, the computed correlation coefficients are too small to be significant, with the exception, perhaps, of a negative coefficient

[4] For factors determining wheat yields in the Prairie Provinces, see three articles by J. W. Hopkins, "Weather and Wheat Yield in Western Canada. I. Influence of Rainfall and Temperature during the Growing Season on Plot Yields," *Canadian Journal of Research* (National Research Council of Canada), March 1935, XII, 306–34; "II. Influence of Pre-Seasonal Precipitation on Plot Yields," *ibid.*, May 1936, XIV, 229–39; and "III. Relation between Precipitation and Agricultural Yields," *ibid.*, May 1936, 240–44. See also, "Influence of Precipitation and Temperature on Wheat Yields in the Prairie Provinces, 1921–40," *Quarterly Bulletin of Agricultural Statistics* (Dominion Bureau of Statistics), July–September 1941, XXXIV, 167–87. Factors determining yields of spring wheat in the United States Spring wheat region are discussed by F. E. Davis and J. E. Pallesen, in "Effect of the Amount and Distribution of Rainfall and Evaporation during the Growing Season on Yields of Corn and Spring Wheat," *Journal of Agricultural Research* (Washington, D.C.), January 1940, LX, 1–23.

[5] In the computation of the measures of correlation given in Table 2 (p. 224), wheat yields per harvested acre were used for the Pacific Northwest and Southwest. As, in some portions of these regions, abandonment is great in some years, variations in yields on sown acreage differ substantially from those on harvested acreage. It was advisable, therefore, to control established relationships between variations in wheat yields in these regions by using also yields on sown acreage, which it was possible to compile roughly beginning with 1901 (the method and the sources of compilation of yield on sown acreage are explained in WHEAT STUDIES, April 1942, XVIII, Appendix Note, p. 333). The accompanying tabulation gives measures of correlation between wheat yields on sown acreage

of correlation (−.26) between variations in wheat yields in the Prairie Provinces of Canada and in the United States Hard Winter region. The magnitude of this last coefficient is very close to a significant value at 5 per cent significance level. This additional evidence of the existence of an inverse relationship between variations in yields of spring and winter wheat in North America is further considered below (pp. 230–31).

A few general observations may be made concerning established interregional correlations in wheat yields in North America before the problem of explaining the relationships between individual regions is approached.

First, interregional correlations among variations in wheat yields in the major wheat regions of North America are not very close.

in the Pacific Northwest and in the Pacific Southwest and wheat yields in the other wheat regions of North America as given in Table 2.

Region	Relationship[a]	Pr. Prov. Canada[s] 1889-1935	U.S. Spring[s] 1870-1935	Eastern U.S.[h] 1870-1935	U.S. Soft Winter[s] 1870-1935	U.S. Hard Winter[s] 1870-1935	Pacific Northwest[s] 1873-1935
Pacific North-	+	29	35	31	33	30	
west	—	17	28	29	29	31	
(sown	0	1	0	3	1	2	
acreage)	r	+.35*	..[b]	..[b]	..[b]	..[b]	
1873–1935							
Pacific South-	+	34	35	30	37	30	33
west	—	11	30	32	27	33	29
(sown	0	2	1	4	2	3	1
acreage)	r	+.40**	..[b]	..[b]	—.06	..[b]	..[b]
1870–1935							

[a] For explanation of relationships, see pp. 217–18.
[b] Coefficient of correlation not computed.
[s] Sown acreage.
[h] Harvested acreage.
* Significant at 5 per cent significance level.
** Significant at 1 per cent significance level.

From a comparison of this tabulation with the corresponding part of Table 2, it appears that, if the yield on harvested acreage for 1901–35 is replaced by the yield on sown acreage in the two Pacific regions, only slight changes in the number of like signs result. The replacement reduced, however, the coefficient of correlation between the variations in wheat yields in the Prairie Provinces and in the Pacific Northwest from +.47 to +.35. But this smaller coefficient still indicates a significant positive correlation between these yields. No change took place in regard to the other highly significant coefficient of correlation between yields of wheat in the Prairie Provinces and in the Pacific Southwest, which is +.40 in both cases.

[6] See WHEAT STUDIES, March 1943, XIX, 177–78.

This is evident from the fact that significant correlations were established in only 7 out of 21 possible combinations of seven regions by two. The magnitude of the established correlation coefficients — the largest of which is +.55 —points in the same direction. A coefficient of such magnitude indicates that only about 30 per cent of the variability in wheat yields is common to the two respective regions, while 70 per cent of the variations are not related. The percentage of common variations in yields is still smaller in all the cases for which correlation coefficients of lesser magnitude were established.

A great deal of diversity among variations in wheat yields per acre computed for the major wheat regions of North America was already indicated by comparison of the variability of yields in the major wheat regions with that for the total continental wheat area of North America.[6] This comparison suggested either that there was no correlation among regional wheat yields in North America, or that some of the interregional correlations are direct and others inverse. It appears from the correlation analysis that the second alternative is the one that characterizes the interregional relationship among wheat yields in North America.

Second, the major wheat regions of North America may be divided, with respect to interregional correlations in wheat yields, into two groups, within either of which there is a certain degree of similarity of yield variations, resulting in several significant and positive correlation coefficients. But little correlation in wheat yields exists between these two groups of regions. The significant correlations that were established for the regions classed with these two groups are negative, and this points to an inverse relationship in yield variations between the two groups.

The first group includes the major regions of winter wheat of the United States extending from east to west: (1) the Eastern United States, (2) the United States Soft Winter region, and (3) the United States Hard Winter region. The second group includes two important spring-wheat regions, one in the United States and the other in Canada, and also the Pacific wheat region, which for the purpose of correlation analysis is divided into the Pacific Northwest and the Pacific Southwest (Chart 1, p. 229). From Table 2 (p. 224) it appears that all of the significant positive correlation coefficients established are between regional yields within one or the other of the two groups—three within each group. On the other hand, the negative correlation coefficients, one significant and another closely approaching the level of significance (5 per cent), characterize the relationships between the variation in yields of winter wheat in the two regions of the first group and in yields of spring wheat in two regions of the second group. A significant negative correlation (the coefficient of correlation is −.27 for the period 1870–1935) was established, as mentioned earlier, between variations in wheat yields in the Eastern United States and in the United States Spring wheat region. That approaching the level of significance (the coefficient of correlation is −.26 for the period 1889–1935) was established between yields in the United States Hard Winter region and in the Prairie Provinces of Canada.

The distribution of the North American wheat regions into such groups suggests the existence of two geographical areas with peculiar characteristics of weather variations. One, the more southern, extends from the eastern coast of the United States to the southern part of the Great Plains in the west. The other, the more northern, extends in an east-western direction on both sides of the political boundary between the United States and Canada from the Great Lakes in the east to the Pacific Coast in the west, and then turns southward along the Pacific Coast. Variations of wheat yields correlate positively in each of these areas but show some tendency to an inverse relationship as between the areas. This may suggest that weather variation within each of these two areas is dominated by certain common factors that result in similarity of weather variation throughout the wide territory of each area, but that these variations for some reason tend to be in inverse relation as between the two areas.

Such an assumption regarding the similarity of weather developments within the two areas and regarding the divergency between them may find a certain support in the fact that the principal paths of cyclones, which dominate weather variations in North America to a certain extent, may also be divided into two groups with respect to the geographical areas under discussion. This relates particularly to the paths of spring and autumn cyclones, which dominate variations in rainfall during these two seasons when rainfall is of particular importance for wheat crops. The analyses of the factors determining variations in wheat yields indicate that, with the exception of the Pacific Coast, winter precipitation has little influence upon the variation in wheat yields in North America, at least in the regions where rainfall is among the major factors determining yields. On the other hand, in most of North America summer weather depends little on cyclones. Consequently, our principal interest is in relation to the paths of spring and autumn cyclones.

Of course, spring and autumn cyclones are more erratic than winter ones, and they dominate the weather less.[7] Furthermore, the so-called storm or cyclone tracks are broad belts or districts over which cyclones travel more frequently than elsewhere. Consequently, presentation of seasonal paths of cyclones on a map involves a great deal of generalization. Still a generalized picture of those paths during the spring and autumn may be of service in explaining the peculiarities of the interregional correlations in wheat yields discussed above.

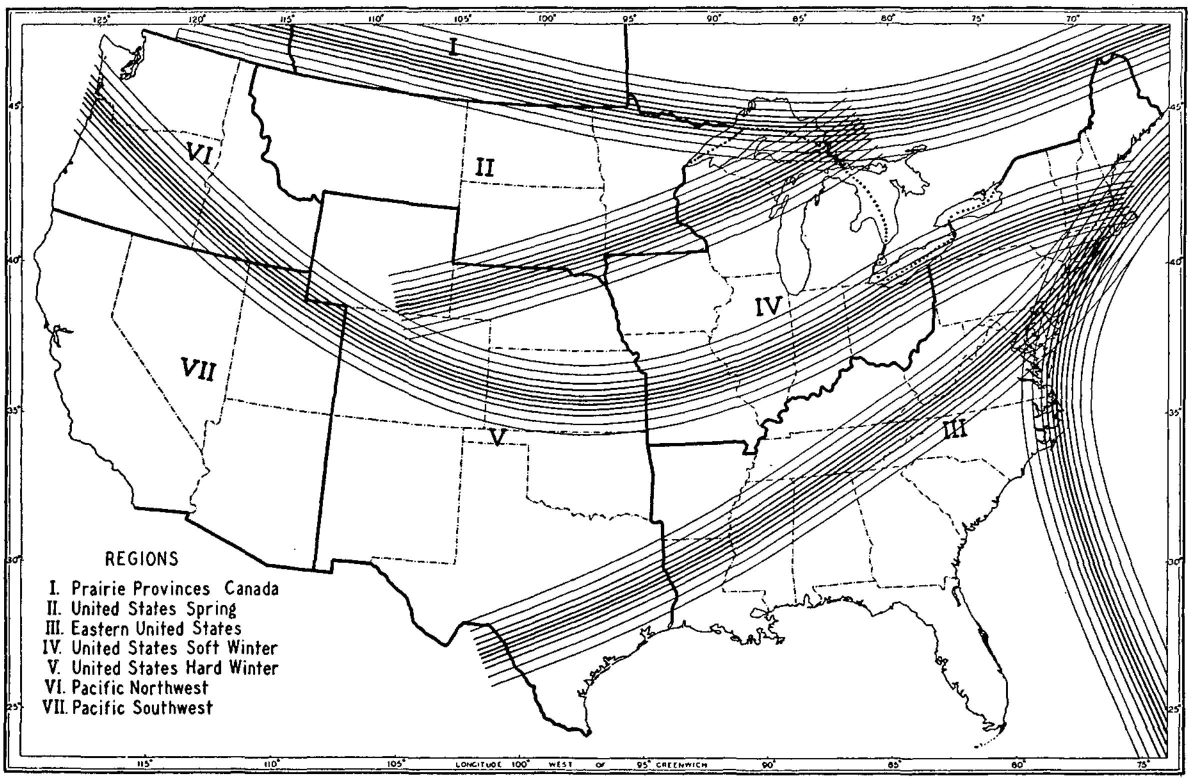
Chart 1 presents such a generalized picture of spring and autumn storm paths, as well as the boundaries of the major wheat regions of North America used in this analysis. It appears from this chart that the so-called northern circuit, a path usually followed in these seasons by the Northwestern or Alberta type of cyclone, passes along the political boundary between the United States and Canada and then across Lake Superior into the St. Lawrence Valley. Cyclones traveling along this track may thus affect weather developments in the two spring-wheat regions and, to a certain extent, also those in the Pacific Northwest. However, they can hardly affect weather

[7] R. DeC. Ward, *The Climates of the United States* (Boston and London, 1925), p. 41.

in the fourth region of this group—the Pacific Southwest. Similarly, they cannot affect the development of weather in all of the winter wheat regions of our second group. On the other hand, the North Pacific storms, entering the continent on the Pacific Coast in Washington and Oregon, deflect to the south and make their journey through Colorado, Kansas, Missouri, Illinois, Indiana, Ohio, Pennsylvania, and then New York and New England. These cyclones would thus influence weather developments not only in all three winter wheat regions of the United States but also those in the Pacific Northwest. However, the path of these cyclones is too far to the south of the spring wheat area to affect weather developments in the spring and autumn there. Similarly, Texan cyclones, originating on the border of Texas and Mexico, travel in a northeastern direction into New York State and then New England. These cyclones may affect weather developments at least in some portion of all three major winter wheat regions of the United States, but cannot have any influence on weather developments in the wheat regions of the second group of North American wheat regions.

Thus, only the Colorado type of storm, which travels along the track extending from Colorado to the Great Lakes and passes along the borderline of the two areas under discussion, may influence weather in both areas.[8]

CHART 1.—GENERALIZED SPRING AND AUTUMN CYCLONE PATHS AND WHEAT REGIONS IN NORTH AMERICA*



* The cyclone paths are adapted from R. DeC. Ward, *The Climates of the United States* (Boston and London, 1925), Fig. 7, p. 42.

This picture of the generalized tracks of spring and autumn cyclones may suggest that weather developments during these seasons have common characteristics within both of the two areas and differ as between the areas. However, it does not explain the existence of a highly significant positive correlation be-

[8] Winter storm paths, which are removed more to the south and cover practically the whole territory of the United States, are more intricate. However, in their distribution as between the two areas under discussion, they show nearly the same picture as the generalized spring and autumn storm paths.

tween wheat yields in Canada and the Pacific Southwest. Nor does it imply that there should be a tendency to an inverse correlation between weather elements in the two areas. It suggests rather that weather variation in the two areas should be unrelated.

It must be emphasized, moreover, that the entire hypothesis that the peculiarities of interregional correlations in wheat yields in North America may be explained by the geographical distribution of cyclone paths is based on the assumption that interregional correlations in weather are of the same character as correlations in yields. That is, direct correlations in yields imply also direct correlations in weather elements such as rainfall or temperature, while inverse relationships in yields imply inverse relationships also in weather elements.

However, because of the very intricate relationship between yields and weather developments, the situation is much more complex. The two geographical wheat areas being discussed, within both of which yields tend to vary in a direct relationship, are not homogeneous climatically. The more southern of the two, the winter wheat area, is divided into the humid, eastern part and the subhumid western; while the more northern consists of the subhumid (or semi-arid) spring-wheat belt, with prevailing summer rainfall, and of the Pacific region, with prevailing winter precipitation. As mentioned earlier, owing to the climatic characteristics of portions of these areas, similarity in weather variations throughout the entire area may result in an inverse variation of yields in these portions, while a direct relationship between variations in yields may indicate an inverse relationship in rainfall.

The situation is complicated further. Winter wheat prevails throughout the more southern of these areas, while spring wheat dominates in that part of the northern area where summer rain prevails, and winter wheat is of greater importance in the Pacific region, particularly in the Southwest. Hence, even in those portions of the two areas where the climatic characteristics are more or less similar, no similarity may exist in interregional correlation of yields and of weather (rainfall).

Specific Correlations

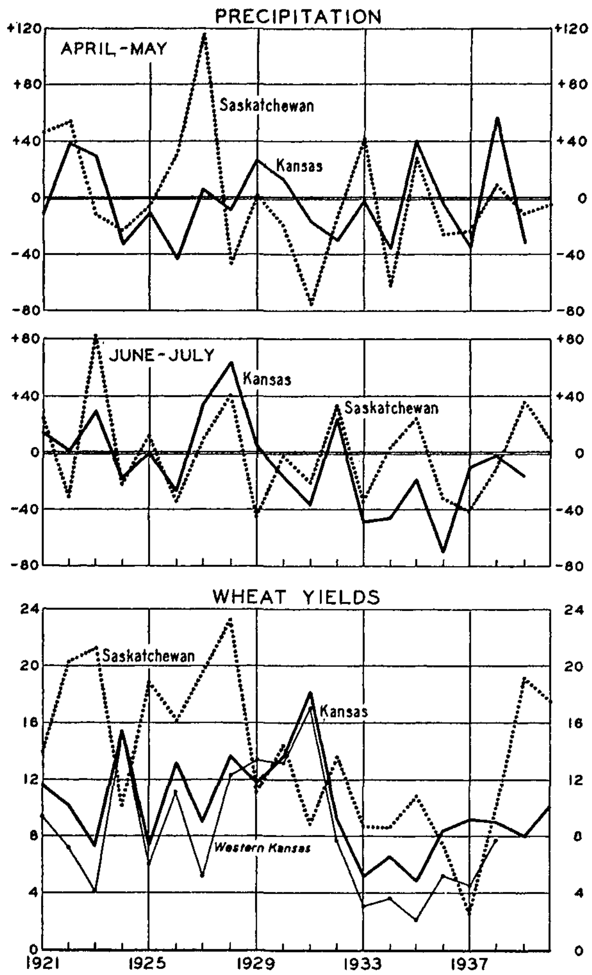
In this respect, the pronounced tendency to an inverse relationship between the yields of spring wheat in the Prairie Provinces of Canada and of winter wheat in the United States Hard Winter region is of particular interest. The amount of seasonal rainfall dominates variations in wheat yields in these two regions because of the prevailing subhumid or semi-arid climates. Consequently, it is natural to infer that the established tendency to an inverse correlation between wheat yields in these regions suggests an inverse correlation also between their rainfall. Such a relationship would be expected particularly in those portions of the two regions that especially suffer from droughts, e.g., Saskatchewan Province in Canada and the western part of Kansas.

A comparison of spring and summer rainfall and of wheat yields in Saskatchewan and in Kansas, given in Chart 2, indicates, however, that while spring and summer rainfall in both regions moves fairly closely together, wheat yields tend to vary in the opposite direction. In order to show that variations in wheat yields in Kansas as a whole are dominated by variations of wheat yields in western Kansas, data on yield in western Kansas are shown separately. It appears from the chart that both lines, the one showing wheat yield in the entire state of Kansas and that in western Kansas, move fairly well together. From the same chart it also appears that rainfall in Saskatchewan, both in April–May and in June–July, and wheat yields move fairly closely together,[9] while wheat yields in Kansas tend to move in the opposite direction from rainfall, particularly in June–July. Because of the difference in the time of ripening and harvesting of wheat crops in these two areas, the June–July rainfall, which is beneficial in Canada, is apparently unfavorable for

[9] From Figure 1 of an article on "The Influence of Precipitation and Temperature on Wheat Yields in the Prairie Provinces, 1921–1940," *Quarterly Bulletin of Agricultural Statistics*, July–September 1941, XXXIV, 172, it appears that regressions of yield on rainfall are positive for rainfall in April–May or June and in August–October of the preceding year. This indicates that above-average rainfall in any of these seasons tends to increase yields of spring wheat in Saskatchewan.

wheat crops in Kansas. Thus, in spite of the similarity in climatic characteristics of these two regions (at least in respect to rainfall), a direct relationship between spring and summer rainfall results in an inverse tendency in variations of their wheat yields.

CHART 2.—APRIL–MAY AND JUNE–JULY PRECIPITATION (PERCENTAGE DEVIATIONS FROM NORMAL) AND WHEAT YIELDS (BUSHELS PER ACRE) IN KANSAS AND SASKATCHEWAN, 1921–40*



* Data on precipitation: for Saskatchewan from the *Quarterly Bulletin of Agricultural Statistics*, July–September 1941, p. 173; for Kansas from U.S. Dept. Agr. and U.S. Dept. Comm., *Crop Yields and Weather* (Misc. Pub. 471, by L. H. Bean, February 1942). For the source of data on wheat yields, see WHEAT STUDIES, April 1942, XVIII, 333.

It is therefore hazardous, even for regions with similar climatic characteristics, to infer that correlations in yields point to similar correlations between variations in weather elements. Such an inference would be still more hazardous in relation to regions with different climatic characteristics, such as the two regions of winter wheat discussed earlier—the Eastern United States and the United States Hard Winter region. The fact that a highly significant direct correlation was established between variations in wheat yields in these two regions can hardly be explained simply by the similarity in the variation of their rainfall. The explanation of this highly significant positive correlation is complicated still more by the existence of a significant inverse correlation between variations in wheat yields in the Eastern United States and in the United States Spring wheat region.

The complexity of the relationships between weather and yields suggested a more detailed study of these interregional correlations in wheat yields. Since the major wheat regions are large and since, consequently, their climatical homogeneity is only limited, relationships between the subregions of the respective major wheat regions were studied. The Eastern United States is divided (on the southern boundary of Maryland) into two subregions—Northeastern and Southeastern; the United States Hard Winter region is divided into three subregions — Northeastern, Northwestern, and Southern;[10] and finally the United States Spring wheat region is divided into two subregions, one of which includes Minnesota and South Dakota, and the other North Dakota and Montana.

The detailed analysis indicates that yields in the three subregions of the Hard Winter area correlate more closely with yields in the Southeastern subregion of the Eastern United States than with those in the Northeastern subregion. This is evident from the accompanying tabulation, which gives coefficients of correlation between wheat yields in the two subregions of the Eastern United States and in the three subregions of the United States Hard Winter region. While all three correlation coefficients between wheat yields in the Southeastern subregion of the Eastern United States and in the three sub-

[10] The Northeastern subregion includes Nebraska and the eastern half of Kansas; the Northwestern, the western half of Kansas, Colorado, and Wyoming; and the Southern, Texas, New Mexico, and Oklahoma.

regions of the United States Hard Winter region are highly significant, significant correlation coefficients were obtained between wheat yields in the Northeastern subregion and only the two Northern subregions of the United States Hard Winter area. The third coefficient of correlation is not large enough to be significant.

Eastern United States	United States Hard Winter Northeast 1889–1935	Northwest 1889–1935	South 1870–1935
Northeast 1870–1935	+.30*	+.32*	+.16
Southeast 1870–1935	+.42**	+.44**	+.41**

* Significant at 5 per cent level of significance.
** Significant at 1 per cent level of significance.

Similarly, a detailed analysis of the relationship between wheat yields in the Eastern United States and in the United States Spring wheat area indicates that a significant inverse correlation exists only between variations of wheat yields in the Southeastern subregion of the Eastern United States and the northwestern portion of the United States Spring wheat area (North Dakota and Montana). The correlation coefficients between variations of wheat yields in the other subregions of the two regions, although negative, are not large enough to be significant, as the accompanying tabulation shows:

Eastern United States	United States Spring wheat Minnesota–S. Dakota 1870–1935	N. Dakota–Montana 1877–1935
Northeast 1870–1935	−.11	−.22
Southeast 1870–1935	−.16	−.31*

* Significant at 5 per cent level of significance.

It appears, thus, that significant correlations between wheat yields in the Eastern United States and in the United States Hard Winter and Spring wheat regions are much more pronounced in the case of the Southeastern subregion of the Eastern United States than in the case of the Northeastern. Moreover, only in the northwestern portion of the United States Spring wheat belt (North Dakota and Montana) did wheat yields vary systematically in an inverse direction from those in the Eastern United States. In Minnesota and South Dakota this tendency is not pronounced enough to result in a significant inverse correlation. Consequently, attention must be concentrated on the weather characteristics of the southern subregion of the Eastern United States and of the northwestern subregion of the United States Spring wheat region if the tendency to inverse variations in wheat yields in the Eastern United States and in the United States Spring wheat belt is to be explained. Similarly, weather variations in the Southeast must be compared with those in the Hard Winter area in order to explain the highly significant positive correlation in wheat yields in the Eastern United States and in the Hard Winter wheat area.

A full explanation of these correlations would require, however, an extended study of correlations between weather elements of the respective wheat regions, as well as a detailed study of the factors determining variation in wheat yields in these regions. These problems have not been sufficiently studied statistically by meteorologists and plant physiologists; hence, not enough generally accepted conclusions and data are available for a statistician to use in an explanation of the established interregional correlations in yields. It is not our problem, as was mentioned in the introduction, to go into a thorough explanation of established correlations. We limit ourselves to a few suggestions that may be of some help toward such an explanation.

Correlations in Regional Rainfall

First, we present here information on the relationships between seasonal precipitation in several climatic districts of the United States. This information may be serviceable in explaining some of the significant correlations established for wheat yields in North America or the absence of such correlations in other cases. For this purpose, we use information on seasonal precipitation by climatic districts of the United States for the period 1889–1930, as compiled recently by the United States Weather Bureau.[11] As these

[11] R. H. Weightman, "Preliminary Studies in Seasonal Weather Forecasting," *Monthly Weather Review* (U.S. Dept. Comm., 1941), Supplement 45, pp. 11–12, 16–18.

data were compiled for a study of correlations between variations in precipitation (and temperature) in the United States and atmospheric pressures reported by meteorological stations throughout the world, the 12 climatic districts for which data are compiled (see map, p. 234) are not particularly suited to the purpose of our analysis. The boundaries of the climatic districts do not coincide at all with the boundaries of the wheat regions used in this study. This is particularly true of the relatively large climatic districts 5 and 7, both of which include certain portions of the Spring wheat belt and also the Hard Winter wheat area, while region 5 also includes a part of the Soft Winter area. Although this complicates the use of interdistrict correlations in seasonal precipitation in the explanation of interregional correlations in wheat yields, it would be prohibitive for us to undertake to compile data on seasonal precipitation by regions used in the analysis of wheat yields. We are obliged, therefore, to use the information in the form in which it has already been compiled. In spite of the difficulties involved, a study of interdistrict correlations in seasonal precipitation is still of interest for a preliminary explanation of some of the interregional correlations of yields.

Data on seasonal precipitation for the 12 climatic districts are given for four 3-month periods (December – February, March – May, June–August, and September–November) in the form of departures from the district averages for the period 1889–1930.[12] For the sake of brevity, we shall call these periods winter, spring, summer, and autumn. Studies of factors determining variations in wheat yields, at least in those North American wheat regions where the amount of precipitation is one of the principal factors determining yield, indicate that the precipitation of the spring and preceding autumn is of greater importance for wheat yields than winter and summer rainfall. Hence, we limit our study of interdistrict correlations in seasonal precipitation to these two seasons, although June precipitation, included in the summer total, is also of importance. Two of the 12 climatic districts (6 and 10), where production of wheat is of relatively small importance, are excluded from this analysis, leaving only 10 climatic districts. Of the possible 45 relationships, only 27, or 60 per cent, were actually studied as of greater interest for the purpose of our analysis. Data on these relationships are summarized in Table 3 (p. 234).

Figures in the two pairs of three columns, given separately for spring and autumn precipitation, indicate the results of comparison of these precipitations in the respective districts. Figures in the columns headed with a plus sign indicate the number of years when departures of seasonal precipitation from respective seasonal averages are in the same direction in both districts under comparison; that is, when seasonal precipitation in both districts is above or below their respective seasonal averages. Figures in the columns headed with a minus sign indicate the number of years when departures of seasonal precipitation from the respective seasonal averages are in the opposite direction in the two compared districts; that is, when seasonal precipitation in one is above the respective seasonal average but below it in the other. Finally, figures in the columns headed with a zero sign indicate the number of years (usually small) when seasonal precipitation in one or both of the compared districts does not depart at all from the respective seasonal averages. In all these cases when the number of like signs equals or exceeds 28, a significant correlation between variations in seasonal precipitation in the respective climatic districts is indicated.[13]

[12] For 9 of the 12 climatic districts, these data are compiled on the basis of information from ten meteorological stations evenly distributed over the respective districts, and for 3 districts on the basis of information from five meteorological stations.

[13] The significance of the correlations is established according to the test of significance developed by W. G. Cochran. (See footnote 5, p. 218.) It is not excluded, however, that significant correlation coefficients may be obtained also in some cases when the number of like signs, although smaller than 28, closely approaches this value (for the reasons, see p. 218). But with the exception of two cases, which point to a possibility of a negative correlation between seasonal precipitation in some districts (districts 2 and 5 for autumn precipitation, and districts 5 and 8 for spring precipitation), no such control computation of correlation coefficients was made, and those computed were negative but nonsignificant.

From the table it appears that interdistrict correlations of autumn precipitation are more numerous than those of spring precipitation. In 11 of the 27 cases presented in the table, significant correlations are indicated between variations of autumn precipitation. In only 6 cases out of 27 are there significant correlations between variations of spring precipitation. Still fewer interdistrict correlations are to be expected for summer precipitation, which in the United States is controlled very little by cyclones. There may be substantially more for winter precipitation, which is dominated by cyclones throughout the United States. This situation may have some relation to the dearth of correlations between winter-wheat yields, which depend more directly on autumn precipitation, and spring-wheat yields, which depend upon precipitation in the preceding fall to a lesser degree.

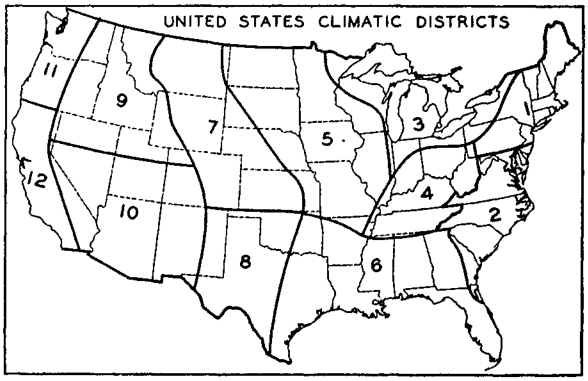
TABLE 3.—CORRELATIONS OF SPRING (MARCH–MAY) AND AUTUMN (SEPTEMBER–NOVEMBER) PRECIPITATION BETWEEN SPECIFIC CLIMATIC DISTRICTS OF THE UNITED STATES, 1889–1930†

Order numbers of climatic districts	Spring precipitation			Autumn precipitation		
	+	—	0	+	—	0
1-2	26	15	1	25	17	0
1-3	25	17	0	33*	9	0
1-4	25	16	1	33*	9	0
2-3	20	21	1	22	20	0
2-4	28*	12	2	22	20	0
3-4	29*	12	1	34*	8	0
1-5	22	20	1	28*	14	0
2-5	22	19	1	15	27	0
1-7	21	20	1	23	18	1
2-7	24	16	2	16	25	1
1-8	22	20	0	28*	14	0
2-8	25	16	1	23	19	0
3-5	31*	11	0	29*	13	0
3-7	16	25	1	26	15	1
3-8	17	25	0	27	15	0
4-5	32*	9	1	31*	11	0
4-7	25	15	2	26	15	1
4-8	23	18	1	27	15	0
5-7	27	14	1	29*	12	1
5-8	16	26	0	24	18	0
5-9	28*	14	0	26	15	1
5-11	21	21	0	23	19	0
7-8	26	15	1	29*	12	1
7-9	29*	12	1	30*	10	2
7-11	22	19	1	16	25	1
9-11	25	17	0	23	18	1
11-12	21	19	2	28*	14	0

† *Monthly Weather Review* (U.S. Dept. Comm.), Supplement No. 45, 1941, District Map, p. 11, and pp. 16–18.

* The number of like signs is sufficient to indicate a significant correlation between precipitation in respective districts.

Of the total number of 27 relationships between variations in seasonal precipitation in specific districts, given in the table, 15 are for noncontiguous districts and 12 for contiguous. From further study of these, it appears that very few correlations exist between variations in precipitation in noncontiguous climatic districts, even for autumn precipitation. Only 1 out of the 6 significant correlations established between variations in spring precipitation, and only 2 out of the 11 between variations in autumn precipitation, were for noncontiguous districts.[14] A comparison of this with the correlations in regional wheat yields in North America, presented in Table 2 (p. 224), leaves us with the impression that there is less correlation between seasonal precipitation in distant climatic districts than between wheat yields in those regions.[15] If this impression is correct, then correlations established between wheat yields in remote regions must be explained not by correlations of seasonal precipitation but by correlations of some other weather elements, for instance, such as seasonal temperature.



[14] These correlations are for spring precipitation in districts 5 and 9 and for autumn precipitation in district 1 as compared with districts 5 and 8.

[15] Of course, the differences in the number, size, and boundaries of climatic districts and of wheat regions does not permit strict comparison in this respect. Furthermore, there is a possibility that, in those cases in which the number of like signs does not indicate significant correlation between the precipitation of two districts, a significant correlation coefficient might still be obtained. It must be remembered also that only 60 per cent of the possible interdistrict relationships were studied.

Another characteristic of the relationships among seasonal precipitation in various climatic districts of the United States is that all significant correlations established between variations in seasonal precipitation are direct. In no case was the tendency to inverse variation in rainfall between districts strong enough to indicate a significant inverse correlation. However, this does not mean that an appreciable tendency to an inverse variation in precipitation does not exist for both autumn and spring precipitation. Such a relationship between variations in rainfall was established for a few climatic districts, and it is characteristic only of noncontiguous districts, as was to be expected. For autumn precipitation a marked tendency to inverse variations in precipitation was established for the following pairs of districts: 2 and 5, 2 and 7, and 7 and 11. For spring precipitation, a similar tendency was established for the following pairs of districts: 3 and 7, 3 and 8, and 5 and 8 (see Table 3, p. 234). Geographic distribution of districts in which rainfall tends to vary in opposite directions appears more or less systematic in the case of both autumn and spring precipitation. Districts with inverse variations in autumn precipitation extend from the southeast on the Atlantic Coast (district 2) in a northwesterly direction to the Pacific Northwest (district 11), following more or less a straight line. The respective districts for spring precipitation extend from the northeast (district 3 on the shores of the Great Lakes) to the southwest on the Texan-Mexico border (district 8).

Both groups of districts with inverse relationships between variations in seasonal precipitation extend so systematically along some definite direction that their location may point to a real relationship, in spite of the fact that the individual correlation coefficients are not significant.[16] We leave to meteorologists the decision concerning this question and the explanation of these tendencies to inverse relationships in seasonal precipitation. In any case, these relationships must be taken into consideration in explaining correlations between wheat yields in remote regions. Of special interest in this respect is a tendency to an inverse relationship between autumn precipitation in district 2, which lies in the middle of the Eastern United States wheat region, and in districts 5 and 7, which cover most of the territory of the United States Spring wheat belt and of the United States Hard Winter region. Interest also attaches to the tendency to inverse relationships in spring precipitation in climatic district 3, covering the northeastern portion of the United States Soft Winter region, and in districts 7 and 8, covering the subhumid and semi-arid portions of the Hard Winter and Spring wheat regions.

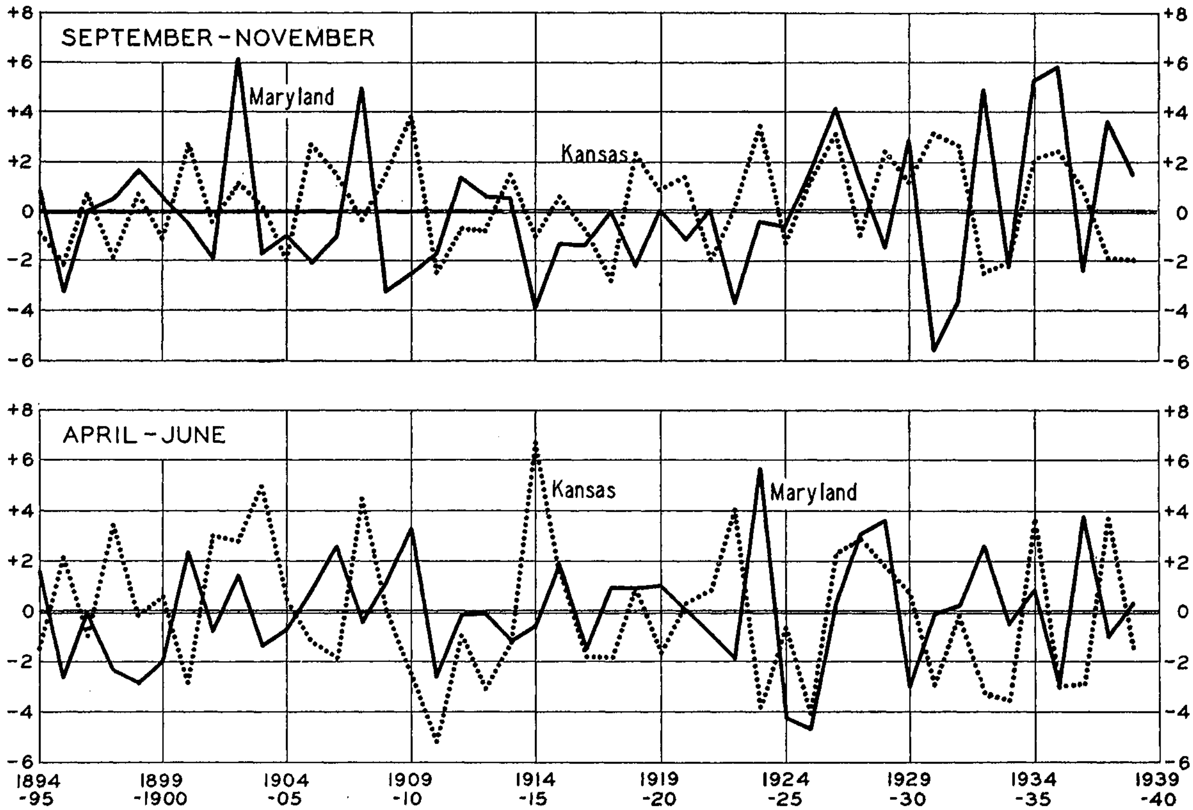
As climatic districts 5 and 7 cover both the Spring and the Hard Winter wheat areas, it was advisable to select within each a more limited area and to compare the seasonal precipitation therein with that in a limited area within climatic district 2 or closely adjacent to it. For this purpose, seasonal rainfall in Kansas and in North Dakota was compared with that in Maryland. The autumn precipitation used in this comparison was the same as in the preceding comparison (September–November), but the spring precipitation taken was that for April–June, since the rainfall during the last period appears to have greater influence upon wheat yields than does that for March–May. These comparisons, for sufficiently long periods, are presented in Charts 3 and 4.

The first impression from the two charts is that variations in rainfall (both autumn and spring) in Maryland reveal little systematic relationship with those in either Kansas or North Dakota. A more attentive study of the charts, however, indicates a certain tendency to an inverse variation, particularly in autumn precipitation for Maryland–Kansas. Departures of the September–November rainfall from the normals in these two states are in opposite directions in 26 years and in the same direction in only 18 years. The same appears also from a comparison of exceptionally rainy or dry seasons in one state with the characteristics of the respective season in the

[16] The coefficient of correlation between departures from the average of the autumn precipitation in districts 2 and 5 is −.27 for the period 1889–1930; between departures of the spring precipitation in districts 5 and 8 it is −.16 for the same period. Both coefficients are negative but nonsignificant.

other state. Exceptionally rainy autumns in Kansas are, in most cases, drier than the average in Maryland, while exceptionally dry autumns in Maryland are in most cases rainier than usual in Kansas. Consequently, there is a marked tendency to an inverse variation in the autumn precipitation in Maryland and Kansas. This tendency is less definite for spring precipitation in these two states. But, when rainy springs alone are compared, it still appears that rainy springs in Kansas tend to coincide, in most cases, with drier than average seasons in Maryland, and vice versa. However, this tendency is compensated for, to a certain extent, by a lack of a similar tendency in respect to dry springs. Consequently, although no correlation appears between spring precipitation in Maryland and Kansas, there is still a more or less systematic tendency to an inverse relationship between exceptionally rainy springs in the two states.

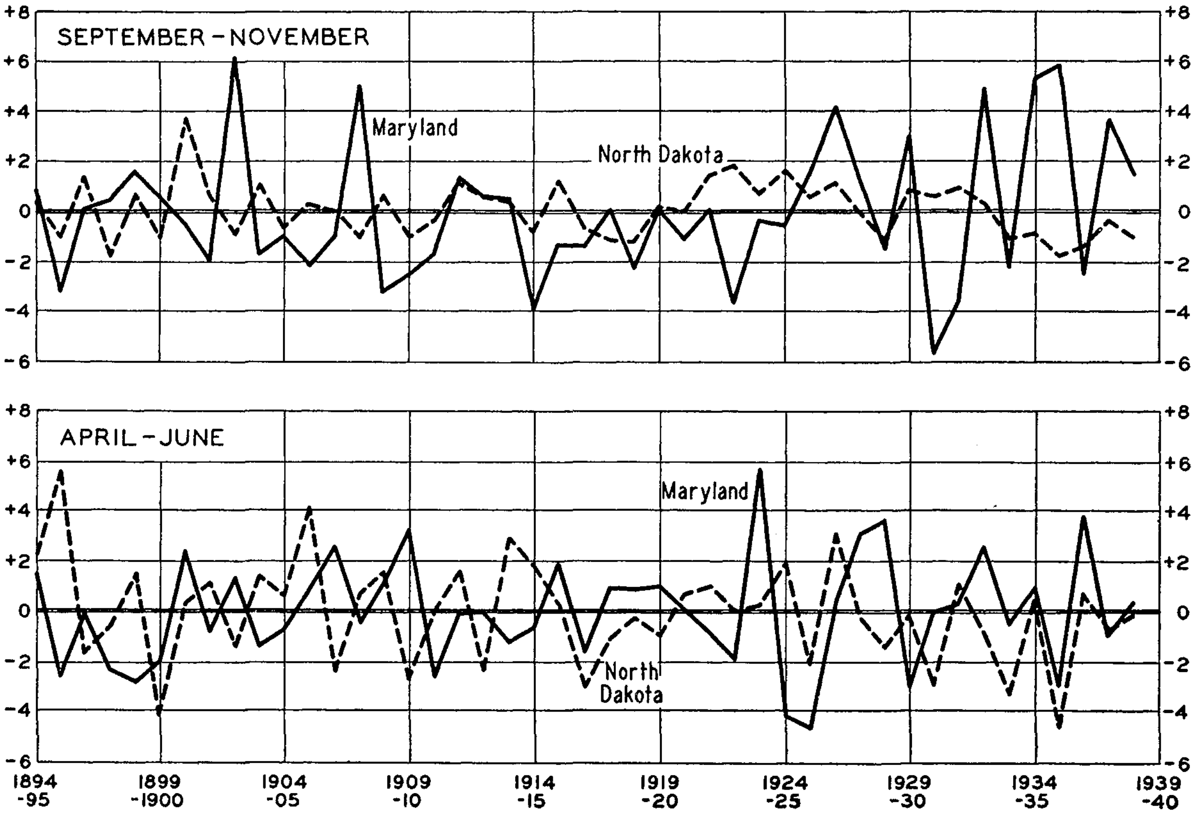
CHART 3.—SEPTEMBER–NOVEMBER AND APRIL–JUNE PRECIPITATION (DEPARTURES FROM NORMAL IN INCHES) IN KANSAS AND MARYLAND, 1894–95 TO 1938–39*



* Data from U.S. Dept. Agr. and U.S. Dept. Comm., *Crop Yields and Weather* (Misc. Pub. 471, by L. H. Bean, February 1942).

The relationship of spring precipitation in Maryland and North Dakota is similar to that of spring precipitation in Maryland and Kansas. Exceptionally rainy springs in one of these states tend, in most cases, to coincide with drier than usual seasons in the other. But usually dry seasons in one state tend to coincide with drier than average seasons also in the other state. The combination of these two systematic tendencies results in an impression that there is no correlation between spring precipitation in Maryland and North Dakota, but this impression is not quite correct. It must be recognized, however, that no systematic relationship appears in the variation of autumn precipitation in Maryland and North Dakota. This last relationship may indicate that the established tendency for autumn precipitation on the humid Atlantic Coast (climatic district 2) to vary in the opposite direction from autumn rainfall in the subhumid and semi-arid west (climatic districts 5 and 7) is more pronounced for the southern portion of the last area, where hard-winter wheat is produced, than for the northern part, which coincides with the spring-wheat belt. It may also contribute, to a certain extent, toward explaining the fact that wheat yields in the moist area of the Atlantic Coast tend to vary in the same direction as respect to hard winter wheat in Kansas and spring wheat in Saskatchewan during 1921–40 (p. 230). In those areas spring and summer precipitations also tend to fluctuate in the same direction, but wheat yields moved mainly in the opposite direction. The contrast is less pronounced, however, in the case of the United States spring and hard winter wheats. Yields of these wheats do not move in the opposite

CHART 4.—SEPTEMBER–NOVEMBER AND APRIL–JUNE PRECIPITATION (DEPARTURES FROM NORMAL IN INCHES) IN NORTH DAKOTA AND MARYLAND, 1894–95 TO 1938–39*



* See note to Chart 3, p. 236.

yields in the Hard Winter region, but in the opposite direction from spring-wheat yields, particularly in North Dakota and Montana.

The contrast between yield variations of hard winter and spring wheats in the subhumid and semi-arid areas of the west compared to yield variations in the humid region of the Atlantic Coast of the United States is not irreconcilable with the fact that autumn and spring rainfalls in Kansas and in North Dakota tend to vary in the same direction. We know that a similar situation was observed in direction; they simply do not show any systematic relationship.

CANADIAN PRAIRIE PROVINCES VERSUS UNITED STATES PACIFIC COAST

It would require an additional study to explain the highly significant positive correlations between variations in wheat yields in the Prairie Provinces of Canada and in the Pacific Northwest and Pacific Southwest. Factors affecting variations of yields on the Pacific Coast have not yet been studied sufficiently by statisticians, and meteorological data on the Prairie Provinces, although carefully studied by Canadian agronomists and statisticians,[17] cover a relatively short period. We, therefore, limit ourselves to presentation of more detailed data on the correlation of wheat yields within these areas.

The accompanying tabulation gives, for the period 1901–35, six correlations between wheat yields (deviations from respective trends) in each of the three Prairie Provinces of Canada and in the Pacific Northwest and Pacific Southwest (on harvested acreage). Highly significant correlation coefficients (1 per cent level) are marked with two asterisks. Only three of

Region	Alberta	Saskatchewan	Manitoba
Pacific Northwest	+.62**	+.50**	+.02
Pacific Southwest	+.29	+.53**	+.30

the six correlation coefficients are significant. The highly significant positive correlation coefficients between yield variations in Alberta and in Saskatchewan compared with those in the Pacific Northwest may be explained easily by the relatively close proximity of these two Canadian provinces to the Pacific Northwest. The direct correlation between the variation in the Canadian wheat yield and that in the Pacific Northwest declines as we proceed from west to east. The correlation coefficient between yields in the Pacific Northwest and in Alberta is the highest, the one between yields in the Pacific Northwest and Saskatchewan is somewhat smaller, and practically no correlation exists between yields in the Pacific Northwest and in Manitoba. The explanation of these correlations by proximity of the regions involved meets with the objection, however, that wheat yields in the Pacific Northwest correlate very little with those in the neighboring western portion of the United States Spring wheat regions (Montana and North Dakota). In fact, the positive coefficient of correlation between yields in these regions for the period 1877–1935 (+.17) is not significant. These contradictory relationships need further explanation.

As to the relationship between wheat yields in the Prairie Provinces and in the Pacific Southwest, it appears from the tabulation that a highly significant direct correlation exists only between the yields in the Pacific Southwest and in Saskatchewan. The relationship of yields in the other two Canadian provinces with those in the Pacific Southwest tends to be a direct one, but the correlation coefficients are not large enough to be significant. We do not know what meteorological factors are responsible for this correlation, as we do not know also why it is more pronounced in the case of Saskatchewan than in the case of the other Prairie Provinces, particularly Alberta. Hence, it would be safer to explain the mechanism of this relationship before relying on it as a real one. We leave this for specialists familiar with conditions in the respective regions.

Intraregional Correlations in Yields

As stated at the beginning of this section, our interest in this study is centered principally upon correlations in wheat yields in noncontiguous and remote areas. For this reason, we do not intend to give much attention to the discussion of correlations among wheat yields in the smaller subdivisions within the major wheat regions. For studying variability in wheat yields, our major wheat regions, shown in Table 2 (p. 224), were subdivided into two or three more homogeneous subregions. The six major wheat regions of North America were thus subdivided into 17 smaller subregions. As was to be expected, fairly close positive correlations were established between variations in yields in practically all of the smaller subdivisions within each major region of North America. A few exceptions were noted, however; and these point to a lack of homogeneity of the major wheat regions in respect to variability of yields. These merit some attention.

Of the three Prairie Provinces of Canada, Manitoba and Alberta are apparently too far distant from each other to show much similarity in variations of yields. Their yields still vary in most cases in the same direction, but the correlation coefficient is not large enough to be significant (for the period 1901–35 it is +.21). However, a fairly close direct

[17] Hopkins, *op. cit.*

correlation exists between the variation in wheat yields in Saskatchewan as compared with those in Manitoba and in Alberta.[18] This indicates that in this respect there is no definite break in the homogeneity of the Prairie Provinces of Canada as a whole. The differences within this area accumulate gradually as we proceed in our comparison from the center to the periphery. Hence, it was found advisable to treat all three Prairie Provinces of Canada as one wheat region of major importance.

The situation in Ontario, where winter wheat is normally cultivated, was found to be somewhat different. In the study of variability of wheat yields, this province was regarded as a subregion of the larger wheat region of Eastern North America. It was found, however, that the variation in wheat yields in Ontario does not agree sufficiently well with that in both the Northeastern and Southeastern subregions of that region. It was decided, therefore, to omit Ontario from the Eastern North American wheat region;[19] and, for the purpose of correlation analysis, to use only that portion of the region lying within the United States, dividing it into two subregions —Northeastern and Southeastern. Wheat yields in these two subregions correlate fairly closely (the coefficient of correlation between yields on harvested acreage for 1870–1935 is +.50).

The two subdivisions of the United States Pacific wheat region—the Pacific Northwest and the Pacific Southwest—were not found to be sufficiently homogeneous with respect to variation in wheat yields. While wheat yields in the three states of the Pacific Northwest (Washington, Oregon, and Idaho) move fairly closely together, they do not correlate closely with the yield in the Pacific Southwest. Hence, it was decided to treat the Pacific Northwest and the Pacific Southwest as two separate regions in the correlation analysis. We know that the coefficient of correlation between variations in yields in these two regions (+.16 for the period 1873–1935) is not significant (Table 2, p. 224).

Fairly close direct correlations were established among variations in wheat yields for the smaller subdivisions of all other major wheat regions of North America. Consequently, after the Eastern North American and the Pacific regions were modified, all the major wheat regions included in the correlation analysis summarized in Table 2 are sufficiently homogeneous with respect to variations in wheat yields within their respective areas. Hence it can hardly be expected that the general picture of the relationships among variations in the regional wheat yields of North America would be substantially modified if a larger number of smaller wheat regions were to be included in the correlation analysis. The more detailed studies of specific interregional correlations in yields of particular interest, given earlier, also substantiate this conclusion.

Logically, the next step in advancing our knowledge of interregional correlations in wheat yields in North America would be to proceed with a further explanation of the correlations established or with an explanation of the fact that significant correlations among variations in wheat yields do not exist for some regions. Such explanations, however, would require a more detailed analysis of factors determining variations in regional wheat yields in several regions than has yet been made. They would also require a detailed study of interregional correlations among weather elements such as seasonal rainfall and temperature.

As yet very little has been done in this direction by American meteorologists, in spite of the fact that factual data on local meteorological observations have been accumulated for sufficiently long periods. We hope that statistical analysis of these data, with the purpose of obtaining generalized conclusions, will be undertaken in connection with efforts directed toward the practical purpose of seasonal weather forecasting. This subdivision

[18] Yields in Saskatchewan move in the same direction as those in Manitoba in 26 out of 35 years, and as those in Alberta in 25 out of 35 years.

[19] The yield of winter wheat in Ontario varies with still less agreement with spring-wheat yields in the Prairie Provinces of Canada. Consequently, it was not reasonable to add Ontario Province to this region. As the Ontario wheat area is not large enough to be treated as a separate wheat region, it was decided to omit it completely from the correlation analysis.

of the North American continent into weather districts with specific characteristics, in contrast with climatic districts, may be envisaged as a final result of such generalization of weather data. Generalization of meteorological data of this type would contribute also to a better explanation of the correlations in yields established in this study.

IV. INTERREGIONAL CORRELATIONS OF WHEAT YIELDS IN OTHER CONTINENTS

Europe ex-Russia

Europe is another continent where wheat is widely cultivated. Abundant crop statistics, extending over long periods of years for several countries, make it possible to study in some detail relationships between variations in wheat yields in various wheat regions of that continent. The uniform analysis of these relationships for Europe is, however, more difficult than for North America, mainly because the crop statistics available vary from one country to another as regards both quality and duration. For several countries reliable crop statistics do not extend beyond the beginning of the current century. For a few others, statistics are not sufficiently reliable even after that date. Furthermore, because of boundary changes following World War I, long series on crop yields and production for comparable regions are not always available, even for the countries where such statistics have been collected from an early date. Hence it was necessary to omit from the study of correlations among wheat yields several European countries for which it was impossible to obtain reliable statistics on yields for a sufficiently long period.[1] For similar reasons, Table 4, summarizing interregional correlations of wheat yields in Europe, also does not include the Russian wheat regions. Correlations of regional wheat yields in Russia, among themselves and with yields in certain European regions, are discussed separately.

Correlations among wheat yields in Europe were studied, as were those in North America, mainly for the major wheat regions and not for their smaller subdivisions. Preliminary analysis indicated that fairly close direct relationships existed between wheat yields in the smaller subdivisions of practically all of the major wheat regions of Europe ex-Russia. Consequently, the major wheat regions may be regarded as sufficiently homogeneous with respect to variations in yields, and a study of correlations among yields in those regions may give a fairly satisfactory general picture of correlations of yields in Europe. However, the two subregions of Northern Europe included in this analysis—the Western subregion and Germany—are treated as separate regions. It was established that there is not much correlation between variations in wheat yields in the British Isles, the major part of the Western subregion of Northern Europe (called in this study Northwestern Europe), and in Germany; the coefficient of correlation between yields in these two countries, +.19 for the period 1882–1935, is not significant.[2] This lack of homogeneity in variation of yields and substantially different climatic characteristics of most of Germany, in comparison with Northwestern Europe (the climate of the former is the more continental), suggested this break into two regions for the purpose of correlation analysis.

With this modification, six major wheat regions were included in the correlation anal-

[1] It was found advisable to omit from this analysis the Eastern subregion of Northern Europe, including Poland, the three Baltic States, Finland, Austria (postwar), and Bohemia, Moravia, and Silesia in Czechoslovakia. For purposes of our analysis, crop statistics for this region for years prior to 1919, compiled from heterogeneous sources, appeared unsatisfactory. Also omitted were Albania and Greece in Southeastern Europe, and Portugal and French Morocco in the Western Mediterranean region, which were excluded likewise from our previous analysis of variability of wheat yields because of the lack of reliable crop statistics except for recent years. For years preceding 1901 the crop statistics available for Bulgaria, Serbia, Spain, and Tunisia are not very reliable. This reflects on the quality of the series in wheat yields in the Southeastern European and in the Western Mediterranean regions, in which these countries are included.

[2] Even within the Western subregion itself, consisting of the British Isles, Belgium, the Netherlands, and the three Scandinavian countries, correlations between wheat yields in separate countries are far from close. But it was not advisable to go into a further subdivision of that region, which is more or less homogeneous climatically.

ysis summarized in Table 4. From this table it appears that wheat yields in the various regions of Europe ex-Russia are in closer relationship among themselves than regional yields in North America. Indeed, for 8 out of the 15 possible paired combinations of six regions, significant direct correlations were established.[3] This means that in more than a half of the total number of possible combinations of regions significant direct correlations existed among regional wheat yields.

TABLE 4.—CORRELATIONS BETWEEN WHEAT YIELDS (DEVIATIONS FROM TRENDS) IN SPECIFIED WHEAT REGIONS OF EUROPE EX-RUSSIA†

Region	Relationship[a]	Northwestern Europe 1889–1935	Germany 1889–1935	Southeastern Europe 1889–1933	France 1889–1935	Italy 1889–1935
Germany 1889–1935	+	29				
	—	18				
	0	0				
	r	+.39**				
Southeastern Europe 1889–1933	+	21	31			
	—	24	14			
	0	0	0			
	r	..[b]	+.30*			
France 1889–1935	+	36	30	23		
	—	10	16	21		
	0	1	1	1		
	r	+.67**	+.53**	..[b]		
Italy 1889–1935	+	32	30	25	28	
	—	15	17	20	18	
	0	0	0	0	1	
	r	+.40**	+.37*	..[b]	+.49**	
Western Mediterranean 1889–1935	+	30	25	23	23	30
	—	16	21	21	22	16
	0	1	1	1	2	1
	r	+.36*	..[b]	..[b]	..[b]	+.25

† For definition of regions and sources of statistics, see source footnote to Table 1, p. 217.

[a] For explanation of relationships, see pp. 217–18.

[b] Correlation coefficients were not computed.

* Coefficient of correlation significant at 5 per cent significance level.

** Coefficient of correlation significant at 1 per cent significance level.

It is well to remember here that in only one-third of the possible relationships among regional wheat yields in North America were significant correlation coefficients established, and that one of these was negative, pointing to an inverse relationship of yields. The uniformity in the variation of wheat yields in Europe ex-Russia is thus greater than in North America.[4]

A close direct relationship among wheat yields was particularly characteristic of the following four wheat regions of Europe: the Northwest, France, Germany, and Italy. In all the possible paired combinations of these four regions (6), significant direct correlations in yields were established (5 of them highly significant). Some of these correlation coefficients are not only highly significant, but also relatively large. For instance, the correlation coefficient between wheat yields in Northwestern Europe and in France is +.67 for the period 1889–1935.[5] There was also a close direct relationship between the variation in wheat yields in France and in Germany (the coefficient of correlation for the period 1889–1935 is +.53), and between that in France and in Italy (coefficient +.49). A highly significant correlation was established also between wheat yields in Germany and in Northwestern Europe, in spite of the fact that the variations of yields in Germany and in the British Isles were little related. This must be explained by a better agreement between variations in yield in Germany and in other parts of Northwestern Europe, particularly the

[3] Five of the eight significant correlation coefficients are significant at 1 per cent significance level and may therefore be called highly significant. Three others are significant at 5 per cent significance level. The minimum number of like signs indicating a significant correlation in the case of 47 observations, as is the case for all comparisons presented in the table except those in which Southeastern Europe is involved, is 31. It thus appears that, on the basis of this test, correlations are significant only in three cases out of fifteen. But we know that the efficiency of this test of significance is low (see footnote 5, p. 218), and, consequently, correlation coefficients were computed also in those cases in which the number of like signs, although below the required minimum (31), substantially exceeded one-half of the total number of observations.

[4] Our study on variability in wheat yields in the two continental areas, in which was disclosed a greater degree of compensation of variations in regional wheat yields in North America than in Europe ex-Russia, led us to expect this result. WHEAT STUDIES, March 1943, XIX, 177–78.

[5] This relationship apparently persisted over a longer period of time. This appears from the fact that the coefficient of correlation for the period 1856–1935 between yields in France and in the British Isles, which dominates the series for Northwestern Europe, is +.59, only slightly smaller.

Scandinavian countries (for the last, a coefficient of correlation of +.58 was established for the period 1882–1935).

These four regions cover practically all the countries of Europe that normally import wheat in large quantities. Some of them, it is true, became nearly self-sufficient in wheat during the years immediately preceding World War II. But under normal conditions, these regions represent the principal wheat-deficit area of the world. The close agreement in the variation of wheat yields in this area results in a substantial fluctuation in the demand for imported wheat for Europe as a whole, despite the fact that the variability of wheat yields in the individual countries is relatively small, much smaller than in practically all wheat-exporting countries.[6]

Wheat yields in the two other regions of Europe ex-Russia—Southeastern Europe and the Western Mediterranean—do not vary in close relationship with yields in the four regions just discussed. This is evident from the fact that in only one out of the five possible relationships of these regions to other wheat regions of Europe ex-Russia were significant correlations established between variations in wheat yields. Yields in the Western Mediterranean vary in direct correlation with those in Northwestern Europe, and those in Southeastern Europe with those in Germany. Both correlation coefficients are significant but relatively low.

We must remember here that crop statistics in both the Southeastern European and Western Mediterranean regions are not very reliable for years preceding 1901 (p. 240). Consequently, this makes the respective correlations also questionable. However, the fact that there is no close correlation between wheat yields in these two regions and in other wheat regions of Europe ex-Russia can be substantiated by specific meteorological characteristics of these regions. Therefore, it need not be much questioned on the basis of the quality of the statistical data.

The significant direct correlation between wheat yields in the Western Mediterranean region and in Northwestern Europe depends mainly on the correlation between yields in the North African portion of the Western Mediterranean area and in the British Isles, while variations in wheat yields in Spain do not correlate with those in the British Isles or with those in the other neighboring wheat regions of Europe—France and Italy. Indeed, the coefficient of correlation between wheat yields in the British Isles and in French North Africa (+.47 for the period 1889–1935) is highly significant,[7] while the wheat yield in Spain does not show any systematic relationship with that in the British Isles, and the coefficients of correlation between wheat yields in Spain and those in France and Italy, although positive, are too small to be significant (for the same period they are +.09 and +.16 respectively). This situation with respect to Spain may be explained perhaps by the fact that, from the meteorological point of view, the Iberian peninsula may be regarded as a separate continent.[8]

The situation in Southeastern Europe is in some respects similar to that in the Western Mediterranean wheat region. Two subregions of that region, the Eastern (consisting of Rumania in its 1914 frontiers and Bessarabia) and the Southern (Bulgaria), are dominated by meteorological factors different from those dominating western and central Europe. The valley of the Danube within Rumania and Bulgaria, where wheat is mainly produced, is dominated by north and east winds in contrast to the westerlies that dominate in western and central Europe. The northeast winds bring into this area the influence of the Russian steppe, and the greater portion of the rain in Rumania also falls under their influence.[9] The

[6] WHEAT STUDIES, March 1943, XIX, 197–98, Appendix Table I.

[7] Wheat yields in French North Africa are also in highly significant direct correlation with those in Spain (the coefficient of correlation for the period 1889–1935 is +.51) and with those in Italy (the coefficient of correlation for the same period is +.45). They should also be in significant correlation with those in France, since yields in the latter country are in significant direct correlation with yields in Algeria, the wheat crop of which composes the major portion of the French North African crop. The coefficient of correlation for variation of wheat yields in France and in Algeria for the period 1879–1935 is equal to +.34.

[8] For characteristics of the meteorological regime of the Iberian peninsula as described by Teisserenc de Bort, see *Handbuch der Klimatologie* by Julius Hann (Stuttgart, 1911), pp. 103–04.

[9] *Ibid.*, p. 157.

climate in eastern Rumania and northern Bulgaria is, thus, a transition to that of eastern Europe. But the Western subregion of Southeastern Europe (consisting according to our definition of Hungary, Yugoslavia, and the northwestern portion of Rumania, which before the war of 1914–18 belonged to the Austro-Hungarian Empire) belongs in central Europe with respect to climate and to factors influencing weather variations. However, this must not be understood to mean that southeastern Europe lacks homogeneity in respect to yield variations. On the contrary, a significant direct correlation exists between variations in wheat yields in the Eastern and Western subregion of Southeastern Europe. Yields in Bulgaria also tend to vary in direct relationship with yields in both subregions to the north of it. In spite of this, certain peculiarities in the variations of wheat yields in the Western portion of Southeastern Europe bring yields in that area into closer relationship with yields in other wheat regions farther west and northwest. When wheat yields in the Western subregion of Southeastern Europe are compared with those in Germany, the correlation is highly significant (the coefficient of correlation for 1889–1933 is +.43). They also correlate significantly with yields in Italy (the coefficient of correlation for the same period is +.32). They tend to vary in direct relationship with yields in France, although the coefficient of correlation (+.13) is not significant.

In contrast with this, there is no correlation between wheat yields in the Eastern subregion of Southeastern Europe and those in Germany or in Italy. Furthermore, wheat yields in the Eastern portion of Southeastern Europe tend to vary in the opposite direction from those in France and from those in Northwestern Europe. The negative coefficient of correlation between yields in France and in the Eastern portion of Southeastern Europe (−.34 for the period 1889–1935) is significant. The tendency to a negative relationship with yields in the British Isles is less pronounced but still well marked. These are the only indications of the negative relationship between variations in wheat yields in Europe, a relationship that is more pronounced in North America.

This tendency to a negative correlation between wheat yields in the British Isles and in France compared with those in the Eastern part of Southeastern Europe is not easy to explain, as was also true of similar relationships in North America. Factors determining wheat yields have been studied statistically for European countries even less than for this country, and very little is known about the interregional correlations of various weather elements in Europe. The inverse relationship between wheat yields in these two areas of Europe may be explained without recourse to a hypothesis of an inverse correlation in weather in these regions. Wheat yields in northwestern France, a humid area, are affected unfavorably by greater than usual precipitation.[10] The same situation also exists, as we know (see p. 222), in the British Isles. On the contrary, the Eastern portion of Southeastern Europe suffers from droughts perhaps more than any other European wheat region excluding Russia. Consequently, negative relationships between wheat yields in Rumania compared with those in France and in the British Isles may exist concurrently with positive correlations in seasonal precipitation in the two areas. From the previous discussion, however, it seems probable that there is not much correlation between precipitation in Northwestern Europe, including northern France, and in Southeastern Europe.[11]

Returning now to the relatively close direct correlations between variations in wheat yields in the four regions making up the body of Europe ex-Russia, they may be explained to a certain extent (1) by the relative proximity of these regions; (2) by the similarity in climatic conditions in the greater part of the continent; and (3) by the fact that cyclones, which dominate weather variations over most of this territory, follow paths that interweave all these regions (see Chart 5, p. 244).

The hypothesis that direct correlations between variations of yields are caused by sim-

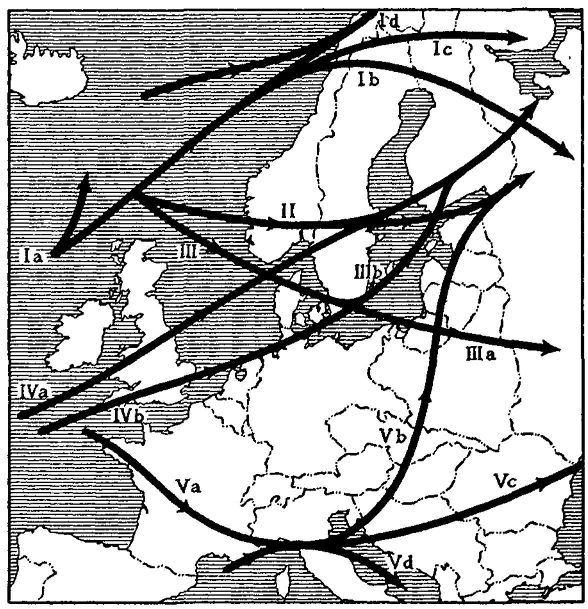
[10] Joseph Sanson, *L'Atmosphère et l'Agriculture* (Paris, 1932), pp. 53, 85.

[11] We encounter similar difficulties when we try to explain the highly significant direct correlation between variations in wheat yields in the humid British Isles and in the subhumid and semi-arid French North Africa (see p. 242).

ilar correlations between variations in weather elements appears to us much more reasonable when applied to the limited area of the four European regions now being discussed than when applied to the entire territory of North America. In these four European regions, no such contrasts in climatic characteristics exist as do in North America. Practically their entire territory (except Southern Italy) may be divided between two types of climates, both of which are humid. The northwestern portion has a humid marine climate, the southeastern a humid continental one.[12] Consequently, similar variations in seasonal rainfall in this territory can hardly result in an inverse variation in wheat yields; or a tendency to inverse variations in seasonal rainfall, if such exists, should not result in positive correlations in yields. Such relationships appeared probable in North America and, perhaps, also between northwestern Europe and eastern Rumania, with its climate transitory to the steppe climate of southeastern Russia; and they may prevail also between the British Isles and French North Africa. But they can scarcely exist within the territories of the four European regions now under discussion. There, similarity of weather variations, caused by the influences of cyclones, may sufficiently explain the positive correlations between variations in wheat yields characteristic of these regions.

In this respect, considerable importance is attached to the influence of cyclones traveling over paths IV_a and IV_b—the routes followed by cyclones mainly in summer and autumn (Chart 5). These cyclones have great influence on the weather in central Europe,[13] and they also affect weather in the entire area of Northwestern Europe and probably in the northern portion of France. Cyclones traveling on the route V_a, less frequent than those traveling on routes IV_a and IV_b and passing mainly in winter, must influence weather in the southern part of the British Isles, in France, and in northern Italy. Very important are the cyclones traveling on track V_b, which runs from northern Italy through the Western portion of Southeastern Europe and then through Poland and along the Baltic Sea on its eastern shores. This route is followed by cyclones mainly in the summer half of the year. They bring rain in spring and summer to Hungary, Austria, and Sudeten,[14] and must also affect weather in eastern Germany and in Italy.

Chart 5.—Paths of Cyclones in Europe*



* Adapted from Julius Hann and Reinhard Süring, *Lehrbuch der Meteorologie* (Leipzig, 1926), Fig. 56, p. 524.

The net of the cyclonic paths thus connects all four regions in which wheat yields vary fairly closely together. On the other hand, the two regions in which yields vary differently, except the Western portion of Southeastern Europe discussed earlier, lie outside this net. Because Europe lies further north than the United States, its weather, even in summer, is more dependent upon cyclonic storms; and the paths of cyclones even in that season pass over the most important wheat regions of Europe ex-Russia. In this perhaps lies the explanation of the fact that regional wheat yields in Europe ex-Russia are generally in closer direct relationship among themselves than are wheat yields in the several regions of North America.

[12] According to the classification used by T. A. Blair, *Climatology, General and Regional* (New York, 1942), map facing p. 478.

[13] Julius Hann and Reinhard Süring, *Lehrbuch der Meteorologie* (Leipzig, 1926), p. 523.

[14] *Ibid.*, pp. 524–25.

EUROPEAN RUSSIA

Regional series on wheat yields in European Russia were not included in Table 4 (p. 241), summarizing correlations among regional wheat yields in Europe, partly because prewar and postwar crop statistics in the territory of the USSR are not quite comparable. This limited comparability is due not only to several changes in the methods of crop reporting but also to numerous shifts in the boundaries of crop-reporting areas. It is practically impossible to obtain series on yields in Russia for a sufficiently long period in identical regions. The difficulty was only partly overcome by taking only three wheat regions of a relatively large size, covering the main wheat-producing area in southeastern European Russia. These regions are (1) Ukraine, including Crimea, (2) the North Caucasus, and (3) the Volga region.[15] In the first two regions, yields of winter and of spring wheats are given separately, but for the Volga region the yield of spring wheat alone is included in this study, since winter wheat is of minor importance there. Wheat production in the area northwest of these three regions is left out of consideration, but until recently wheat was only of secondary importance there.

Regional wheat yields in this limited area of the USSR[16] were studied, first, to establish interregional correlations in yields within the area itself; and second, to find out if there were significant correlations between variations in wheat yields in the Russian regions and in the European regions discussed earlier.

[15] For detailed definition of regions and of sources of crop statistics, see WHEAT STUDIES, April 1942, XVIII, 332–33.

[16] Crop statistics for the Asiatic provinces of Russia began to be reported only lately, and hence they are not included in the present study. However, wheat production in the three regions included in this study composed by far the greater portion of the total in European Russia. The variation in wheat yields in this area even dominated the variation in yields of the entire USSR. This is evident from the fact that the series on the average (weighted) wheat yield for the three regions included in this study varies in close agreement with the wheat yield for the entire USSR (as adjusted in WHEAT STUDIES, April 1933, IX, 265). Indeed, in 37 out of the 42 years covered by the comparison (1889–1930), wheat yields in both series departed in the same direction from their respective trends, and practically all peaks and troughs in the two series coincide.

It may be stated at the outset that fairly close direct correlations among regional wheat yields were found within the Russian wheat region, but that very little correlation was established between variations in yields in Russia and in Europe ex-Russia.

Correlations between the Russian regional wheat yields are summarized in Table 5, which presents the relationships between five

TABLE 5.—CORRELATIONS BETWEEN WHEAT YIELDS (DEVIATIONS FROM TRENDS) IN SPECIFIED WHEAT REGIONS OF EUROPEAN RUSSIA†

Region	Relationship[a]	Ukraine Spring 1887–1930	Ukraine Winter 1887–1930	Volga Spring 1887–1930	North Caucasus Spring 1896–1930
Ukraine, Winter 1887–1930	+	33			
	—	10			
	0	1			
	r	+.74**			
Volga, Spring 1887–1930	+	23	23		
	—	20	21		
	0	1	0		
	r	..[b]	..[b]		
North Caucasus, Spring 1896–1930	+	22	20	22	
	—	10	13	11	
	0	3	2	2	
	r	+.40**	+.24	+.57**	
North Caucasus, Winter 1896–1930	+	23	27	25	23
	—	11	8	10	10
	0	1	0	0	2
	r	+.50**	+.57**	+.52**	+.70**

† See source footnote to Table 1, p. 217.
[a] See pp. 217–18 for explanation of relationships.
[b] Correlation coefficient not computed.
** Significant at 1 per cent significance level.

series on yields (three for spring wheat and two for winter wheat) in the three regions. The table shows that highly significant coefficients of correlation were obtained for seven out of the ten possible paired relationships between five series. It is true that the two largest coefficients characterize the relationship between yields of winter and of spring wheats within the same regions (they are respectively +.74 for Ukraine and +.70 for the North Caucasus). However, even in these cases coincidence of the regions is only nominal, for cultivation of winter and spring wheats was not evenly spread over the territory of the Ukraine or the North Caucasus. In Ukraine, winter wheat is cultivated mainly in the western portion and on the Crimean peninsula, while spring wheat is grown mainly in the northeastern portion. The distribution of winter and spring wheat is also similar within the North Caucasus, where winter wheat occupies the southwestern half and spring wheat the northeastern. Consequently, these two correlation coefficients characterize not only intervariety relationships but also interregional relationships, although they are between yields in closely proximate and partly overlapping regions. However, a fairly close direct correlation also exists between yields of winter and of spring wheats in Russian wheat regions that are not proximate. This is confirmed by the coefficient of correlation (+.50) between the yield of spring wheat in the Ukraine and of winter wheat in the North Caucasus, and by the coefficient of correlation (+.52) between the yield of winter wheat in the North Caucasus and of spring wheat in the Volga region. Only in the case of the yield of winter wheat in the Ukraine and of spring wheat in the North Caucasus was the correlation coefficient not large enough to be significant, although it was positive (+.24). Variations of winter wheat yields in the Ukraine and of spring wheat in the Volga region apparently are not related at all. They moved as frequently in opposite directions as in the same, and consequently it was found unnecessary to compute the correlation coefficient.

The highly significant direct correlation between yields of winter and spring wheats in the North Caucasus and in the Volga region is of particular interest. In natural location these regions may be compared to the United States Hard Winter region and the spring-wheat belt in the Canadian Prairie Provinces. The distance between the centers of the respective regions (some 800 miles) is also about the same. In North America, the yield of hard winter wheat tended to vary in the opposite direction from that of spring wheat in Canada, although the negative correlation coefficient was hardly significant, whereas a highly significant direct correlation exists between the yields of winter wheat in the North Caucasus and of spring wheat in the Volga region. This clearly indicates that the relationships between variations in winter and spring wheat yields in Russia are quite different from those in North America. Variations of yields in Russia are much more uniform.

Interregional correlations between yields of the same class of wheat—winter or spring wheat alone—appear even closer than those between winter and spring wheats, as the respective correlation coefficients in Table 5 indicate. Consequently, there is generally more uniformity in the variations of regional wheat yields in the principal wheat regions of European Russia than in North America. But greater uniformity in the variation of regional yields means also greater variability in total wheat production. It is a well-known fact that the total wheat production in the principal wheat-producing area of European Russia is very unstable.

However, it also appears from the table that variations of wheat yields in the Volga region are related very little to variations of both winter and spring wheats in the Ukraine. Wheat yields in the Ukraine and in the Volga region moved as frequently in the opposite as in the same direction. The lack of correlation between yields in these two areas may appear somewhat surprising, in the light of the fact that the eastern European steppe, which is fairly uniform in its climatic characteristics, extends over the southern Ukraine as well as over most of the Volga wheat region. There are, however, certain differences in the meteorological factors that control weather variations in the Ukraine and the North Caucasus on the one side and in by far the greater portion of the Volga region on the other.

In respect to the direction of prevailing winds, eastern Europe, as well as Siberia, must be divided into two parts. Voeikoff, the Russian geographer and meteorologist, established a dividing line, which he called the great continental axis. It extends from western Siberia, at a latitude of about 53° N., through Stalingrad on the Volga, across the most eastern bend of the Dnieper, and then to the Carpathian Mountains north of Kishinev. This line represents a crest of the extension of the Asiatic winter high-pressure area into the southern part of middle Europe (about 47° N. latitude). In the area north of this line, west or southwest winds prevail, and its weather is therefore under the influence of the Atlantic barometric low, which extends into the European Arctic. South of the great continental axis, east and southeast winds prevail, particularly in winter.[17]

Consequently, weather controls in these two parts of eastern Europe are substantially different. Most of the Ukrainian wheat region and the entire region of the North Caucasus lie to the south of the continental axis, while by far the greater portion of the Volga wheat region is to the north of it. Consequently, weather developments in the Volga region are controlled by the same factors as in central and western Europe, while in the Ukraine and the North Caucasus these controls are different. This may, to a certain extent, contribute to an explanation of the fact that wheat yields in the Ukraine and in the Volga region are related so little. However, a similar relationship regarding weather controls between the North Caucasus and the Volga region, which are more proximate, does not prevent the existence of a fairly close correlation between wheat yields in these two regions. Perhaps the proximity or remoteness of respective regions is of greater importance than differences in weather controls.

This distinction between the two areas of eastern Europe in respect to factors controlling weather developments must be taken into account also in the discussion of correlations between regional wheat yields in Russia and in Europe west of Russia. It indicates that, in respect to weather developments, the Ukraine may have much in common with the Eastern subregion of Southeastern Europe, while the Volga region may have much in common with central and western Europe. The last relationship, however, should be weakened considerably by the great distance between the Volga region and western Europe, and the remoteness of the two areas may overshadow the similarity in weather controls. The last statement is supported by the fact that, generally speaking, little correlation was found between variations of wheat yields in Russia and in Europe west of Russia. A considerable degree of independence between variations in wheat yields in these two areas may be demonstrated in two ways: (1) by comparison of variations in average wheat yields for the entire Russian wheat area included in this study with those for Europe ex-Russia, and (2) by a more detailed comparison of variations in wheat yields in the individual regions of the two areas.

The immediate impression from the first approach to the problem is that there is a well-pronounced tendency for wheat yields in the two areas to vary in the same direction. Indeed, in 27 years out of 45 (1889–1933) average wheat yields in both areas departed in the same direction from the respective trends, and in only 16 years were these departures in the opposite direction. Still, the number of years when yields departed in the same direction is not large enough to indicate a significant direct correlation.[18] Furthermore, a more attentive study of the two series indicates that exceptionally good crops in one area coincide more frequently with exceptionally poor in another than exceptionally good (or exceptionally poor) crops occur simultaneously in both areas.

Indeed, of the ten best wheat crops in each of the two areas for the period 1889–1933,[19] only two coincide—in 1913 and in 1925. Similarly, only two out of the ten worst crops in each area coincide, namely, in 1897 and in 1924. But in four years when Russian crops were among the ten best—1904, 1922, 1926, and 1930—crops in Europe ex-Russia were among the ten worst. Inversely, in three years when Russian crops were among the ten worst—namely 1906, 1911, and 1921—crops in Europe ex-Russia were among the ten best. Thus, extreme departures of yields from the normal in the two areas more frequently tend to be in the opposite rather than in the same direction. Hence it is hardly possible to speak of a systematic direct relationship between variations in wheat yields in the two areas. A

[17] Hann, *Handbuch der Klimatologie*, pp. 274–77.

[18] A minimum of 30 like signs is required, according to Cochran's test of significance, to indicate a significant correlation between two variables in 45 observations. See footnote 5, p. 218.

[19] The ten worst and ten best crops were selected according to the size of deviations of yields from respective trends. Average wheat yields for Europe ex-Russia, used in this comparison, were computed for the area including the Eastern subregion of Northern Europe, a subregion not included in Table 4, p. 241.

tendency to an inverse relationship is not excluded.[20] As no one tendency definitely prevails, variations of the average wheat yields in the two areas appear to be little related, although perhaps they are not quite independent.

This conclusion finds further support from the more detailed comparisons of variations of regional wheat yields in the two areas presented in Table 6. In this table six series on wheat yields in the Russian wheat regions (one of which presents average yields of winter and spring wheats for the three regions) are compared with similar data for six European countries or regions. The table records only directions of the departures of yields from the respective trends; no correlation coefficients were computed. As in the previous tables, the upper figure in each intersection of the columns and rows, designated by a plus sign in the left column, indicates the number of years when yields in the two regions (indicated by the designations of the respective columns and rows) departed in the same direction from the respective trends. The second figure, designated by a minus sign, indicates the number of years when yields departed in the opposite direction. Finally the last figure indicates the number of years when yields in one or both of the respective regions did not depart at all from the trend.

TABLE 6.—CORRELATIONS BETWEEN WHEAT YIELDS (DEVIATIONS FROM TRENDS) IN SPECIFIED REGIONS OF RUSSIA AND IN EUROPE WEST OF RUSSIA†

Region	Relationship	Ukraine Spring 1887–1930	Ukraine Winter 1887–1930	Volga Spring 1887–1930	N.Cauc. Spring 1896–1930	N.Cauc. Winter 1896–1930	Three Regions, Winter Spring together[a]
British Isles 1887–1935	+	16	19	22	19	16	19
	—	24	22	19	13	16	22
	0	4	8	3	3	3	3
Germany 1887–1935	+	25	28	25	18	18	26
	—	18	16	19	15	17	18
	0	1	0	0	2	0	0
France 1887–1935	+	18	18	26	20	17	24
	—	24	25	17	12	17	19
	0	2	1	1	3	1	1
Italy 1889–1935	+	18	25	18	14	17	19
	—	23	17	24	19	18	23
	0	1	0	0	2	0	0
Southeastern Europe, East 1889–1934	+	24	29	17	18	20	24
	—	15	11	23	13	13	16
	0	3	2	2	4	2	2
Southeastern Europe, West 1889–1934	+	18	26	20	19	19	26
	—	22	15	21	13	15	15
	0	2	1	1	3	1	1

† See source footnote to Table 1, p. 217.
[a] For 1887–1895 the average yield for spring and winter wheat is given for Ukraine and the Volga region only.

It appears from an analysis of these figures that very little correlation exists between regional wheat yields in the two areas. In only one case—for yield of winter wheat in Ukraine and wheat yield in the Eastern subregion of Southeastern Europe — does the number of plus signs reach the minimum required to indicate a significant direct correlation between variations in yields. In all other cases, the numbers of like signs are below the required minimum.[21] It is of interest to notice that the only established significant correlation (direct) is between yields in two contiguous regions—the Ukraine and the Eastern subregion of Southeastern Europe—in which climatic conditions and weather controls are closely similar. Tendencies to a direct relationship, not significant but still marked, are also more characteristic of relatively proximate regions.

In several cases there are slight indications of an inverse relationship between variations

[20] The possibility of such a tendency to an inverse relationship between yields in middle Europe and in Russia finds some support in the assertion of Hann that there is a certain causal relationship between hot summers in Russia and cool and moist summers in middle Europe. The first may condition the second. It occurs frequently, says Hann, that the higher the temperature rises in Russia in the summer and the farther a drought develops, the more persistent become the northern and northwestern winds in middle Europe that bring cool and moist weather. See *Handbuch der Klimatologie*, pp. 241–42.

[21] As the efficiency of Cochran's test of significance is low, it is probable that significant but small correlation coefficients might be obtained in a few cases, where the number of like signs, although below the required minimum, approaches it. Such a situation may occur in the following cases: (1) for yield of winter wheat in Ukraine and wheat yield in Germany; (2) for yields of winter wheat in Ukraine and wheat yield in the west of Southeastern Europe; and (3) for yield of spring wheat in the Volga region and wheat yields in France. The probability of significant correlations in all other cases appears still smaller since the numbers of like signs are considerably below the required minimum.

in regional wheat yields, but in no case are these relationships sufficiently pronounced to be significant. It is of interest to notice, however, that yields of both spring and winter wheat in the Ukraine tend to vary in the opposite direction from wheat yields in France and in the British Isles. We know that a significant inverse correlation was established between variations in wheat yields in France and in the Eastern portion of Southeastern Europe. In this respect the Ukrainian wheat region, contiguous to Southeastern Europe, shows the same characteristics, perhaps owing to a similarity in weather controls. In contrast to this, yields of spring wheat in the Volga region tend to vary in the same direction as yields in France and, to a smaller degree, in the British Isles. This may result from the difference in weather controls in the southern Ukraine and in the Volga region to the north of Stalingrad, discussed earlier. There are other cases when slight tendencies to an inverse relationship between variations in yields appear, particularly between wheat yields in most of the Russian regions and in Italy. But in all these cases they are not pronounced enough to warrant discussion. The two series on wheat yields in the North Caucasus are too short (1896–1930) to supply conclusive evidence concerning their correlation with wheat yields in the European regions.

The general conclusion from the two approaches to the relationship between wheat yields in Russia and in Europe west of Russia is that, except in the cases of contiguous or fairly proximate regions, there is little correlation between variations in yields in these two areas. In connection with this, it is necessary to point out that our previous conclusion that there is a greater degree of correlation between regional yields within Europe ex-Russia than within North America might need to be qualified if wheat yields in the Russian regions were included in the European series.

AUSTRALIA

Australian crop statistics are more complete than those for other continents, and they run as far back as 1860. This makes it possible to undertake a study of interregional correlations in wheat yields also for that continent. Of course, the total wheat acreage within the four principal wheat-producing states of Australia studied here (see Table 7) is equal to only a fraction of the wheat acreage in North America or in Europe. In fact, total wheat acreage in Australia is even smaller than that in such wheat regions as the United States Hard Winter region, the United States Spring wheat region, the Prairie Provinces of Canada, or Southeastern Europe. Consequently, the Australian wheat area may be regarded as one of the major wheat regions rather than as a continent. Still, the wheat-producing regions, although limited to the southern part, extend from east to west the entire width of the continent. It is true that only one region (the smallest one, located in Western Australia) is located apart; the three others compose a continuous area in the southeast of the continent. Consequently, only the relationships between wheat yields in Western Australia and in the other three regions—New South Wales, Victoria, and South Australia—may be regarded as relationships between yields in remote regions.

Table 7 presents in the usual manner six relationships between wheat yields in the four Australian states. It appears from the table that all six correlation coefficients, corresponding to the number of possible paired

TABLE 7.—CORRELATIONS BETWEEN WHEAT YIELDS (DEVIATIONS FROM TRENDS) IN FOUR AUSTRALIAN STATES†

Region	Relationship[a]	New South Wales 1864–1935	South Australia 1864–1935	Western Australia 1872–1935
South Australia 1864–1935	+	46		
	—	24		
	0	2		
	r	+.40**		
Western Australia 1872–1935	+	42	38	
	—	19	23	
	0	3	3	
	r	+.38**	+.43**	
Victoria 1864–1935	+	45	51	40
	—	24	18	20
	0	3	3	4
	r	+.69**	+.60**	+.51**

† See source footnote to Table 1, p. 217.
[a] For explanation of relationships, see pp. 217–18.
** Significant at 1 per cent significance level.

combinations of four regions, are highly significant. The coefficients of correlation are the largest between yields in contiguous states—Victoria and New South Wales, and Victoria and South Australia. For the period 1864–1935 these are +.69 and +.60 respectively. But the coefficient of correlation between wheat yields in such remote regions as Victoria and Western Australia is also fairly large (for the period 1872–1935 it is +.51). The smallest correlation coefficient is for wheat yields in Western Australia and New South Wales (+.38). The climates of these last two regions differ most among all Australian regions under discussion. In the wheat region of Western Australia, rainfall is concentrated in the winter months, and it is fairly reliable; in the greater part of the New South Wales wheat region, most of the rainfall is in summer, and it is rather unreliable. But even here the correlation between variations in wheat yield is highly significant. There is no sign of an inverse relationship between wheat yields in the four Australian wheat regions.[22]

It appears, thus, that the direct relationships between wheat yields within Australia are closer than they are for other continents discussed earlier. It was natural to expect this, because the territory is smaller and because the Australian wheat regions lie in closer proximity to each other than in Europe and in North America. The similarity in weather controls in the four principal wheat regions of Australia, especially in the area where winter rain prevails, must be indicated as another factor contributing to a close direct relationship between variations in wheat yields. Winter rains, which prevail throughout the entire wheat regions of Western and South Australia, in the greater part of the Victorian wheat region, and in the southern portion of New South Wales, are largely associated with the more northerly path of the Antarctic cyclones in the winter season. The Antarctic cyclones, which determine the rain in the southern littoral in Australia, move around Antarctica more or less regularly from west to east. In the winter time, the southern coast of Australia comes under the influence of the northern portions of the procession of these cyclones.[23] Hence, the weather developments, particularly of rainfall, must have some common characteristics in the four principal wheat regions of Australia. This is less true of the northwestern portion of the New South Wales wheat region, where rain falls mainly in the spring and summer. As the rainfall during the winter half of the year (April–September) is the major factor determining wheat yields in the four regions of Australia, there should be close correlation between regional wheat yields in Australia.

Partly because of the close correlation between variations in regional wheat yields in Australia, total production of wheat also varies widely. The variability of both the average yield and the total output of wheat is greater in Australia than in any other wheat-exporting country, although it declined somewhat during the interwar period 1919–35.[24]

Available wheat statistics for the Asiatic and South American continents relate only to small portions of these continents. Consequently, the data are not sufficient to discuss interregional correlations among yields in remote regions of these continents. However, little correlation among regional wheat yields was found even within the limited areas of these continents for which the necessary crop statistics are available. It was found that variations of regional wheat yields in India, for such regions as Northwest, Northeast, and South, are little related. Also, significant correlations were not found between variations of wheat yields in Argentina and Uruguay, in spite of the proximity of their wheat regions. Still less correlation among variations in regional wheat yields on these continents should be expected if other, more remote regions could be included in the analysis.

22 We did not study the relationships between wheat yields in the four states mentioned and in the more humid areas of Queensland and Tasmania, where wheat production is small.

23 Griffith Taylor, *Australia* (New York, 1943), pp. 56–66.

24 During the same period, variability in wheat yields and outputs was somewhat greater in Canada than in Australia. As we know, correlations of provincial wheat yields within the Prairie Provinces of Canada are also fairly close, and the variability of provincial yields increased there from 1901–18 to 1919–35. WHEAT STUDIES, March 1943, XIX, 197–98, Appendix Table I.

V. CORRELATIONS AMONG WHEAT OUTPUTS

In this section we undertake a study of correlations among variations of wheat outputs in the principal wheat-exporting and wheat-importing countries (or groups of countries) of the world. The emphasis here is somewhat different from that in the study of interregional correlations in yields. The ultimate purpose there was to explain established correlations between regional yields in terms of interregional relationships between the factors determining yields. It is true that, because of insufficient knowledge about the factors determining variations in regional yields, and particularly about the interregional relations between these factors, it was not possible to do more than to supply a few suggestions in the direction of an explanation. But the ultimate purpose, to a considerable extent, influenced our approach to the study of interregional correlations in wheat yields, for it determined the selection of the regions. With this purpose in view, wheat regions selected had to be at least moderately homogeneous with respect to variations in yields and to factors determining those variations. Only by selecting suitable wheat regions is an approach to such explanation of interregional correlations in yields possible.

In our study of correlations among variations in wheat outputs in the principal wheat-exporting and wheat-importing countries, we undertake to supply data necessary for analysis of the world wheat market rather than to go into the explanation of these correlations. For this reason, the criteria used as a basis for selecting the regions for this analysis were different from those determining the selection of regions for the study of interregional correlations in yields. The economic or commercial characteristics of regions, their economic entity, and their relation to the world wheat market, rather than their homogeneity in respect to variations in wheat output, provided the basis for the selection. It appeared that the most appropriate units would be the principal wheat-exporting and wheat-importing countries of the world; and, in order to simplify our analysis and to make it more economical, a few countries were grouped together. For instance, the wheat-importing countries of Northwestern Europe, all of which depend greatly on imported wheat, were grouped together in the same way as in the analysis of correlations in wheat yields. Similarly, wheat-exporting countries of Southeastern Europe were grouped together. On the other hand, the Western Mediterranean region was divided here into two parts: Spain was included with the wheat-importing countries of Europe, while French North Africa was regarded as one of the wheat-exporting regions. Wheat production in the USSR as a whole was taken instead of the regional wheat outputs in the three regions of European Russia. North American wheat production is represented by the wheat production of the United States and of Canada, instead of by the seven regional units used in the correlation analysis of wheat yields.[1]

In the interpretation of the established correlations among wheat outputs, it must be borne in mind that the factors which may cause these correlations are different in certain respects from those responsible for correlations in yields. Responses of farmers to such economic factors as prices very slightly affect year-to-year variations in wheat yields, the relationships between which are studied in our correlation analysis. The changes in yields caused by farmers' responses to economic stimuli are reflected mainly by slow changes in the trends of yields, the relationships between which are not reflected in our measures of correlations.

The situation is different with respect to wheat outputs. The changes in wheat acreage in response to economic stimuli may, under certain conditions, be quite sudden and erratic; consequently, they may cause year-to-year variations in total outputs that will affect not only the trends in output but also the variation around these trends. Hence, changes in wheat acreages, due to the influences of economic stimuli or other factors, may affect

[1] The regions used in the study of correlations among wheat outputs are the same as those used in the study of the variability in wheat outputs. For the sources of information, consult WHEAT STUDIES, April 1942, XVIII, 332–33.

correlations among wheat outputs to a considerable extent. In this respect, an interpretation of correlations among wheat outputs is more complicated than that among wheat yields. Year-to-year variations in outputs are dominated mainly by variations in yields, but in many cases the influence of sudden changes in acreage should not be neglected.

The fact that variations in output depend on changes in acreage introduces another complication into the interpretation of correlations among outputs. Variations in yields, as we know, have certain characteristics of random variations, while variations of acreage are far from random. In some cases, variations in acreage are definitely of a cyclical character, although this is hardly true of wheat acreages. At any rate, the nonrandom character of acreage variations results in the fact that fluctuations in regional wheat outputs diverge more from random fluctuations than do those in yields.[2] Consequently, the test of significance is less dependable when applied to correlations among wheat outputs than it was when applied to correlations among regional wheat yields. In connection with this, it is necessary to scrutinize and discriminate more carefully in interpreting the significance of correlations among wheat outputs than of those among regional yields. Correlations among outputs may be relied on as an indication for the future relations much less than those among yields. For these reasons, those correlations between wheat outputs that are in striking contradiction with respective correlations between regional yields will be particularly scrutinized. However, correlations between regional wheat outputs established in this study mostly confirm rather than contradict correlations between wheat yields in the comparable regions. This may serve as an additional check on the significance of both kinds of correlations.

Eight wheat-exporting countries (or groups of countries) and five wheat-importing countries of Europe were selected for the study of correlations among wheat outputs. There are 78 possible relationships between thirteen regional outputs, taking two regions at a time. Since the economic relationship between wheat-exporting countries, as competitors on the world wheat market, may differ from those among wheat importers, it was advisable for convenience in interpretation to break these 78 possible relationships into three separate groups: 28 relationships between wheat outputs in the eight wheat-exporting countries, 10 between wheat outputs in five wheat-importing areas of Europe, and 40 between wheat outputs of the eight exporters on the one side and the five importers on the other. These relationships are summarized in three separate tables.

Wheat Exporters

Table 8 presents the 28 relationships between wheat outputs in eight exporting countries or regions, including the four principal wheat exporters of the world, British India, the wheat exporters of Southeastern Europe, French North Africa, and the USSR. These eight regions represent fairly well all the important wheat-exporting countries of the world as well as all continents. As the wheat-exporting countries included in this analysis are spread throughout the world, by far the greater part of the relationships included in the table are between wheat outputs in remote areas located on different continents. Only four of the 28 combinations characterize relationships between wheat outputs in regions of the same continents.[3] But even in these cases the wheat-producing regions are fairly remote. In this respect, correlations between wheat outputs in the eight exporting regions are fairly comparable with intercontinental correlations in wheat yields discussed in the first section of this study. Under such circumstances, it was natural to expect that very little significant correlation will be found among wheat outputs in the wheat-exporting countries. An analysis of the table confirms this. Only two out of the 28 correlations may claim to be significant.

It is of interest to observe that none of the four relationships between wheat outputs in the regions belonging to the same continents

[2] Wheat Studies, April 1942, XVIII, 307–10.

[3] French North Africa is treated in this study as a part of the Mediterranean region of Europe, and the wheat production in the Asiatic portion of the USSR is regarded as European production.

(according to our definition) is significant. This includes the correlation coefficient between wheat outputs in Canada and in the United States, +.13 for the period 1889–1935. A comparison of the direction of deviations in wheat outputs in those two countries from respective trends points to a significant correlation between them. Indeed, in 33 out of 47 years, wheat outputs in these two countries were on the same side of the trend and in only 13 years on the opposite side.[4] But we know

TABLE 8.—CORRELATIONS AMONG WHEAT OUTPUTS (DEVIATIONS FROM TRENDS) IN EIGHT WHEAT-EXPORTING AREAS FOR SPECIFIED PERIODS†

Region	Relationship[a]	United States 1870–1935	Canada 1889–1935	Argentina 1889–1935	Australia 1864–1935	India 1889–1935	Southeastern Europe 1889–1933	French North Africa 1889–1935
Canada 1889–1935	+	33						
	—	13						
	0	1						
	r	+.13						
Argentina 1889–1935	+	24	24					
	—	23	22					
	0	0	1					
	r	+.08	+.36*					
Australia 1864–1935	+	37	24	25				
	—	29	22	22				
	0	0	1	0				
	r	+.04	..[b]	..[b]				
India 1889–1935	+	24	24	29	25			
	—	23	22	18	22			
	0	0	1	0	0			
	r	..[b]	..[b]	+.12	..[b]			
Southeastern Europe 1889–1933	+	20	29	22	29	24		
	—	25	15	23	16	21		
	0	0	1	0	0	0		
	r	..[b]	+.30*	..[b]	+.22	..[b]		
French North Africa 1889–1935	+	21	28	24	18	26	24	
	—	26	18	23	29	21	21	
	0	0	1	0	0	0	0	
	r	..[b]	+.23	..[b]	—.17	..[b]	..[b]	
USSR 1889–1934	+	26	20	31	27	24	25	23
	—	20	25	15	19	22	20	23
	0	0	1	0	0	0	0	0
	r	..[b]	..[b]	+.04	—.04	..[b]	..[b]	..[b]

† See source footnote to Table 1, p. 217.
[a] For explanation of relationships, see pp. 217–18.
[b] Coefficient of correlation not computed.
* Correlation coefficient significant at 5 per cent level.

that wheat yields in the Prairie Provinces, the main production region of Canada, correlated positively only with wheat yields in the United States Spring wheat region and in the Pacific area, while there was a definite tendency for an inverse relationship with yields of hard winter wheat in the United States. As a result, wheat yields in Canada and in the United States as a whole did not indicate a significant correlation (the correlation coefficient of +.22 for the period 1889–1935 is not significant). Consequently, it is not surprising that no significant correlation exists between the total wheat outputs of the two countries. Significant correlations were also not found between wheat yields in the three exporting areas considered as European—Southeastern Europe, the USSR, and French North Africa.[5] In the light of the knowledge on the relationships between wheat yields in these areas, this lack of correlation appears reasonable.

Turning now to the analysis of the 24 relationships between wheat outputs in the remote wheat-exporting areas located in different continents, we find here also very few indications pointing to significant correlations between wheat outputs. In 14 out of 24 cases, the number of deviations of outputs from the respective trends in the same direction and in the opposite are so close that correlation coefficients were not computed, as there was very little probability that these coefficients would be significant. In the 10 other cases, correlation coefficients were computed, because the number of one sign substantially exceeded that of the opposite, or for some other reason. Of the 10 coefficients, only two may be formally called significant, one between wheat outputs in Argentina and Canada (+.36) and

[4] The minimum number of like signs required to indicate a significant correlation for 47 pairs of observations is 31, according to Cochran's test. This is the first case in this study when Cochran's test indicated a significant correlation and the correlation coefficient was not significant. There were several opposite cases, that is, significant correlation coefficients were obtained when Cochran's test did not indicate a significant correlation. It was natural to expect this second result because of the low efficiency of Cochran's test. But the opposite relationship, as obtained here and in the case of the relationship between outputs in the USSR and Argentina (see Table 8), points rather to the fact that output series do not behave quite like random series, and that consequently the test of significance of correlations should be applied with caution to these series.

[5] Coefficients of correlation were not computed in these cases since the number of plus signs were nearly equal to the number of minus signs in all three cases. See Table 8.

the other between outputs in Canada and in Southeastern Europe (+.30).

The first of these coefficients may be questioned on two bases: first, wheat yields in these two countries are not related directly (see p. 221); second, wheat outputs also move nearly as frequently in the opposite as in the same direction. A detailed analysis of the relationship between wheat outputs in Argentina and Canada indicates that the positive correlation depends mainly on the similar and wide fluctuations of wheat outputs in the two countries in only four years (1923, 1924, 1928, and 1929). When these years are omitted from consideration, no correlation between wheat outputs in the two countries exists. Hence, the significance of the direct correlations between wheat outputs in these countries is very doubtful.

There is less reason to question the significance of the direct correlation between wheat outputs in Canada and in Southeastern Europe. But the correlation coefficient is small (+.30), and it is significant only at 5 per cent significance level; that is, in one case out of 20 a coefficient of such magnitude may be obtained for two independent random variables. Table 8 gives 28 relationships. Consequently, one or two coefficients of such magnitude could be caused by chance variation. Therefore, there is no sufficient reason to insist that two coefficients that may claim formal significance are really significant—at least not until the mechanism causing this relationship is satisfactorily explained.

All other correlation coefficients are still smaller and hence will not be discussed. It may be mentioned in passing that wheat outputs in Canada and in French North Africa, as well as those in Australia and in Southeastern Europe, and in Argentina and India, tended to vary together, while wheat outputs in Australia and in French North Africa tended to move in opposite directions. These tendencies were not systematic enough, however, to point to a significant relationship. This is evident from the correlation coefficients, which were respectively +.23, +.22, +.12, and −.17 (see Table 8).

It may be concluded, therefore, that the correlation between wheat outputs in remote regions located in different continents is not closer than that between wheat yields. In this respect, both sets of correlations are in agreement, and this may be regarded as an additional argument for the soundness of the conclusions.

Wheat Importers

Quite a different picture is given by Table 9, which summarizes the relationships between wheat outputs in the five wheat-importing regions of Europe. In 5 out of 10 possible paired relationships between five regions, significant correlation coefficients were established, and three of these are highly significant. But it was natural to expect this, since all importing countries included in this analysis are located in Europe ex-Russia, and we know that wheat yields in this continental area were in fairly close direct correlation among themselves. The lack of reliable crop statistics for a sufficiently long period for non-European wheat-importing countries prevented us from including them in the analysis. It is reasonable to believe that the picture would be substantially different if these countries were included. However, in the past, Europe, excluding Russia and the Southeast, represented the major world market for wheat. Consequently, the picture presented by Table 9 is fairly representative of the general situation in the world import market for wheat.

A detailed comparison of Table 9 with Table 4 (p. 241), representing interregional correlations in wheat yields in Europe ex-Russia, shows that all significant correlations established between regional wheat outputs in wheat-importing countries have their counterparts in significant correlations between yields. Furthermore, coefficients of correlation between wheat yields in practically all cases are somewhat larger than are the respective correlation coefficients between wheat outputs. This may serve as an additional argument that the five significant coefficients of correlation established between wheat outputs in the European importing countries should be regarded as indicating real relationships. It may be noted also that the positive correlation coefficient, (+.24) between wheat outputs in Italy and in Northwestern Europe, although not large enough to be significant, points to a real relationship, since significant positive correlation was established between wheat yields in these two areas (see Table 4).

TABLE 9.—CORRELATIONS AMONG WHEAT OUTPUTS (DEVIATIONS FROM TRENDS) IN FIVE WHEAT-IMPORTING AREAS OF EUROPE†

Region	Relationship[a]	Northwestern Europe 1879–1935	Germany 1882–1935	France 1879–1935	Italy 1889–1935
Germany 1882–1935	+	34			
	—	20			
	0	0			
	r	+.27*			
France 1879–1935	+	40	33		
	—	17	21		
	0	0	0		
	r	+.46**	+.49**		
Italy 1889–1935	+	30	26	29	
	—	17	21	18	
	0	0	0	0	
	r	+.24	+.34*	+.48**	
Spain 1889–1935	+	22	26	23	27
	—	25	21	24	20
	0	0	0	0	0
	r	..[b]	..[b]	..[b]	+.10

† See source footnote to Table 1, p. 217.
[a] For explanation of relationships, see pp. 217–18.
[b] Coefficient of correlation not computed.
* Coefficient of correlation significant at 5 per cent level.
** Coefficient of correlation significant at 1 per cent level.

The analogy between correlations in wheat outputs and in wheat yields in the European wheat-importing countries goes further. It appears from the table that variations in wheat outputs in Spain are not at all related to those in other wheat-importing countries of Europe. This situation is similar to that in respect to wheat yields, discussed earlier.

It may be concluded, therefore, that there is a fairly close direct relationship between variations in wheat outputs in the wheat-importing countries of Europe, representing the major world market for wheat from overseas. As a result of this, the variability of the total wheat output in the five wheat-importing regions taken together is relatively as large as the variability of the total wheat output in the eight wheat-exporting areas, discussed earlier. This is true in spite of the fact that the variability of outputs in the individual exporting countries is in practically all cases substantially greater than in the individual importing countries.[6] In the case of wheat-importing countries, the variations of wheat outputs (as well as of yields) are relatively small but directly related: in the case of exporting countries, they are relatively large but unrelated among themselves. This results in a high degree of stabilization of the total supply of wheat for export as compared with supplies for export from individual exporting countries, but in a low degree of stabilization of the total requirements for imported wheat as compared with the import requirements of individual countries.[7]

EXPORTERS *vs.* IMPORTERS

Table 10 presents 40 relationships between wheat outputs in each of the eight wheat-exporting regions with each of the five wheat-importing areas. As we know, all five importing areas are in Europe; and of the eight exporters, three are in Europe, two in North

[6] WHEAT STUDIES, March 1943, XIX, 200, Table III.

[7] This contrast should not be overemphasized, however. The analysis of the variance applied to the five series on wheat outputs (deviations from the trends) in the wheat-importing countries of Europe for the period 1891–1935 indicates a highly significant intraclass correlation among wheat outputs, equal to .22. But this shows that only 22 per cent of the total variance of the wheat outputs in the five regions taken together is due to the causes that are common for all five regions, while 78 per cent of the variance is caused by factors that differ among the regions (Fisher, *Statistical Methods for Research Workers*, p. 204). When a similar analysis was applied to the eight series on wheat outputs (deviations from trends) in the wheat exporting countries, an intraclass correlation among wheat outputs was equal to .05, which is nonsignificant. It shows, however, that 5 per cent of the total variance of the wheat output in the eight wheat-exporting countries taken together is due to the causes that are common for all eight regions. The difference between 22 and 5 per cent is not so great. Consequently, by far the greater fraction of the variance of the total wheat outputs is due to factors that differ from one region to another, even in the case of wheat-importing countries of Europe, where several fairly close correlations were established between regional wheat outputs. A similar situation exists also in respect to wheat yields; only a relatively small portion of the variance of wheat yields is due to factors common to all regions.

America, and one each in Asia, South America, and Australia. Because of this geographical distribution, 15 out of the total number of 40 relationships between regional wheat outputs characterize the situation within Europe, while 25 characterize intercontinental relationships between wheat outputs.

TABLE 10.—CORRELATIONS BETWEEN WHEAT OUTPUTS (DEVIATIONS FROM TRENDS) OF EIGHT WHEAT EXPORTERS AND FIVE WHEAT IMPORTERS†

Region	Relationship[a]	Northwestern Europe 1879–1935	Germany 1882–1935	France 1864–1935	Italy 1889–1935	Spain 1889–1935
United States 1870–1935	+	31	28	29	20	24
	—	26	26	37	27	23
	0	0	0	0	0	0
	r	..[b]	..[b]	—.09	—.06	..[b]
Canada 1872–1935	+	34	30	32	23	28
	—	22	16	31	23	18
	0	1	1	1	1	1
	r	+.17	+.28[c]	..[b]	..[b]	..[b]
Argentina 1889–1935	+	28	34	29	27	27
	—	19	13	18	20	20
	0	0	0	0	0	0
	r	+.19	+.29*	+.02	—.05	..[b]
Australia 1864–1935	+	20	31	39	23	25
	—	37	23	32	24	22
	0	0	0	1	0	0
	r	—.29*	+.22	..[b]	..[b]	..[b]
India 1889–1935	+	22	22	21	23	25
	—	25	25	26	24	22
	0	0	0	0	0	0
	r	..[b]	..[b]	..[b]	..[b]	..[b]
Southeastern Europe 1889–1933	+	22	28	22	24	27
	—	23	17	23	21	18
	0	0	0	0	0	0
	r	..[b]	+.21	..[b]	..[b]	..[b]
French North Africa 1889–1935	+	31	27	30	32	32
	—	16	20	17	15	15
	0	0	0	0	0	0
	r	+.43**	..[b]	+.27	+.45**	+.51**
USSR 1889–1934	+	27	30	23	24	24
	—	19	16	23	22	22
	0	0	0	0	0	0
	r	..[b]	+.15	..[b]	..[b]	..[b]

† See source footnote to Table 1, p. 217.
[a] For explanation of relationships, see pp. 217–18.
[b] Correlation coefficients were not computed.
[c] For the correlation between Germany and Canada, the period 1889–1935 was used.
* Correlation coefficient significant at 5 per cent level.
** Correlation coefficient significant at 1 per cent level.

On the basis of the previous analysis, it could be expected that several significant correlations should exist between wheat outputs in the European wheat-exporting areas and in the European wheat-importing countries. However, it appears from the table that in only one exporting country—French North Africa—does the wheat output vary in relatively close relationship with wheat outputs in the European importing countries. Indeed, out of five possible relationships between wheat outputs in French North Africa and in the European importing areas, three are highly significant, namely the relationships with Spain, Italy, and Northwestern Europe. The respective coefficients are +.51, +.45, and +.43.[8] There was a tendency for the wheat output in French North Africa to vary in the same direction also with wheat outputs in two other wheat-importing countries—France and Germany—but this tendency was not systematic enough to be regarded as significant, although it was fairly well pronounced in relation to France (the coefficient of correlation +.27 closely approaches a significant level).

Wheat outputs in the two other exporting areas of Europe—the USSR and Southeastern Europe—did not vary in close agreement with outputs in European wheat-importing countries. A significant correlation was not found even between wheat outputs in the exporting area of Southeastern Europe and in proximate Germany (the coefficient of correlation, equal to +.21, is not significant), to say nothing of the relationships with other importing countries of Europe. A similar situation also characterizes the wheat output of the USSR. Although it varied fairly systematically in the same direction as the German wheat output, the coefficient of correlation between outputs in these countries (+.15) is not significant.[9]

Still less agreement existed between variations of Russian wheat outputs and those in

[8] For similar correlation coefficients between yields, see p. 242.

[9] This is another example when the number of plus signs exceeds the minimum required to indicate a significant direct correlation between wheat outputs in the two continents, according to Cochran's test, but a nonsignificant correlation coefficient was obtained. This is another indication pointing to the necessity of caution in the application of the significance test to the production series.

Northwestern Europe, France, Italy, and Spain. In the last three cases, wheat outputs moved in the same direction as many years as they moved in the opposite direction in the respective countries. It thus appears that with the exception of French North Africa, variations in wheat production in the wheat-exporting areas of Europe were but little related to those in the European wheat-importing area. This must be regarded as a factor stabilizing the total wheat supply in the continent as a whole (including the Asiatic areas of Russia).

As was expected, little relationship was established between variations in wheat outputs in the European wheat-importing area and the overseas wheat-exporting countries. Of the 25 relationships between wheat yields in such regions, only two cases resulted in coefficients of correlation of such magnitude that they may be regarded as significant.[10] One of these coefficients is positive; it characterizes the relationship between wheat outputs in Germany and in Argentina (the coefficient of correlation is +.29). The other is negative and characterizes the relationship between wheat outputs in Northwestern Europe and in Australia (the coefficient of correlation is −.29). Both coefficients are small. In one out of 20 cases, coefficients of such magnitude could be obtained between independent random variations. As there are 25 intercontinental relationships in Table 10, two correlation coefficients of such a value could be obtained if there was no correlation between variations in wheat outputs in all regions under consideration. Consequently, these coefficients do not furnish sufficient reason for concluding that a significant direct correlation exists between wheat outputs in Germany and in Argentina, or a significant inverse correlation between wheat outputs in Northwestern Europe and in Australia. It must be added that a significant correlation was not established between wheat yields in Germany and in Argentina (p. 221). This is additional argument why the correlation between wheat outputs in these two countries should be particularly scrutinized.[11] In this respect, the situation is somewhat different in regard to the inverse correlation between wheat outputs in Australia and in Northwestern Europe. It must be remembered that wheat yields in Australia tended to vary in an inverse direction from wheat yields in the British Isles, and a significant correlation was obtained between these yields (p. 222). But we also questioned the significance of that correlation, at least until the mechanism causing it is sufficiently explained.

The preceding analysis shows that wheat outputs in the wheat-importing area of Europe vary with practically no agreement with outputs in the wheat-exporting regions, both in Europe and overseas. The diversity in the variation of wheat outputs is thus not only characteristic of the situation within the group of wheat exporters, but equally characteristic of the relationship between wheat outputs of the exporters and of the importers. This situation contributes further to a stabilization of the world wheat output and, consequently, of the wheat supply on the world markets.

Our previous study on the variability in wheat yields and outputs shows that the coefficient of variability of the total wheat output in the territory of the 13 regions included in the present analysis, when variations are measured from trend, was only 6 per cent for the period 1901–35. At the same time, the respective coefficients for individual exporting countries were as follows: for Australia 28.5 per cent, for Canada nearly 26 per cent, for Argentina above 23 per cent, for the USSR nearly 16 per cent, and for the United States above 13 per cent. Even in the individual wheat-importing countries of Europe, where wheat production is relatively stable, the coefficients of variability of wheat outputs varied within the range of 10–13 per cent, thus being about twice the size of the coefficient of variability for the total wheat production in all countries under consideration. For three of

[10] Only 10 correlation coefficients were actually computed. However, in the other 15 cases, the relationship between the number of plus and minus signs is such that there is only a slight probability of obtaining significant correlation coefficients.

[11] A similar situation exists with respect to wheat outputs in Germany and Canada. The coefficient of correlation in this case (+.28) closely approaches a significant level. But there was practically no correlation between wheat yields in these two countries (see p. 221).

the four principal wheat exporters, the variability of wheat outputs was about four times as great as that for the wheat output in all countries taken together. Even in the United States, where the effect of compensation of unrelated variations in regional outputs within the country was probably greater than for any other important wheat producer, the variability of wheat output was twice as large as the variability of the total production in the 13 regions taken together. This shows the degree of stabilization of the world wheat output that results from the practical absence of correlations between wheat outputs in remote areas.

VI. CONCLUSIONS

The general conclusions obtained from the study of interregional correlations in wheat yields and outputs are, to a certain degree, negative. They may appear disappointing to those who look for uniformity and regularity in world agricultural production rather than diversity and chance irregularity.

The preceding analysis shows that variations in yields and outputs, even of one crop such as wheat, are very little related in the remote regions of the different continents. The correlation between yields is not close even in remote regions of the same continents such as North America or in Europe including the wide Russian territory. There are many reasons for expecting that it would be still less close for the Asiatic continent, if the numerous widely dispersed regions on the territory of that vast continent could be included in the analysis.

Fairly close correlations between yield and outputs were found only within limited areas, in which weather developments are influenced to a considerable extent by common meteorological factors. Such a situation is characteristic of the principal body of Europe west of Russia and to a certain extent also of the Russian plain, or of southern Australia. But even in these cases the proximity of the regions is, perhaps, a more important factor than the similarity in weather controls. This is illustrated by the fact that little correlation was found between wheat yields in the Volga region and in western and central Europe, in spite of the similarity of the weather controls in these remote areas. Moreover, even within these limited areas the correlation among yields is not very close. With the exception of Australia, hardly more than one-fourth of the variance (footnote 7, p. 255) of wheat outputs in such limited areas is caused by factors common to all regions within the respective areas. By far the greater portion of the variance is caused by factors that differ from one region to another.

Still less correlation among regional yields and outputs should be expected, of course, if the question were not limited to one crop such as wheat, but were expanded to cover various crops, or crop production in general. Even for one large country, such as the United States or the USSR, the index of crop production may be regarded as a resultant of the cumulation of several little related series that fluctuate at random. Consequently, only a small portion of the variation of such an index should be caused by factors common to all regions and to all crops. By far the greater portion of the variation should depend on factors that differ from one region to another and among various crops. To a much greater extent, this should be characteristic of world crop production. Only a slight portion of its total variability should depend on common factors.

Hence, it is hardly possible to speak of cycles in world crop production. If there are fluctuations in world crop production that may be called "cycles," they should result from the summation of independent random variations, which are characteristic of regional yields of various crops, rather than be produced by certain factors common to most crops in most of the regions of the world.

The previous statements must be qualified, however. The correlations established in this study characterize the relationships between year-to-year variations in yields and outputs about the respective trends. They indicate nothing of the relationships between trends themselves. It is necessary to keep this in mind, particularly because the trends used in

[12] WHEAT STUDIES, March 1943, XIX, 200.

this study are flexible curves obtained as moving averages from the original series. Most of these trends show not only a certain continuous tendency (mainly a growth) but also wave-like fluctuations of longer duration. There is a possibility that a certain degree of correlation may exist between these wave-like fluctuations in the trends for various regions, as a certain degree of correlation exists, of course, among the general tendencies of trends, since most of these trends are rising. We do not wish to imply that we consider interregional correlations between wave-like fluctuations in trends of yields and outputs as probable. We simply wish to say that we do not exclude the possibility of such correlations, since these relationships have not been studied here. If these wave-like fluctuations are common to many regional series, they may find reflection also in world production.

The absence of close correlation between variations in regional yields and outputs has its gratifying consequences. The diversity in variations of yields and outputs results in a stabilization of crop production in large areas, and particularly of world production as compared with the variability of regional crops. Crops vary widely within many regions of small size, and even within large areas if regional yields in these areas vary in close correlation (Australia). But in wide areas with diversified variations in yields, crops are more stable (United States). This is particularly true of the world crop. Here, once more, the variability caused by general tendencies presented by trends is not considered, but only the variability around these trends. Simultaneous enlargements of crops in many regions, caused by expansion of the acreage mainly under the influence of economic stimuli, will of course result in an instability of world crop production.

The contrast between the relative stability of world crop production and the great variability of crops in many important countries and regions of the world must be taken into consideration by those who see, as the author does, the fluctuations of crops as one of the possible explanations for fluctuations in the world's business. It appears probable that great variations in crops in some of the leading countries of the world, which play an important role in world trade in agricultural products, have more chance to be responsible for the fluctuations in the world's business than small variations in the cumulative total called world crop production.

During the period before World War I, great disturbances to the world's business could have been caused by wide variations in the crops of Russia or of the United States, which at that time dominated the world market for agricultural commodities. In the later period, such disturbances could have been caused by still greater variations in the crops of Argentina, Canada, or Australia—countries that, to a great extent, replaced the former on the world markets for agricultural commodities. The fact that great variations in crops of these or similar countries greatly disturbed their balances of payments may contribute to an explanation of how the disturbances that start within a national economy of one country, that is of great importance in the world economy, spread throughout the business of the whole world.

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