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VARIABILITY IN WHEAT YIELDS AND OUTPUTS

PART II. REGIONAL ASPECTS OF VARIABILITY

V. P. Timoshenko

A study of regional differences in the variability of wheat yields and outputs has a twofold interest. First, it leads to a causal explanation of these differences in terms of climatic and other geographic characteristics of wheat regions. Second, it supplies information that may help to explain fluctuations in other phenomena such as prices or trade. Data on variability of regional yields and outputs may be useful not only for general analysis of the world wheat market but also in connection with national and international regulation of wheat marketing.

Continentality of climate appears to be the most general climatic characteristic of the wheat regions with high relative variability of yields. Aridity of climate must be regarded as the second most general characteristic of these regions. But wheat yields vary widely in some of the humid areas, while they are relatively stable in semiarid regions with the winter regime of rainfall.

Great diversity in the fluctuation of regional yields results in a good deal of compensation of unrelated variations. Consequently, yields and total production of wheat for the large continental areas and for the world as a whole show a considerable degree of stability.

These contrasts between the great variations in the wheat outputs of some important wheat regions, particularly in several wheat-exporting countries, and the relative stability of wheat production in the principal wheat-importing countries of Europe and for the world as a whole, should be studied attentively by those who are responsible for formulating international wheat agreements and planning under them. Significant changes in the variability of wheat yields in some important wheat regions may afford some guides to rational wheat policies in the respective areas.

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In Part I of this study (WHEAT STUDIES, April 1942), variability in wheat yields and outputs was studied in its time-sequence aspect: the order of fluctuations in time was our principal interest. Answers were sought to such questions as these: Are fluctuations in wheat yield and production periodic, cyclical, or random in character? Are there significant differences between regional series of yield and production in this respect, or are they broadly similar? Have fluctuations in yields and outputs some characteristics in common with fluctuations in business, or are they significantly different?

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In this second part of our study, we shall not pay much attention to the time sequence in variations of yield and total production, but we shall attempt to present certain measures of the average variability in regional yields and outputs of wheat. We do this in order to establish regional differences in degree of variability, and to explain them, as far as possible, in terms of climatic and other characteristics of the regions.

The causal explanation of regional differences in the variability of yields is a very complex and difficult problem. At best, it requires a kind of micro-analysis, in which small and homogeneous areas are used for study and in which a multitude of factors affecting yields are taken into consideration. The present state of crop statistics hardly permits even an approach to this kind of analysis, except perhaps by using detailed statistical information on weather and crops accumulated in agricultural experiment stations in various parts of the world. In this study we do not pretend to undertake such an analysis.

The method used here may be called rather a macro-analysis: we try to give a bird's-eye view of variability in wheat yields in its regional aspect. Our regions are large and consequently far from homogeneous in many respects, and they vary greatly in size. The state of crop statistics is responsible for this in several cases; but, generally speaking, it was not our intention to go into detailed analysis of local diversities, and we have purposely limited our task to a presentation of the most general picture of the wheat "world." In presenting such a general picture, however, we frequently use results of specialized researches analyzing the factors determining annual variations of crops in smaller and more homogeneous areas.

We believe that the results of this type of analysis of variability of wheat yields and outputs may be particularly serviceable for study of other kinds of problems connected with the variability of yields and outputs. In these problems the question is not one of explaining the diversity in variability of regional yields, following methods of the natural sciences, but of studying them as factors affecting variations in other phenomena, mainly economic in character. They may be useful not only for general analysis of the world wheat market, as it formerly existed, but also in connection with schemes for so-called "orderly" or organized marketing, both nationally and internationally. For planning any such order, it is necessary to know thoroughly how much, where, and when nature introduces "disorder," in the form of annual variations in yields and outputs that must be measured and compared; and to what extent these disorderly variations are inevitable.

As evidence of the need for this kind of knowledge by those who are interested primarily in wheat planning and policy, we may mention here that Baron de Hevesy, one of the most indefatigable promoters of international wheat agreements, was obliged to give much space to discussion of this problem in his recent book on world wheat planning[1] and to undertake his own statistical analysis of the problem of variability in yields and outputs, just because professional statisticians had not done this before. For this kind of analysis, variability of yields and outputs must be studied not only and not mainly for small homogeneous areas, but also for wide economic regions, for entire continents, and even for the world as a whole. This relates particularly to the variability of total outputs. From the point of view of market analysis or of the planning of international marketing, a knowledge of the variability of total production in large exporting and importing areas may frequently be of greater interest than similar information for smaller areas. For this reason we purposely select, for the study of variability of total wheat outputs, regions even larger than those used in the analysis of variability of yield per acre. Outputs of large exporting and importing countries, or even of groups of such countries, are mainly used in this part of the study.

We do not deny that the study of variability of yields in small homogeneous areas may be more fruitful for a causal explanation of variability of yields. It also supplies useful information necessary for purposes of farm economic policy, or for crop insurance programs for which much more detailed knowledge of variability in yields is needed than that required for market analysis. But these policies are usually planned within national boundaries and in countries where crop statistics are in a better state than they are at the present time for numerous countries of the world. For such limited areas much more detailed analysis of the variability of yields is advisable, but our intention is to give a general world picture and we cannot, consequently, go into such a detailed study. In part, economy of time and, in part, the unsatisfactory state of statistical data for such a study obliged us to renounce the more ambitious project.

It has already been mentioned that the state of crop statistics is responsible in some cases for the great variation in the size of our regions, and for the consequent lack of homogeneity of some of them. Here another shortcoming of crop statistics must be mentioned, which to a certain extent makes our measures of variability of regional yields imperfectly comparable. For a study of the regional aspects of variability of yields, particularly with a view to explaining interregional differences in the degree of variability, it is logical to use statistics of yield on sown acreage rather than those of yield on harvested acreage. Abandonment of crops, especially of winter wheat, varies considerably from region to region, and this variation depends not only on climatic and soil characteristics of regions but also upon various economic considerations. In regions of commercial farming, particularly in new, thinly populated agricultural areas, where labor is short and wages are high (as in some of the wheat regions of North and South America as well as in Australia), abandonment of crops is both more common and larger than in the densely populated areas where small and subsistence farms predominate (as in some regions of Europe or in Russia). This is true even when the regions are similar in climatic characteristics.

Consequently, variability of yields on sown acreage for some regions will differ considerably from that on harvested acreage, and this difference will vary from one region to another. In an interregional comparison of the variability of yields, it would be necessary to use one or the other kind of yield per acre for all regions. For our purpose it appears

[1] Paul de Hevesy, *World Wheat Planning and Economic Planning in General* (London and New York, 1940), particularly pp. 86–100 and Appendix 3, pp. 705–36.

more logical to use yields on sown acreage, though variability of yield on harvested acreage also may be of interest from an economic point of view.

But only a few countries regularly report both kinds of statistics of wheat yields; others, as will be shown (p. 159), report regularly only sown-acreage yields and still others only harvested-acreage yields. Furthermore, it is not always quite clear which kind of yield is reported; and statistics of yield on harvested acreage, usually reported by most European countries, are not strictly for harvested acreage, since acreage is usually reported in the spring or early summer before harvesting is done. For this reason, it was necessary to compare variability of yields on sown and on harvested acreage for countries which reported both, and from this comparison to draw certain conclusions concerning the comparability of these statistics under certain conditions (pp. 160–61).

In spite of these shortcomings of crop statistics it was possible, however, to compute various measures of the variability of wheat yield per acre that appeared appropriate for our purpose, and to use them for analysis of several problems connected with variability of regional wheat yields.

First, an attempt was made to establish certain relationships between the variability and average levels of regional wheat yields. The number of smaller wheat subregions included in this analysis—46 in all—was sufficiently large to permit a kind of statistical treatment of this problem. The distribution of the subregions according to the degree of variability of yields—both absolute and relative—and according to the levels of yield suggested certain conclusions in this respect.

On the basis of this analysis, it was possible to divide the major wheat-producing regions, or their subregions, into wide geographic areas with large, small, or intermediate relative variability of yields. An attempt was also made to explain these broad differences in variability of yield by the climatic characteristics of the respective areas.

Comparisons of the variability of wheat yields in smaller, more homogeneous subregions with that in the major wheat regions made up of them, and comparisons of the variability of yield in major wheat-producing regions with that computed for wide continental areas or for the "world" as a whole, made it possible to arrive at certain conclusions with regard to the effect of the size of region upon the degree of variability of regional yields.[2]

As the measures of variability of yields, both absolute and relative, have been computed not only for the total period under study (1901 to 1939), but also for two subperiods (1901–18 and 1919–39), it was also possible to establish significant changes in the variability of yields in some regions or subregions and to offer some explanation of these changes.

Finally, an attempt was made to study the types of fluctuation in annual yields around the "normal" yield, with a view to answering such questions as these: Which deviations are more usual, large or small? Are crop failures more frequent than bumper crops in some regions, or vice versa?

A short study of variability of total wheat outputs was undertaken for the principal wheat-importing and -exporting areas—regions different from those used in the study of the variability of yields per acre. It was found advisable, however, to make a comparison of the variability of outputs and of yields for the same regions, in order to see to what extent variability of total outputs is determined by variability of yield per acre.

[2] It must here be borne in mind that, in all cases, the wheat yields per acre used in this study were calculated from total production for the respective regions or subregions divided by total acreage in the same areas. Thus, yields computed for the major wheat regions may be regarded as weighted averages of yields computed for the subregions composing the respective major regions, the subregional acreages being used as weights.

I. MEASURES OF VARIABILITY OF YIELDS AND OUTPUTS

The selection of a proper measure of variability of yield and total output involves two important questions: First, what is an appropriate level of yield (or of output) from which deviations of annual data should be measured? Second, what kind of variability—absolute or relative—should be measured? The measure of absolute variability will be expressed here in bushels, while that of relative variability will be expressed as a percentage of an average yield per acre or of an average total output.

MEAN *vs.* TREND VALUE

Deviations of annual yields may be measured from the mean[1] yield for a given period, or from the position of the trend of yield in the respective years.[2] There are several arguments in favor of each method. Gradual and persistent growth of yield during a certain period or a similar decline, which are usually represented graphically by a trend line, make up part of the total variation in yield. Consequently, when the variation of yield or output is measured from the trend, a portion of the variation, that represented by the trend line itself, is excluded from the measurement. The variability from the trend must, thus, be regarded as a partial variability. On the other hand, when variations of yield or output are measured from the average for the period for which a measure of variability is desired, that portion of the variation that is represented by the trend also is included. Hence, the measuring of variability from the mean for a given period may be preferred when a measure of total variability is desired instead of a measure of partial variability.

However, for certain purposes it may be advisable to exclude from the measure of variability of yield or output that portion represented by the trend component. Such a restricted definition of variability is particularly desirable when the problem is one of comparing the variability of several series that exhibit quite different trends. Sometimes it is also desirable for the measurement of variability in a single series. This is particularly true in the case of yield series in which the ordinate of trend in a given year may represent something more real in value than the average yield for a period of relatively long duration. The mean yield computed for a period of 30 or 40 years for a yield series with quite pronounced rising or declining tendencies is an abstract value that is not at all representative of the yield for a larger portion of the period, while the position of the trend in a given year represents the yield that, in a certain respect, may be called a "normal" yield. This is especially so if a flexible curve, such as a moving average of considerable duration (approaching 10 years), is chosen to represent the trend. Weighted moving averages of 9-years duration are used in this study.[3] The position of such a trend line in a given year is fairly representative of the "normal" yield under average weather conditions; consequently, the deviation of yield for the current year from the position of trend also measures something more real than the deviation from the mean yield for a long period.[4]

[1] The terms mean and average are synonymous. The average used throughout this study is the common arithmetic average.

[2] There is still another possibility: to measure variability of yield (or output) without regard to any level from which deviations must be measured; that is, to measure variations of yield (or output) from one year to the next and to average them in some manner. Variations of a series would be represented, thus, by a new series which would consist of the "first differences" of the original series. However, the independence of this measure of variability from the level from which deviations may be measured is only apparent. Actually it will be affected by the diversity of trends characteristic of the series for yield and total output, since by taking first differences of a series we eliminate only the linear trend of the original series, while more complex curvilinear trends remain. Such a measure of variability can hardly be regarded as appropriate for the purpose of interregional comparisons of variability.

[3] 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.

[4] A 10-year moving average is usually regarded as representing a kind of "normal" yield for a given series of annual yield per acre. The International Institute of Agriculture, in its monthly crop reports, expresses the probable yields of crops as a percentage of the average yield of the preceding 10 years. Some statisticians regard this method as superior to that which expresses crop conditions as a percentage of a "normal" crop that has no definite statistical basis. The

Measuring variations of yield from a trend, instead of from the average yield for a period under study, appears to be desirable also, because factors determining deviations of regional yields from their trends are mostly different from those determining the gradual growth or gradual decline represented by respective trend lines. Indeed, among many factors affecting trends of regional yields of wheat, Bennett mentions two as the most important: (1) changes in farm practice in wheat growing or "man-made improvements in the arts of cultivation of wheat," and (2) shifts of wheat acreage within the regions from high-yield areas to low-yield or vice versa. By raising the level of yield, the first of these factors has affected trends of yield favorably during the past 50 to 60 years. The preponderant effect of the second factor has been rather adverse to wheat yield, as the cultivation of wheat in several important wheat-producing regions has spread to low-yielding areas.[5] Both of these two factors work slowly and affect trends of wheat yields rather than short-term fluctuations. It is the measurement of the latter that mainly interests us here.

The greater part of the variation of yield from year to year, on the other hand, is determined mainly by such factors as weather variations, plant diseases, and insect pests. These factors, and notably the most important of them, weather, are of only secondary importance in determining the direction of trends of yield. From his analysis of trends of yield for some 40 regions, Bennett concluded that protracted stretches of unusual weather affect the dips and bulges in regional trends of yield represented by weighted 9-year moving averages, rather than their general direction.[6] Thus, only certain irregularities of trends are affected by factors that also determine most of the year-to-year fluctuations of yield.

The prominence of these irregularities in the trend lines depends on the number of items included in the moving average and on the system of weights used in the averaging. The weighted 9-year moving average used in this study for presentation of trends in yields and outputs serves to minimize the influences of usual weather changes on trends of yield. Indeed, we know from Part I of this study that year-to-year variations in yield dominated by weather changes very seldom occur in "cycles" of long duration. Even when minor fluctuations are disregarded, 3- or 4-year "cycles" are typical of yield fluctuation. Five-year cycles occur relatively seldom, and cycles of 6 or more years duration together make up less than 8 per cent of the total number of cycles.[7] Hence the moving average used in this study would iron out most of the irregularities except those caused by protracted stretches of unusually bad or unusually good crops.

It thus appears that weather variations, which determine year-to-year changes of yield, are partly responsible also for dips and bulges in the trend lines. To some extent, of course, this reduces the variability of yield measured from these trends, as compared with the variability measured from the more smooth and regular trend lines. However, this shortcoming of measuring deviations of yield from the weighted 9-year moving average is small compared to the shortcomings of measuring variability of yield from the mean, which includes in total the trend component of variations. As mentioned earlier, the inclusive character of the latter measure makes its interpretation particularly difficult when the problem is to compare the variability of several series of yields. The variability of regional yields measured from the mean yield for the period under study not only depends on the relative steepness of slopes in the respective trend lines, but the effects of these slopes on the measure of variability will also vary inversely with the degree of variability of yields from their respective trends: the

latter method is the practice in this country. H. D. Vigor, "On the Use of the 'Normal Crop' as a Standard in Crop Reports," *Journal of the Royal Statistical Society*, June 1911, LXXIV, 679–88.

[5] M. K. Bennett, "Trends of Yield in Major Wheat Regions since 1885. Part I. General Considerations and Rising Trends," WHEAT STUDIES, November 1937, XIV, 80, 81, 86.

[6] *Ibid.*, p. 81.

[7] V. P. Timoshenko, "Variability in Wheat Yields and Outputs. Part I. Cycles or Random Fluctuations," WHEAT STUDIES, April 1942, XVIII, 335–36, Table III.

greater the variations of yield from the trend, the smaller will be the effect of the trend. Moreover, the relative importance of the effect of the slope of trend will depend also on the duration of the period for which variability is measured. The effect of the same slope of trend will be of greater importance for a longer period than for a shorter one.

Generally speaking, the relative importance of the trend component in the variability of yield measured from the average yield for a period under consideration would *increase* (*a*) with the increase of the slope of trend; (*b*) with the decrease of the variability around the trend; and (*c*) with the increase of the duration of the period under consideration. It would *decrease* when the above factors change in the opposite direction. This introduces a considerable degree of uncertainty in the interpretation of variability of yield measured from the mean, and makes preferable its measurement from the respective trends.

Some of the arguments in favor of measuring variability of *yield* from trends instead of average yields are equally strong, or even stronger, when similar measures are used for measuring of variability of total *outputs*. This is particularly so when the problem is to compare variability in regional outputs, since trends of outputs, due to changes in acreages, are usually much steeper and more diverse among themselves than trends of yield. Hence, the interpretation of the degree of variability of outputs around the mean is still more difficult than that of variability of yields.

To a certain extent, factors determining gradual and continuous growth or decline of total outputs are different from those determining year-to-year fluctuations in outputs. One of the most important factors causing gradual and continuous expansion of crop areas, and consequently of total outputs, is growth of population, while year-to-year variations in outputs reflect to a great extent fluctuations in yield per acre. However, gradual and continuous changes in outputs, in so far as they reflect changes in acreages, may be regarded also as a result of price developments. And certain kinds of price development may also cause short-term fluctuations in crop areas, which find their reflection in fluctuations of total outputs. This is particularly so in new countries with vast unused reserves of arable lands. Some of the factors determining short-term variations in total outputs may thus be the same as those determining gradual changes in these outputs represented by their respective trends.

In connection with this, there is perhaps less foundation for speaking of a "normal" regional output of wheat in a given year than of a "normal" yield per acre, and consequently for measuring variability of output from the trends rather than from the average output for a certain period. The principal argument for using the latter measure of variability of outputs, however, is that, in connection with the problem of variability of total outputs, our interest is more frequently concentrated on the study of the effects of this variability on other phenomena, such as prices, than on the explanation of variability of outputs themselves. In so far as we are studying the effects of variability of outputs upon such market phenomena as prices, we may be more interested in determining total variability of outputs, measured from the average output for a certain period, than in determining partial variability, measured from the trend.

For this reason, both measures of variability were applied to the few regional series for total outputs of wheat. As will be shown later, steep and diverse trends of total outputs in some of the regions cause considerable differences between these two measures of variability in outputs, and frequently these differences are not easily explained.

Absolute or Relative Variability

The question whether we should measure absolute or relative variability may be answered differently as regards variability of regional yields and variability of regional outputs. There is no doubt that only measures of relative variability can be regarded as adequate means for comparison of variability in regional *outputs*. The measures of absolute variability of outputs—such as mean deviation or standard deviation—depend on the size of regional outputs, which usually differ greatly from one economic region to another.

Regions with approximately equal outputs would be artificially delimited areas rather than actual economic units such as separate countries. The knowledge that the variation in the total wheat output for a certain area amounts on the average to so many million bushels means much more when considered in relation to the average output for that area.

A measure of variability of *yield* per acre in absolute units (so many bushels per acre) has much greater meaning, since yield per acre represents production from a uniform area. But even in the case of yield per acre, comparisons of variability from one region to another are complicated by considerable variation in average levels of yield per acre from one region to another. Thus, comparisons of variability of regional yields also may be facilitated to a great extent by using measures of relative variability expressed in percentage of the regional levels of yield. However, it may be admitted that both kinds of measures, that of absolute and that of relative variability, may have their application in relation to yield per acre. For some problems it is of greater importance to know that the variability of yield per acre—such, for instance, as the mean deviation or the standard deviation—is so many bushels per acre; for other problems the variability expressed as a percentage of the average yield is of greater interest. These measures are complementary in character, each helping to a better understanding of the other. Hence both kinds of measures are used in our analysis of variability of regional yields of wheat per acre.

For reasons just given, the deviations of annual regional yields from their respective trend lines were averaged in order to obtain measures of absolute variability. The standard deviation of these deviations from trends, expressed in bushels per acre, was selected as the most appropriate measure of the absolute variability of regional yields and outputs for our purposes, though it is somewhat more difficult for the general reader to understand than is the mean deviation.[8]

To obtain a measure of relative variability of regional yields and outputs of wheat, the standard deviation was expressed as a percentage of the average yield (or the average output) for a specific region in a selected period. We call this measure a "coefficient of variability" of yield per acre, or of output, depending on the series for which it is computed. It has characteristics in common with the *coefficient of variation*, but is not exactly the same, since the standard deviation is computed for deviations of annual yields or outputs from the ordinates of their trends in the respective years and not from the average yield (or output). This standard deviation for deviations from respective trend ordinates, which in the presence of a definite trend is always smaller than the standard deviation computed for corresponding items in the usual way, is divided by the mean yield or output for the period under study.[9]

The period 1901–39 was selected for the more detailed study of variability of regional yields. Series of yields for smaller areas, subregions of the major wheat-producing regions, were used.[10] Beginning with 1901, statistics of acreage, output, and yield per acre of wheat for several secondary wheat-producing regions, particularly in Europe, are sub-

[8] Two considerations were decisive in this choice: (1) mathematical properties of the standard deviation are better explored than those of the mean deviation, and this facilitates the application of the test of significance of differences between measures of variability of yield for various regions or for different periods of time for the same region; (2) the computation of the standard deviations for deviations of annual yield from the respective trend was necessary also for the computation of the coefficients of correlations between regional yields and outputs. These may be analyzed later in another part of this research.

[9] An alternative measure of relative variability, which in some respects may be a little more precise than the above-described coefficient of variability, could be obtained by computing for each year the percentage deviation of the annual yield (or output) from the ordinate of its trend for the same year and finding the standard deviations of these percentage deviations. The computation of this alternative measure is somewhat more laborious than the computation of the coefficient of variability described above, while it differs from the latter only slightly. Hence, it was thought to be unnecessary to undertake the additional burden of computation. The computation of such alternative measures of relative variability of yield per acre for a few series has confirmed our expectation that the divergences are slight even in those cases when greater divergence between the two alternative measures could be expected. They are of the order of one point in the respective coefficients.

[10] For definition of regions and subregions, see Table I, first footnote.

stantially better than earlier statistics.[11] This made it possible to cover a wider area for this period without including statistical data of doubtful quality. It was not advisable, however, to take a shorter period for the study of variability of yield, since one of the purposes of this research is to study also the changes in variability of regional yields over time; and for this purpose the period 1901–39 is divided into two parts, 1901–18 and 1919–39. These subperiods are so short that only large differences between measures of variability can be regarded as significant. Thus, for the study of variability of regional yields, it was advisable to take a period as long as available crop statistics permitted; and the period 1901–39 appeared to be the most logical. The division into two parts, the first ending with 1918, was also determined by the character of the statistics available: statistics for new postwar frontiers, which substantially changed for some European countries, begin with 1919; and the best adjustment of data could be made for these subperiods.

These measures of the absolute and relative variability of yield of wheat per acre, and of total outputs for various regions and subregions, are presented for the period 1901–35 and for the two subperiods 1901–18 and 1919–35 in Tables I and III.[12]

II. VARIABILITY AND LEVEL OF REGIONAL YIELDS

In our subdivision of the wheat "world" into major wheat-producing regions and subregions, we followed with a few minor modifications the scheme of regional subdivisions employed by Bennett in his study of trends of yield.[1] This seemed particularly advisable since our measures of variability of yield measure variations from the respective trends, and this presupposes preliminary study of the latter. In his definition of the major wheat regions and their subdivisions, Bennett made an attempt to make them homogeneous with regard to type of wheat grown, climate, place of wheat in agriculture, and some other characteristics. Although the smaller subdivisions of major wheat regions may be regarded as fairly homogeneous in these respects, they vary substantially in respect to magnitude of wheat acreage. This may be seen from the following tabulation showing the distribution of the 46 wheat subregions into six groups according to their wheat acreages, averaged for 1901–39:

Average wheat acreage (*million acres*)	Number of subregions
0–2	6
2–4	14
4–6	11
6–8	5
8–10	4
10–12	6

The average acreage for all 46 subregions is about 5 million acres, but subregions with acreages from 2 to 4 million acres are most numerous, and there are several subregions with acreages smaller than 2 million acres. On the other hand, several very large subregions have wheat areas exceeding 8 or even 10 million acres.

This wide variation in the magnitude of wheat acreage in our subregions is emphasized here, because variability of regional wheat yields may be affected to a certain extent by the size of the wheat acreage of the respective regions. If smaller wheat regions are combined into wider areas, the variability of yield per acre computed for the wider areas tends to be smaller than those for the regions composing them (pp. 172–78). However, scrutiny of the measures of variability of yields for the major wheat-producing regions and for the subregions composing them (Table I) reveals that this tendency is not very pronounced in the case of the subregions and regions used in this study. Indeed, only in the case of a few major wheat-producing regions are the coefficients of variability of wheat yields smaller than the smallest of the

[11] Beginning with this year, crop statistics for the principal crops are assembled by the International Institute of Agriculture in its regular *Yearbooks*.

[12] As deviations of yield were measured from 9-year moving averages, the last year for which deviations were computed was 1935. For some regions the lack of statistics for recent prewar years made the period even shorter. In computation of 9-year moving averages for 1901 to 1903, crop statistics for 1897–1900 were used, disregarding their relatively low quality for some regions.

[1] WHEAT STUDIES, April 1942, XVIII, 300, 331–33.

coefficients of variability of yields in the subregions composing them. In most cases, regional coefficients of variability lie between the smallest and the highest of the respective subregional coefficients.

Furthermore, the size of wheat acreage does not always indicate the size of the territory of the respective wheat regions. In some regions, wheat acreage is large because wheat predominates among the crops. This is characteristic, for instance, of the Prairie Provinces of Canada, the Spring Wheat belt of the United States, and some portions of the United States Hard Winter area. On the other hand, the Northeastern and Southeastern subregions of Eastern North American and the Western subregion of Northern Europe have small wheat acreages, reflecting the small importance of wheat in these areas compared to other crops or other uses of land. Their territories are not small when compared with the territories of some regions with large wheat acreages where wheat predominates.

The topographical characteristics of regions must also be considered when the influence of the size of wheat acreage upon variability of yields is considered. Weather changes usually affect open plains uniformly over wide areas, while weather developments in broken localities are far from uniform even over short distances. Consequently, the component parts of a relatively small wheat acreage in broken regions may experience quite different weather influences, and this may affect the variation of yields in the region as a whole in a compensatory way, while a large wheat acreage in open places may experience very little of such compensatory influences. Several regions with smaller wheat acreages, for instance the subregions of the Pacific Coast, are characterized by broken topography, while several regions with the largest wheat acreages are in open plains, for instance the Spring Wheat belt and the Hard Winter area of the United States, and the Volga region of Russia.

All these factors may reduce, to a considerable extent, the effects of the wide variation in the magnitude of regional wheat acreages upon the variability of regional yields. However, it must be recognized that such effects always exist. Consequently, certain reservations must always be made when the variability of yields in one region is compared to that of another. On the whole, we do not believe that these effects overshadow other influences responsible for the great variation in the degree of variability of wheat yields from one geographic area to another. Although the measures of variability of yields computed for the 46 subregional areas are not ideal in many respects,[2] we believe that our analysis will provide a satisfactory general picture of interregional variation in the variability of wheat yields.

We must mention here another limitation of our measures of the variability of regional wheat yields from the point of view of their interregional comparability. As explained earlier (p. 153), in a study of the variability of yield, there are definite advantages in using estimates of yield on the basis of the acreage sown to the respective crops rather than on the acreage harvested. It would perhaps be still better to measure variability of regional yields determined on these two bases and then to compare them between themselves. However, crop statistics of wheat yield per acre are not available for all wheat regions of the world on the same basis. Only two countries—the United States and Argentina—have published systematically, and for a sufficiently long period of time, estimates of both sown and harvested wheat acreage. For a group of other countries—the Prairie Provinces of Canada, Australia, and India—statistics of wheat acreage relate rather to acreage sown, while for most of the European regions and some others, the only statistics of wheat acreage systematically recorded are for harvested area.[3] Thus, in our comparison of

[2] In several cases the statistical data available precluded selection of smaller and more homogeneous subregions. In other cases it seemed desirable to omit many details in order to present a bird's-eye view of the wheat "world."

[3] These statistics do not represent, however, harvested acreage in the strict meaning of the term. Usually information on the crop acreage in most European countries is collected before harvest, sometime early in the summer after the completion of the spring sowing. For crops sown in spring, the information collected is practically identical with acreage sown to specific crops, while for fall-sown crops it represents harvested acreage only to the extent that those

the measures of variability of regional wheat yields, we were obliged to use yield on sown acreage for non-European regions and yield on harvested acreage for European countries, including Russia.

Since measures of variability of wheat yields for most of the regions of the United States and Argentina are given in Table I on the basis of both sown and harvested acreage, it is possible to ascertain how much the variability of wheat yields on sown acreage exceeds that on harvested acreage. For winter wheat, winterkilling is one of the principal factors responsible for the greater variability of yields on sown acreage as compared with that on harvested acreage. Hence, in those winter wheat regions that show high percentages of abandonment of acreage because of winterkilling (this is characteristic of the Soft Winter and Hard Winter wheat areas in the United States and of wheat in Argentina), the variability of wheat yields on sown acreage is substantially greater than that on harvested. This statement relates particularly to coefficients of variability expressed in percentages of average yields, since not only is the absolute variability greater for yield on sown acreage than on harvested, but the average yield on sown acreage is smaller.

It may be seen from Table 1 that the measures of absolute variability of wheat yields on sown acreage (standard deviations for the period 1901–35), computed for the regions of the United States Soft Winter and Hard Winter areas and for Argentina, exceed similar measures of variability of yields on harvested acreage (taken as 100) by some 30 to 40 per cent, while the coefficients of variability of yields on sown acreage for the same regions exceed the same measures for yields on harvested acreage by some 40 to 60 per cent. In the Pacific Southwest also, variability of yields on sown acreage is much larger than that of yields on harvested acreage. On the other hand, in Eastern United States, particularly in its Northeastern subregion, where abandonment of the winter wheat acreage is relatively small, the variability of wheat yield on sown acreage only slightly exceeds the variability on harvested acreage. The Pacific Northwest occupies an intermediate position in this respect.

TABLE 1.—MEASURES OF VARIABILITY OF WHEAT YIELDS PER SOWN ACRE, EXPRESSED AS PERCENTAGES OF CORRESPONDING MEASURES OF WHEAT YIELDS PER HARVESTED ACRE, IN SPECIFIED REGIONS, 1901–35*

Region	Standard deviation	Coefficient of variability
Eastern United States	109	113
Northeastern subregion	102	105
Southeastern subregion	109	115
United States Soft Winter	135	145
Eastern subregion	133	142
Western subregion	131	141
United States Hard Winter	138	159
Pacific Northwest	116	124
Washington	115	124
Oregon	122	130
Idaho	102	106
Pacific Southwest	135	151
Argentina	136	149

* Computed from data in Appendix Table I.

It is important to note that the difference between the variability of yield on sown and on harvested acreage is not large in the Atlantic states of the United States, since conditions of wheat growing in these states are most nearly like the conditions in Europe ex-Russia, at least in respect to the small percentage of abandonment of winter-wheat acreage.[4] Consequently, it may be reasonably

portions of the fall-sown acreage that were reseeded in the spring to other crops (including spring wheat) are excluded to avoid double counting. Since by far the greater portion of wheat grown in Europe ex-Russia is fall-sown, yields of wheat per acre for these countries are, in practical effect, yields on the basis of harvested acreage.

[4] Abandonment of winter wheat (as reported on May 1) for the great majority of the Atlantic states averages between 2 and 5 per cent. Details are given in U.S. Dept. Agr., *Crops and Markets*, May 1933 and May 1941. For most European countries ex-Russia, such percentages are not higher and may be lower. George Capone, Chief of Section, Statistical Department of the International Institute of Agriculture, says that for most European countries (he excepts Germany, Greece, Hungary, and Yugoslavia) the difference between harvested and sown acreage is not stated because it does not exceed 2 per cent. (De Hevesy, *op. cit.*, pp. 95–96.)

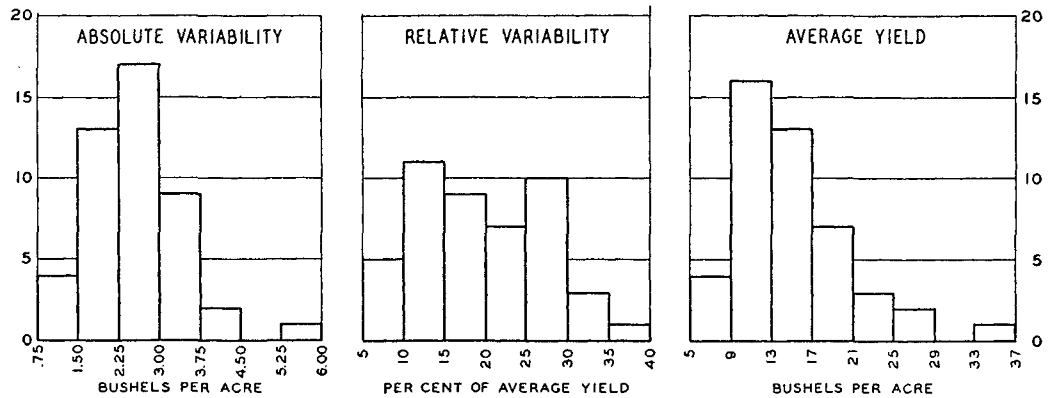
In Germany, the area of winter wheat that is plowed under because of winterkilling seldom exceeds assumed that the measures of variability of wheat yields computed for the regions of Europe ex-Russia on the basis of yield on harvested acreage are only slightly lower than corresponding measures of variability of yields in the same areas on acreage sown would be. Under such circumstances our interregional comparison of the variability of wheat yields will not be invalidated by the fact that we have used measures of variability of yield on harvested acreage for Europe and corresponding measures based on yield on sown acreage for non-European regions.

Chart 1 presents three frequency distributions for the 46 wheat regions used in our comparison. The figure on the right shows the distribution of regions according to the average level of wheat yields. The left shows the distribution of regions according to the magnitude of the absolute variability (standard deviations) of their wheat yields. The figure in the middle presents a similar distribution according to the magnitude of relative variability of yields.

The distribution of wheat regions according to the average level of yields is definitely skew: the right tail, representing regions with a high level of yields, extends much farther to the right of the modal class than the left tail; and the mean yield (unweighted) for the 46 regions is 14.9 bushels per acre, while the median yield is only 13.5 bushels. The positive skewness of this distribution may perhaps be explained partly by the fact that regions with higher yields used in this comparison have on the average somewhat smaller wheat acreage than regions with lower yields.[5] Consequently, the high-yielding areas of the wheat "world" receive representation that is more than proportional.

The distribution of wheat regions according to the magnitude of the absolute variability of their yields is much more symmetrical. The median standard deviation is only slightly smaller than the arithmetic mean (this points to a slight positive skewness of the distribution), but the difference between them is too slight to be definitely indicative of skewness of the distribution.

CHART 1.—FREQUENCY DISTRIBUTIONS OF 46 WHEAT SUBREGIONS ACCORDING TO MAGNITUDE OF ABSOLUTE AND RELATIVE VARIABILITY AND AVERAGE LEVEL OF WHEAT YIELD PER ACRE*



* Data in Table I.

1 per cent of the area sown, and is often considerably less. The percentages for 1924 and 1934 (6.6 and 5.9 respectively) are regarded by Naum Jasny as exceptionally high (WHEAT STUDIES, November 1936, XIII, 117). Consequently, in Germany also abandonment of winter wheat on the average is not larger than that in the Atlantic states. The enormous winterkilling in Germany in 1942 must be regarded as still more exceptional.

Winterkillings of fall-sown wheat in Russia are on the average greater than in western Europe, but usually lower than in the interior areas of North America, since until recently winter wheat was cultivated in Russia only in a limited area where climatic and soil conditions were definitely favorable for this crop. Winter rye was the principal winter crop in the regions where winter wheat was much exposed to weather hazards. Furthermore, under conditions of peasant farming, abandonment of crops in Russia was less usual than it is in North America, also for various economic reasons.

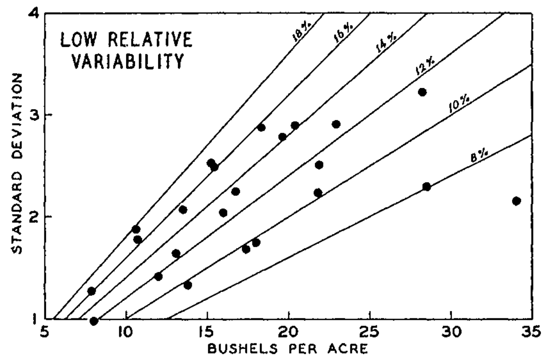
[5] The average wheat acreage for the 23 regions with wheat yields exceeding the median is 4.1 million acres, while that for the 23 regions below the median is 6.1 million acres.

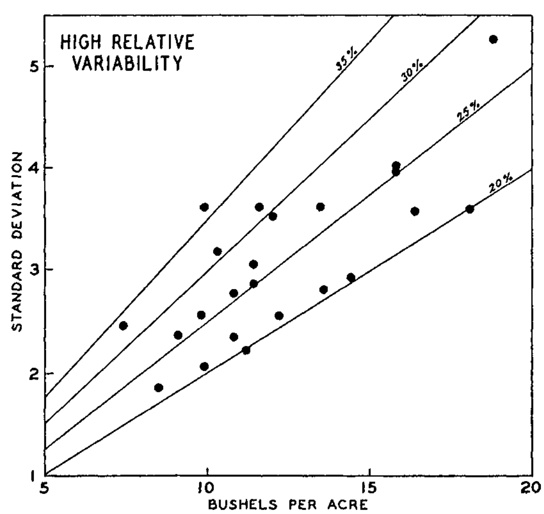
In contrast to the two distributions just discussed, both of which have only one point of concentration of regions, the distribution of wheat regions according to the magnitude of the relative variability of yields (coefficients of variability) has two well-defined points of concentration: one, for regions with low variability of wheat yields, is characterized by coefficients of variability from 10 to 15 per cent; the other, for regions with high variability, is characterized by coefficients of variability from 25 to 30 per cent.[6] The average coefficient of variability of regional wheat yields is the same as the median, both being between 19 and 20 per cent. They are not representative of two typical groups of regions, and characterize rather an intermediate group. The character of this distribution indicates that there are two types of wheat regions—those with smaller relative variability of yields, concentrating around 10 to 15 per cent, and those in which wheat yields tend to fluctuate widely, with coefficients of variability concentrating around 25 to 30 per cent.

Further scrutiny of wheat regions divided between these two distinct groups with quite different degrees of relative variability of yields indicates that this division is not accidental but rather reflects a real and significant difference. Most decisive in this respect is the fact that the division of wheat regions between these two groups shows a systematic character from the geographic point of view, as will be demonstrated in the following section. Consequently, for further statistical analysis, it was found advisable to divide the 46 wheat regions into two subgroups more homogeneous with respect to relative variability of yields.

The first group is formed by 23 regions with coefficients of variability of yields below the average of the coefficients of variability for all 46 regions (19.1 per cent), and the second group is composed of regions with coefficients of variability exceeding this average. When these two groups are considered separately, it becomes evident that a fairly close positive correlation exists between the absolute variability of regional wheat yields and the average levels of yield in respective regions. This correlation is clearly demonstrated by the two scatter diagrams presented in Chart 2: the upper for the 23 regions with low relative variability, and the lower for the 23 regions

CHART 2.—DISTRIBUTIONS OF (*a*) 23 WHEAT SUBREGIONS WITH LOW RELATIVE VARIABILITY OF YIELD AND (*b*) 23 WHEAT SUBREGIONS WITH HIGH RELATIVE VARIABILITY OF YIELD, ACCORDING TO AVERAGE LEVEL AND ABSOLUTE VARIABILITY OF WHEAT YIELD PER ACRE*





* Data in Table I.

with high relative variability. On the horizontal axes of these diagrams are shown the average regional yields of wheat per acre (in bushels); on the vertical, the standard deviations measuring the absolute variability of respective regional yields (also in bushels per acre). Both diagrams show clearly that the absolute variability of yields within the two

[6] With selection of somewhat different class-interval limits, the bimodality of the distribution became less pronounced, but the distribution is always very flat-topped. This indicates that there is no one definite point of concentration.

groups of regions, measured by standard deviations, tends to be large in regions with high average levels of yield and small in regions with low average yields. This is also demonstrated by the highly significant and fairly large positive coefficients of rank correlation between the standard deviations measuring variability of regional wheat yields and the average levels of yield in respective areas.[7]

Positive correlation between the level and the absolute variability of regional yields within the two groups of regions is so pronounced that the coefficients of variability, expressed in percentages of average yields, do not show either significant *positive* correlation with the standard deviations measuring absolute variability of yields in the respective regions, or significant *negative* correlation with the average levels of regional yields. When there is no significant correlation between the absolute variability and level of yields, such correlations are to be expected, since our coefficients of variability are percentage ratios of these standard deviations to average regional yields. Such correlations for all 46 wheat regions mingled together were found to be significant. These correlations, however, do not mean anything more than that ratios of values of two apparently independent series tend to correlate positively with values of series entering into the numerators and negatively with values of series entering into the denominators of these ratios.

It may be objected that classification of regions into two subgroups according to the size of the coefficients of variability must inevitably strengthen within the subgroups the relationship between the absolute variability, measured by standard deviations, and average levels of regional yields of wheat. We are ready to accept this criticism to a certain extent. But the contrast between the highly significant correlations within the two subgroups, and the practical absence of any correlation for the total group of all 46 regions, may be regarded as an indication that positive correlation between the absolute variability and average levels of regional yields established within the two subgroups points to a real relationship, which is only concealed by the too heterogeneous character of the entire group of all wheat regions used in this study. The rather systematic geographic distribution of wheat regions between these groups strengthens further our hypothesis. However, a further study is necessary in order to substantiate better this hypothesis. For such a study it would be advisable to use crop statistics of some one country with distinct levels of regional yields. This would guarantee better comparability of regional yield series. It would be advisable also to use smaller and more homogeneous regions than those used in this study.

From the accompanying tabulation, it may be noticed that the two subgroups of wheat regions so classified differ among themselves not only in respect to the magnitude of the relative variability of their wheat yields but also in respect to the average levels and magnitude of the absolute variability of wheat yields. Indeed, the regions with smaller relative variability of wheat yields are on the average characterized by a higher level of yields and a smaller absolute variability of yields, while the regions with larger relative variability have lower average yields that also vary more in bushels per acre. The higher relative variability of wheat yields in the second subgroup results from two factors: greater absolute variability and lower levels of yields.

Groups of regions	Average yield	Standard deviation	Coefficient of variability
	Bushels per acre		*Per cent*
Regions with coefficients of variability of yields below 19.1 per cent	17.6	2.12	12.8
Regions with coefficients of variability of yields above 19.1 per cent	12.3	3.09	25.5
All 46 regions	14.9	2.61	19.1

It is of interest to notice that, when a direct relationship exists within each subgroup between the absolute variability and the level of wheat yields, the relationship is inverse for the same values between the subgroups. This

[7] For the 23 regions with low relative variability of yield, this coefficient is equal to +.72; for the 23 regions with high relative variability, it is equal to +.68. Both coefficients are highly significant.

may explain why it was not possible to establish a positive relation between absolute variability and level of yield for all 46 regions mingled together.

The higher average yield of wheat per acre for the 23 regions with smaller relative variability of yields does not indicate that there are no low-yielding areas in this subgroup. On the contrary, regions with very low levels of wheat yield are present in both subgroups. The subgroup with low relative variability of yields includes French North Africa (with an average yield of 7.9 bushels per acre), the Southern subregion of India (8 bushels), Western Australia (10.6 bushels), the Southeastern subregion of Eastern North America (10.7 bushels). The subgroup with large relative variability of yields includes such low-yielding areas as the spring wheat regions on the Volga (7.4 bushels per acre), in Ukraine (8.5 bushels), and in the North Caucasus (9.4 bushels); South Australia (9.8 bushels); the Northwestern subregion of the United States Hard Winter area (9.9 bushels); and Uruguay (9.9 bushels). The difference between the two subgroups is that the range of average regional yields is much wider for the subgroup with low relative variability of yields. It varies from 7.9 to 34 bushels per acre, while for the other subgroup it lies between 7.4 bushels and 18.8 bushels per acre. All high-yielding wheat areas of western and central Europe belong to the subgroup with low relative variability of yields.

III. CLIMATIC CHARACTERISTICS OF REGIONS WITH SMALL AND LARGE VARIABILITY OF YIELDS

To the group of wheat regions with small relative variability of yields belong all wheat regions of Europe ex-Russia, with the exception of the Eastern subregion of Southeastern Europe, east (and partly south) of the Carpathian Mountains. Climatically, this latter region has more in common with the neighboring wheat regions of Ukraine than with western Europe.[1] The group also includes French North Africa, with its Mediterranean type of climate, characterized by the winter regime of rainfall, which is typical also of the several northern coastal areas of the Mediterranean Sea. The wheat regions of North America belonging to this group are the Northeastern and Southeastern subregions of Eastern North America, the Ontario region of winter wheat in Canada, two subregions of the Pacific Northwest,[2] and the Pacific Southwest. The climatic characteristics of the Atlantic Coast area of North America, especially of its northern and middle portions, are much like those of western Europe, while the climate of a large portion of the Pacific Coast of the United States is classified as Mediterranean. Other wheat regions that belong to this group with low variability of yields are the three wheat regions of India (the stability of wheat yields in India requires a special explanation, see p. 172) and Western Australia. Of all the Australian wheat regions, Western Australia has the most pronounced winter regime of rainfall, a characteristic peculiar to the Mediterranean climate.

The wheat regions classified with the group characterized by large relative variability of wheat yields, at least those in the Northern Hemisphere, are located in the interior continental areas of eastern Europe and North America. The group is composed of all wheat regions of European Russia included in this study; the Eastern subregion of Southeastern Europe; all principal, noncoastal wheat regions of the United States; and the Prairie Provinces of Canada. With the exception of Western Australia, all wheat regions of the Southern Hemisphere included in this study also belong to this group, though their climatic characteristics differ somewhat from those of wheat regions in the Northern Hemisphere with large variability of wheat yields (p. 166).

[1] The southern portion of Southeastern Europe, represented in this study by Bulgaria, is included with the group of regions with small variability of wheat yields according to our classification, though its position is to some extent intermediate between the two groups.

[2] Washington state is excluded from this group (the coefficient of variability of its wheat yield is 19.9 per cent), but it is on the border line between the two subgroups and could as well be classified with the group characterized by low relative variability of yields.

In General

It is not easy to ascertain what is the most general climatic characteristic of the wheat regions showing great relative variability of wheat yields, as well as of those regions in which yields are relatively stable. Several climatic factors affect variations of yields, and the combinations of these factors are rather numerous. Under such circumstances, it cannot be expected that some one characterestic of climate alone will explain differences in the variability of regional wheat yields.

The most immediate impression from the classification of wheat regions into these two groups may be that uncertainty of, and great year-to-year variation in, rainfall peculiar to the regions with subhumid and semiarid climates must be regarded as the principal climatic characteristic responsible for the great variability of wheat yields; and that adequate and stable rainfall is characteristic of regions with small variability of yields. The climates of 15 of the 23 wheat regions that are characterized by large relative variability of yields must be classified as subhumid or semiarid, with rainfall deficient in all seasons.[3] This indicates that moisture deficiency, accompanied by large variation of precipitation from year to year, must be regarded as one of the most important climatic factors responsible for great variability of regional wheat yields. On the other hand, all European wheat regions, excluding Russia and the Eastern subregion of Southeastern Europe, have mainly humid or subhumid climates, with rainfall adequate in all seasons. This indicates that adequate rainfall well distributed throughout the year is conducive to stability of yields.

However, climatic conditions characteristic of most of the wheat regions in either one of the two groups are not common to all regions classified therein. Among regions with great variability of wheat yields (on sown acreage) we find, for instance, such regions as the United States Soft Winter wheat area, with its definitely humid climate characterized by adequate rainfall in all seasons. Furthermore, rainfall in the Soft Winter area varies relatively little from year to year. Indeed, the variability of the annual precipitation in this region, especially in its Eastern subregion, being the same as in northwestern Europe, may be characterized as one of the smallest throughout the world, according to the world map of variability of annual precipitation prepared by Biel.[4]

South American wheat regions, characterized by large coefficients of variability of yields, also do not suffer much from droughts (p. 168). The climate of the larger portion of this wheat area must be classified as subhumid, but with rainfall adequate in all seasons. Deficiency of rainfall is characteristic only of the western portion of the Argentine wheat area. However, the variability of annual rainfall in the whole wheat region of South America is substantially greater than that in the United States Soft Winter area.[5]

At the same time, among the regions with small relative variability of wheat yields there are several that have climates characterized by deficiency of moisture, where drought (sometimes together with extreme heat) is the principal hazard for wheat crops. This relates particularly to regions with the winter regime of rainfall, in most of which variability of wheat yields is relatively moderate in spite of their aridity.

Consequently, deficiency of moisture, accompanied by large year-to-year variations of rainfall, is characteristic of many of the

[3] According to the classification of types of climate of C. Warren Thornthwaite adopted by M. K. Bennett and Helen C. Farnsworth, "World Wheat Acreage, Yields, and Climates," Wheat Studies, March 1937, XIII, particularly pp. 273–74 and the attached Map B. Subregions that have such climates on the total or on the larger portion of their areas are: three subregions of the Prairie Provinces of Canada; two subregions of the United States Spring wheat area; the Northwestern and Southern subregions of the United States Hard Winter area; practically all Rusian regions (five), with the exception, perhaps, of the northwestern portion of Ukraine; the Eastern subregion of Southeastern Europe, and at least large portions of New South Wales and Victoria in Australia. The wheat acreage (average for 1901–35) in these 15 subregions makes up about two-thirds of the total wheat acreage in the 23 regions with large variability in wheat yields.

[4] Erwin Biel, "Die Veränderlichkeit der Jahressumme des Niederschlags auf der Erde," *Festband Eugen Oberhummer* (*Geographischer Jahresbericht aus Österreich*, Leipzig and Vienna, 1929, Vol. XIV/XV), map facing p. 180.

[5] *Ibid.*

wheat regions with large variability of yields. It is not, however, general for all of them. Similarly, rainfall adequate in all seasons is not a general characteristic of all wheat regions with small variability of yield, since among these there are several regions with the winter regime of rainfall that are deficient in moisture. It is necessary, therefore, to explain why the relative variability of wheat yield is large in some wheat regions with humid climate, and why it is small or moderate in semiarid or subhumid wheat regions with the winter regime of rainfall.

If we limit our generalization to the Northern Hemisphere, continentality of climate, with extreme differences between the summer and winter temperatures, appears to be the most general climatic characteristic of regions with large variability of wheat yields. In practically all regions of the Northern Hemisphere where the coefficients of variability of wheat yields exceed 19.1 per cent, the difference between the average July and the average December temperature exceeds 40° F. On the other hand, this difference is usually below 40° F. in practically all regions with a variability of yield below this limit.

We do not mean to imply that extreme variation in temperature from winter to summer is directly responsible for great variability in wheat yields, though it is of considerable importance, particularly for winter wheat. Continentality of climate, however, is usually associated with certain other characteristics of weather that may cause wheat yields to vary greatly from one season to another. Among these may be mentioned (1) specific seasonal distribution of, and year-to-year variations in, precipitation, and (2) temperature variations during the growing period of wheat (too hot in summer, too cold in winter, or too variable in spring).

Extreme continentality is not especially characteristic of the principal wheat areas of the Southern Hemisphere, where wheat yields fluctuate widely, but these areas have certain climatic characteristics in common with the continental climates of the Northern Hemisphere. This is especially true of the wheat regions of Argentina, where a certain degree of continentality is characteristic even of the eastern coastal region, to say nothing of the area deeper in the continent. Daily variations of temperature are considerable, spring frosts are characteristic of the southern portion of the wheat area, and winter frosts occur even in the subtropical portion of Argentina.[6] The Australian wheat regions are not handicapped by the low winter temperature characteristic of the continental climate of the Northern Hemisphere; on the contrary, the mild temperatures during the winter months favor winter wheat. But since their springs are unduly short and summers extremely hot and dry, as in the wheat regions of Argentina and of the interior continental areas of the Northern Hemisphere, they are characterized by large variability of wheat yields.[7]

As already mentioned, in 15 of the 23 wheat regions with large variability of yields, moisture deficiency, accompanied by large year-to-year variations in precipitation, must be regarded as the principal climatic factor responsible for instability of yields. Drought, in one season of the year or another, is the principal adverse factor damaging wheat crops in practically all these regions, while rainfall in excess of the average is mainly responsible for wheat crops that are better than average. This does not mean that extremes of temperature (heat in the summer and frost in the winter and early spring) do not contribute to the variability of wheat yields in these regions, but it cannot be denied that variation in rainfall in these regions is the dominating factor, since moisture is at a minimum in a climate characterized by deficiency of rainfall in all seasons. A substantial portion of the abandonment of winter wheat because of winterkilling in these regions must be due to drought during the fall rather than to thermal factors.

There is no question that recurrent droughts are also mainly responsible for the large variability of wheat yields in two of the eight remaining regions of this group—Washington state in the Pacific Northwest and South Aus-

[6] For details, see K. Knoch, *Klimakunde von Südamerika* (*Handbuch der Klimatologie*, Band II, Teil G, Berlin, 1930), pp. 215–16, and Fig. 13, p. 29.

[7] E. S. Clayton, "Factors Involved in Wheat-Growing in Dry Areas," *Agricultural Gazette of New South Wales*, Aug. 1, 1930, XLI, 581–83.

tralia. The only reason that these were not classified with the other 15 regions deficient in moisture is that they have a winter regime of rainfall and experience deficiency in moisture mainly in one season—summer—while the other 15 regions are deficient in all seasons. We know that wheat yields in most of the regions with the winter regime of rainfall vary slightly or only moderately, and therefore they are classified with the group of regions with small relative variability of yield. Washington state is on the border line of that group of regions and might logically have been classified with them (see footnote 2). Thus, of all wheat regions included in our study, South Australia is the only important one with a definitely pronounced winter regime of rainfall that has a high relative variability of yield. The coefficient of variability of its wheat yield exceeds 25 per cent. We shall discuss later the reasons why variability of wheat yield in South Australia so much exceeds that in other regions with the winter regime of rainfall. Here we turn first to the question why wheat yields vary greatly in some humid regions.

Humid Regions with Large Variability of Yield

In addition to the 17 wheat regions in which rainfall is normally deficient in all or in some seasons, and where drought must consequently be regarded as the principal hazard for wheat crops, there are six wheat regions with wide variability of yields in which rainfall is normally adequate in all seasons in all or in the larger portion of their wheat areas.

At least one of these regions, the Northeastern subregion of the United States Hard Winter area (including Nebraska and the eastern half of Kansas), has mixed climatic characteristics. In all seasons moisture is normally adequate in the eastern portion and deficient in the western. This subregion must, to a certain extent, be regarded as transitional between the humid Soft Winter wheat region in the east and the Hard Winter area to the west and south. Its transitional character is evident from the distribution of humid and subhumid crop seasons. In the eastern portion of Kansas, two or three out of four are usually humid, as in the western part of the Soft Winter area, while one or two seasons are subhumid or semiarid, as are usual in the two other subregions of the Hard Winter area. In some years rainfall even exceeds the optimum in eastern Kansas and becomes an important factor damaging to the wheat crop, while in Nebraska such a condition hardly ever occurs. With this qualification, it may be said that recurrent deficiency in moisture remains among the principal hazards responsible for the great variability of wheat yield in this region. For this reason, it is better to limit our analysis of wheat yields in humid regions to the Soft Winter wheat area of the United States and the South American wheat regions.

Moisture is unquestionably sufficient for wheat crops in practically the whole of the United States Soft Winter wheat area. Because of the small year-to-year variations of rainfall in this area, particularly in its Eastern subregion, a humid climate is normal for practically the whole area, and semiarid crop seasons occur very seldom. This is particularly true in its Eastern subregion, while semiarid crop seasons are not so exceptional in the Western. A subhumid (moist) climate normally prevails only in a smaller portion of the Western subregion, an area less important with regard to wheat production (Iowa and adjacent portions of Illinois, Missouri, and Wisconsin).[8] However, the subhumid climate prevailing in this limited area is characterized as adequately moist in all seasons. When crop seasons alone are considered, it must even be regarded as a humid one.

It is of interest to note that the relative variability of wheat yields tends to be smaller in the western, less humid, portion of the Soft Winter area than in its eastern portion.[9] In the latter, superhumid years are not exceptionally rare, particularly in the southern

[8] C. W. Thornthwaite, *Atlas of Climatic Types in the United States, 1900–1939* (U.S. Dept. Agr., Misc. Pub. 421, 1941), particularly Plates 3, 4, 87, 88, 95, and 96.

[9] The coefficients of variability of wheat yields are somewhat higher in the Eastern subregion than in the Western, for the yield on both sown and harvested acreage (Table I). The differences are, however, not so large that they cannot be explained by chance.

half; and in such years the supply of moisture may exceed the optimum for wheat. Hence, in many localities of the United States Soft Winter region, damage to wheat crops from deficient moisture is usually less important than damage from excessive rainfall. This is perhaps more usual in Ohio and Indiana; but in some stretches of years it is true also in Illinois and Missouri.[10]

Generally speaking, in the larger portion of the United States Soft Winter region, rainfall —both excessive and deficient—results in less damage to wheat crops than do other climatic factors. This is natural in a region with an adequate supply of moisture and small year-to-year variations of precipitation. Moisture is always sufficient to produce a good wheat crop, and crop variations must correlate better with variations in other climatic (or nonclimatic) factors than with variations in moisture. Temperature variations appear to be of greater importance than rainfall fluctuations in explaining the large relative variability of wheat yields in this area.[11] We have already noted that in the Soft Winter area abandonment of winter wheat because of winterkilling is responsible for a great portion of the variability of wheat yields on sown acreage (p. 160).[12] But variation of temperature is also of great importance—directly or indirectly—for the development of wheat crops during other seasons. It has been established that high temperature in combination with rainfall is responsible for the intensity of plant diseases such as rust,[13] which play an important role in the explanation of the variability of wheat yields in humid regions.

The situation in the wheat regions of South America is similar. Statistical analyses of factors determining yield of wheat in Argentina have led to the more or less general conclusion that, for the country as a whole, there is relatively little relationship between yield of wheat and rainfall. This is true in spite of the fact that variability of annual rainfall is rather large in the Argentine wheat area, much larger than in the United States Soft Winter area. Although the climate of most of Argentina's wheat area must be classified as subhumid and even as semiarid in its western portion, rainfall is, except very rarely, sufficient to make a good crop of wheat. Variations of the Argentine wheat crop appear to be in much closer correlation (negative) with variations of temperature than of rainfall. A high temperature in the spring (September–October), particularly when associated with heavy dew while the grain is filling, is regarded as a particularly damaging factor.[14]

This may be explained partly by the fact that variation of temperature, being more general in character than rainfall, affects wheat yield uniformly over large areas, while the effects of rainfall are more localized. Indeed, regional studies indicate that in the southwest and west of the Argentine wheat area, shortage of rain in spring (September–October) is a frequent cause of damage to the wheat crop, while in the northern wheat regions (Entre Ríos) excessive precipitation in the spring accounts for low yields per acre. However, negative effects of high temerature are noticeable in all provinces, particularly in the northern, while in the southern provinces frost injury frequently occurs.[15] Thus, large varia-

[10] Based on unpublished information by states, obtained for examination from the U.S. Department of Agriculture, on the reduction from full yield of wheat per acre from stated causes, in the years 1926–30.

[11] J. W. Smith, *Agricultural Meteorology* (New York, 1920), particularly pp. 199–208; T. A. Blair, "A Statistical Study of Weather Factors Affecting the Yield of Winter Wheat in Ohio," *Monthly Weather Review*, December 1919, XLVII, 841–47.

[12] Recent studies have established that winterkilling of wheat in this region is dependent upon soil characteristics. Heavy winterkilling is more usual on heavy, poorly drained soils than on lighter, well-drained ones. See E. G. Bayfield, *The Influence of Climate, Soil, and Fertility upon Quality of Soft Winter Wheat* (Ohio Agr. Exp. Sta. Bull. 563, March 1936), particularly pp. 5–15; C. A. Lamb, *The Trend of Wheat Production in Ohio* (Ohio Agr. Exp. Sta. Bull. 507, August 1932), pp. 4–5.

[13] L. R. Tehon, "Epidemic Diseases of Grain Crops in Illinois, 1922–1926," *Illinois Natural History Survey Bulletin* (1927), Vol. XVII, Art. 1.

[14] For details, see N. A. Hessling, "Relations between the Weather and the Yield of Wheat in the Argentine Republic," *Monthly Weather Review*, June 1922, L, 302–08; W. E. Swenson, *A Survey of Wheat-Crop Estimation Studies for Canada, Australia, and Argentina* (U.S. Dept. Agr., Bur. Agr. Econ., *Statistics and Agriculture*, No. 3, July 1941), which summarizes earlier studies undertaken by the Bureau of Agricultural Economics; and an article by P. O. Nyhus, "Argentine Wheat," *Foreign Agriculture*, July 1938, II, 328–32.

[15] Hessling, *op. cit.*; Nyhus, *op. cit.*

bility of wheat yields in South America also must be explained mainly by factors other than variations in rainfall.

We have already seen that variability of wheat yields is small in other wheat regions that are adequately supplied with moisture in all seasons. Most of these regions are in western and central Europe ex-Russia, but a few of them are in Eastern North America, on the Atlantic Coast or not far from it. In these wheat regions not only is rainfall adequate and relatively stable, but other climatic characteristics also are favorable to stability of wheat yields. Being more maritime than continental in character, they do not suffer from the extreme variations of temperature characteristic of the humid regions just discussed. Consequently, we do not need to give any special explanation of the small relative variability of wheat yields in these regions.

However, among regions with small variability of wheat yields, a considerable number have a climate characterized by deficiency of moisture, where drought (sometimes together with extreme heat) is mainly responsible for damage to wheat crops.[16] As it was found necessary to explain why variability of wheat yields in some of the humid regions was large in spite of abundant or adequate rainfall in all seasons, here reasons will be given why wheat yields are relatively stable in some subhumid or even semiarid regions.

In all these relatively arid regions with moderately stable yields, rainfall occurs mainly in winter, while summers are dry. As will be shown below, such a seasonal distribution of rainfall is more favorable to stability of yields of winter wheat than is the regime of summer rainfall, if the winters are sufficiently mild.[17] In this case, we have clear evidence that the total annual precipitation and the degree of its year-to-year variations do not furnish a sufficient climatic basis for judging the condition of the growth of wheat. Hellmann[18] has established that year-to-year variations of annual precipitation tend to be larger in regions characterized by concentration of rainfall in some one season than in regions with more or less even distribution of precipitation throughout the year. The world map of variability of annual rainfall prepared by Biel, showing relatively large variability of rainfall in the areas with the Mediterranean climate in Europe and Africa as well as in California, confirms this. Nevertheless, wheat yields in regions with winter regime of rainfall tend to vary less than they do in the subhumid continental regions with rain predominant in summer but more evenly distributed through the year.

Small Variability of Yields in Regions with Winter Regime of Rainfall

In most of the wheat regions with the Mediterranean type of climate, winters are sufficiently mild to allow growth of wheat to proceed during the winter months. Such conditions prevail in most of the wheat area of French North Africa, of Southern Italy, and in the littoral (not elevated) portion of southeastern Spain. They are especially characteristic of practically all wheat regions of Australia, and also in a portion of the wheat area of the Pacific Southwest. Australia presents conditions particularly favorable for comparison of the influences of winter and summer regimes of rainfall on variability of wheat

[16] Among these regions must be mentioned French North Africa, Spain (except its northwestern humid fringe), and Southern Italy in Europe; the Pacific Southwest, and Oregon and Idaho of the Pacific Northwest in America; and Western Australia. As explained earlier (footnote 2), Washington state also belongs here logically, but it is formally classified with the other group, because the variability of its wheat yield is larger than in the other above-named regions. In all these regions, drought must be regarded as the principal adverse factor affecting wheat crops; heat appears mainly the second in importance, but only in some of them. For detailed analysis of the adverse factors affecting wheat yields in the above-mentioned European regions, see Girolamo Azzi, *Le climat du blé dans le monde* (Rome, 1930), particularly pp. 65–99, 226–53, 937–41. Information from the U.S. Department of Agriculture by states (footnote 10) reveals that moisture deficit is also the most important damaging factor for wheat yield in the United States Pacific area.

[17] W. Köppen, in his classification of the climates of the earth (*Die Klimate der Erde*, Berlin and Leipzig, 1923, pp. 121–22), assigns greater efficiency to precipitation in areas of winter than in areas of summer precipitation, assuming that a higher percentage of the moisture is lost by direct evaporation in summer than in winter. See also K. H. W. Klages, *Ecological Crop Geography* (New York, 1942), pp. 169–70.

[18] G. Hellmann, *Untersuchungen über die Schwankungen der Niederschläge* (Veröff. d. Preuss. Met. Inst., No. 207, Berlin, 1909). Cited from Biel, *op. cit.*, p. 151.

yields. Summer rainfall is characteristic of most of the wheat area of New South Wales and of a considerable portion of Victoria, while winter rainfall dominates in the wheat regions of South and Western Australia, particularly in the latter. But growth of wheat proceeds throughout the winter in all Australian wheat regions. Clayton[19] says that Australian investigators have shown that fall-sown wheat in Australia adds to its dried weight at an increasing rate for the first four months, reaching the maximum rate when wheat is going into ear in *early October.* Thereafter the rate of increase decreases until harvest. To meet this increasing rate of growth, the plant foods in the soil should be in an available form; the presence of moisture is therefore particularly necessary a few months before the period of maximum increase. The August–September rainfall, consequently, is a dominant factor for wheat crops in several Australian wheat regions.[20] Richardson establishes a close relationship between the *average* yield of wheat in a locality and the rainfall during April–October, the total growing period of the crop. According to him, April–October rainfall is the limiting factor for wheat production in the Australian wheat belt.[21]

If the conclusion that August–September or April–October rainfall controls wheat crops in Australia is correct, then it is easy to explain why the winter regime of rainfall is more favorable to stability of wheat yields than the summer regime. Data for meteorological stations representative of the principal wheat regions of Australia show that August–September rainfall makes up more than one-fourth of the annual total in Western Australia, about one-fifth in South Australia, less than one-fifth in Victoria, and only about one-eighth in the region of summer rain of New South Wales. In the region of summer rainfall, August and September are among the months with the lowest and the least certain rainfall, while in Western Australia these months still have relatively high rainfall following the maximum during June–July. Comparison of April–October rainfall in the respective areas indicates similar advantages of the Western Australian wheat region over those of New South Wales and Victoria.[22] Under such circumstances, it is easy to see why the relative variability of wheat yields in New South Wales and Victoria is among the highest (coefficients of variability are respectively 31.2 per cent and 29.5 per cent), while in Western Australia it is relatively low (coefficient of variability, 17.7 per cent). It must be added, however, that variability of annual rainfall also is smaller in the larger portion of the Western Australian wheat area than it is in most of the wheat area of southeastern Australia.[23]

It was mentioned earlier (p. 167) that the South Australian wheat region is the only area with the winter regime of rainfall where wheat yields fluctuate widely. The reason for this is that a large portion of this region is one of the most arid wheat areas of Australia. Furthermore, the northern portion of this region, where the variability of wheat yield is the greatest, is deficient in moisture not only in summer but in all seasons. This may explain why wheat yields in South Australia vary so much in spite of the fact that a winter regime of rainfall prevails over the larger portion of its wheat area.

The conclusion that a winter regime of rainfall is favorable to stability of wheat yields may be reasonably generalized in respect to those European and North African wheat regions that have a winter regime of rainfall and

[19] See E. S. Clayton's note, "Rainfall and Wheat Yields," *Agricultural Gazette of New South Wales,* Aug. 1, 1930, XLI, 566.

[20] Henry Barkley, in "The Victorian Wheat Harvest: Climatic Controls and World Prices," *Wheat and Grain Review* (Melbourne), Aug. 6, 1927, pp. 8–11, says that in Victoria 80 per cent of the variations in the wheat harvest can be ascribed to the rainfall of August and September. Next in importance, according to his analysis, is the June rainfall.

[21] A. E. V. Richardson, "Relationship between Wheat Yield and Rainfall," *Journal of the Department of Agriculture of Victoria,* March 1925, XXIII, 158–71.

[22] E. C. Clayton, in "Rainfall of the Roto Mallee Area," *Agricultural Gazette of New South Wales,* Sept. 1, 1930, XLI, 685–91, says that in only one out of ten years does the April–October rainfall in the Western Australia wheat area fall to the level reached in the Mallee area of New South Wales once in every three years. And he adds that the Mallee area in New South Wales is in some respects more favorable than a similar area in northwest Victoria.

[23] The last statement is based upon the map given by S. M. Wadham and G. L. Wood, *Land Utilization in Australia* (Melbourne, 1939), p. 158.

mild winters. But it can hardly be applied directly to the Pacific Northwest wheat area in the United States, since winters there are much more severe and fall-sown wheat remains dormant during a considerable portion of the winter season of heavy precipitation. However, recent studies have shown that, for yield of winter wheat grown in the semiarid and continental climate of the Northwestern portion of the United States Hard Winter wheat area, rainfall is very important during the early period from seeding to the time wheat enters the winter semidormant stage[24] (about December 1 under conditions existing in western Kansas). A similar relationship was found by Klages between the August–November rainfall and the yield of winter wheat in the Palouse area of northern Idaho and eastern Washington.[25] This supplies a basis for an explanation of why the variability of wheat yield on the United States Pacific Coast is much smaller than it is in the Northwestern and Southern portions of the United States Hard Winter area. The coefficient of variability of wheat yield in the Northwestern subregion of the Hard Winter area is the largest of all 46 regions (36.6 per cent) and in the Southern subregion only a little smaller (31 per cent), while in all Pacific regions, even in Washington state, the coefficients are much smaller (Table I).

October–November rainfall is least reliable in the Hard Winter area, particularly in the northern part (Nebraska and Kansas), because it constitutes, on the average, only a small portion of the annual total rainfall (about one-tenth) and because it varies more from year to year than that of any other months. In the wheat area of the Pacific Northwest, on the other hand, October–November rainfall contributes on the average a much larger portion of the annual total (it exceeds one-fifth of the total), and it appears to vary less from year to year than it does in Kansas and Nebraska. This is particularly true of November rainfall. Hence, winter rainfall must also be regarded as a factor favoring stability of winter wheat yields even under the severe winter conditions characteristic of the Pacific Northwest.[26]

It must be emphasized, however, that the Mediterranean type of climate with the winter regime of rainfall is favorable to stability of wheat yields but not to a high average level. With the sole exception of the Pacific Northwest, all regions with the winter regime of rainfall are characterized by wheat yields be-

[24] See J. E. Pallesen and H. H. Laude, *Seasonal Distribution of Rainfall in Relation to Yield of Winter Wheat* (U.S. Dept. Agr., Tech. Bull. 761, January 1941). For wheat grown on plots of the experimental stations in western Kansas (Hays, Colby, and Garden City), the authors found that rainfall during the period from seeding time to December 1 (during which time germination, emergence, tillering, and the development of secondary roots normally take place) clearly had the most influence on yield. Rainfall over the three months prior to planting was very important; less so, however, than during October and November. Rainfall above average from the middle of April until the time of harvest tended to be associated with increased yields, though the influence was less marked than for rain during fall and early winter. See also H. J. Henney, "Estimation of Future Wheat Production from Rainfall," *Monthly Weather Review*, June 1935, LXIII, 185–87.

[25] Klages, *op. cit.*, pp. 196–97. The coefficients of correlation between rainfall and yields of winter wheat in different crop rotations (12) on the University Farm at Moscow, Idaho, are generally relatively low. This points to the optimal rainfall condition for wheat in this locality; the average annual rainfall during the period of the test was 21.1 inches. But the coefficients are the highest and for several rotations they are significant for the relationship between wheat yields and August–November rainfall.

[26] It has been definitely established that the reserve of soil moisture at the time of seeding winter wheat is an important factor favorably affecting yield in the semiarid climate of the Great Plains (see A. L. Hallsted and O. R. Mathews, *Soil Moisture and Winter Wheat with Suggestions on Abandonment*, Kans. Agr. Exp. Sta. Bull. 273, January 1936). It may appear, therefore, that regions with the summer regime of rainfall are more favorable for stability of yields than those with the winter type of rainfall. However, this is compensated for by another factor: summer fallowing of land seeded to wheat is much more general in the Pacific Northwest wheat area than in the Great Plains. For the importance of fallow land in the principal cash-grain area of the Pacific Northwest, see O. W. Freeman and H. H. Martin (eds.), *The Pacific Northwest: A Regional, Human, and Economic Survey of Resources and Development* (New York, 1942), chapter 15, "Wheat and Wheatland Utilization," particularly p. 350. See also A. S. Burrier and W. W. Gorton, *Land Use and Production Costs on Dry-land Wheat Farms, Columbia Basin, Oregon* (Oregon Agr. Exp. Sta. Bull. 373, June 1940), p. 22; and B. H. Pubols and C. P. Heisig, *Historical and Geographic Aspects of Wheat Yields in Washington* (Washington Agr. Exp. Sta. Bull. 355, December 1937), p. 7. Klages (*op. cit.*, p. 207) says that fallows are most effective in areas with winter and early spring precipitation. It is difficult, he says, to conserve moisture supplied by summer rains.

low the average. Furthermore, the relative stability of yield in the Pacific Northwest is achieved at the cost of less intensive utilization of the arable land, as a large portion of it remains idle when summer fallowed.

India

We have now to consider why the variability of wheat yield in India is small, in spite of the facts that the growing period of wheat, as a winter crop, coincides mainly with the dry period from October to March and that drought in winter and spring is a major hazard for nonirrigated wheat crops.

It must be said, first, that Indian regional series of wheat yields per acre represent real variations of yield less than do any other regional yield series. In the two northern wheat regions of India—Northwestern and Northeastern—nearly half of the total wheat acreage is irrigated wheat. This, of course, results in greater stability of the average wheat yields for irrigated and nonirrigated wheat combined. Furthermore, nonirrigated wheat acreage varies greatly from year to year in close correlation (positive) with the monsoon rainfall,[27] while the irrigated wheat area is much more stable. As a result the proportion of irrigated to nonirrigated wheat acreage changes from year to year. In years following small monsoon rains, the proportion of nonirrigated wheat to irrigated usually declines; and this tends to raise average yield, since yields of irrigated wheat are, on the average, higher than those of nonirrigated. Thus, variability of yield per acre in these regions is reduced because of these shifts in the proportion of irrigated and nonirrigated wheat. The variability of wheat yields upon nonchanging acreage must be substantially larger.

This fluctuation in the acreage of nonirrigated wheat tends to stabilize *average* yields also in the Southern region, where irrigated wheat does not play so important a role (it is on the average, 10–15 per cent of the total wheat acreage in this region). A small monsoon rainfall usually results in a reduced wheat acreage, while in years of ample rain wheat is expanded on the margin of cultivation. Consequently, variations of the average yield on the changing acreage tend to be more stable also in this area, where the relatively small proportion of the irrigated wheat acreage does not greatly affect variability of yield.

Variability of yield of nonirrigated wheat in India *measured on the same acreage* must be substantially larger than that indicated by the coefficients of variability computed for Indian yield series shown in Table I.

In India variations in summer rains, which are rather large, result more in the fluctuation of wheat acreage than of the average yield per acre. Variations of wheat yields on nonirrigated land correlate better with the fluctuations of winter rains, which are scanty and uncertain from year to year.[28] As a consequence of the wide fluctuation of wheat acreage, the variability of the total wheat production in India substantially exceeds the variability of the average yield per acre.

IV. EFFECT OF THE SIZE OF REGIONS ON THE VARIABILITY OF AVERAGE REGIONAL YIELDS

In the preceding sections, our analysis of the variability of wheat yields was limited to yields of wheat per acre in the smaller, more or less homogeneous wheat areas, which we usually call subregions of the major wheat regions. This was appropriate because of the character of the problems discussed there. A study of the relationship between the variability and average level of yield, or of the dependence of variability of yield upon climatic characteristics of the respective wheat regions, can be fruitful only when the areas selected for these purposes are relatively small and sufficiently homogeneous. For fuller understanding of these problems, it would have been better to select even smaller and consequently more

[27] See Azzi, *op. cit.*, pp. 765–66. The coefficients of variability of wheat *acreage* for the three Indian wheat regions, when year-to-year variations of regional acreage are measured from the respective trend lines, are nearly as large as the coefficients of variability of regional *yields* of wheat per acre.

[28] For a summary of the analysis of the relationship between wheat yield and rainfall in India, see *Foreign Crops and Markets* (U.S. Dept. Agr., Bur. Agr. Econ.), Mar. 14, 1927, p. 360; also C. P. Wright and J. S. Davis, "India as a Producer and Exporter of Wheat," WHEAT STUDIES, July 1927, III, 352–53.

homogeneous wheat areas, but the use of smaller subdivisions would have involved prohibitive computations.

However, variability of yields on larger areas—for the major wheat regions or for a combination of these regions into large continental areas—is of considerable interest for the study of certain economic problems. From the point of view of market analysis, for instance, fluctuations of wheat production in the Hard Winter or Spring wheat areas of the United States, or in the deficit area of Northern Europe as a whole, may have greater interest than fluctuations of production in smaller portions of these regions. In so far as year-to-year fluctuations of regional output are determined mainly by fluctuations in yield per acre, it is of interest to study these fluctuations also for larger regions, in spite of the fact that average yield per acre for a large region is a rather abstract value, frequently not representative of any part of the region.

The central problem in the comparison of the variability of average yield per acre for a large area and for the smaller subdivisions of the same area is to find to what extent unrelated fluctuations of yields in separate portions of a large area result in stabilizing the average yield for the area as a whole, and to what extent increase in the size of the area affects this stabilization. Full explanation of the differences in the variability of the average wheat yields in smaller areas and in the larger ones composed of them presupposes sufficient study of interregional correlations between fluctuations of regional yields.

From Part I of this study, we know that regional series on wheat yield have, to a great extent, characteristics of random series; that is, fluctuations of regional wheat yields are dominated by many independent, fortuitous factors. Hence, when wheat regions with independent fluctuations of yields are combined in a larger area, the variability of yield per acre computed for the larger area will tend to be smaller than that for the smaller regions of which it is composed. As the number of regions combined is increased, the variability will tend to decrease. The result will be different, however, if fluctuations of yields in the regions combined are not independent but correlated among themselves. If, under the influence of similar factors, regional yields fluctuate in the same direction, the variability of yield in a large area would tend to remain of the same order as that for yields in the regions composing it. The closer this positive correlation among regional yields, the more pronounced will be this tendency. On the contrary, when regional yields tend to fluctuate in the opposite direction, the compensatory effects of such fluctuations will be even greater than for independent fluctuations of regional yields; and the variability of the average yield for the greater area composed of such regions will tend to be much smaller than the average variability of the respective regional yields.

The elucidation of many problems resulting from comparisons of the variability of the average wheat yields computed for wide continental areas, for the major wheat regions, and for the subregions composing them, must therefore be postponed until correlations between fluctuations in regional yields have been studied.[1] However, some conclusions from these comparisons may be given here, and certain preliminary conclusions as to the existence or nonexistence of interregional correlations between fluctuations of wheat yields may be drawn from these comparisons.

We shall proceed with these comparisons in two steps: first, the major wheat regions and their subregions will be compared with respect to variability of average yields per acre; second, the large continental areas and the "world" will be compared in a like manner with the regions and subregions.

Variability of Wheat Yields in Major Regions and Their Subregions

The first of these comparisons is presented in Table 2, in which measures of absolute variability (standard deviations for deviations of average annual yields from their respective trends) and relative variability (coefficients of variability) are shown for each major wheat region (excluding Russia) and for the subregions composing them. For the latter these measures are given as unweighted means

[1] This may be the subject of a later issue of Wheat Studies.

of the respective measures for individual subregions making up a major region. In addition to this, we show for each major wheat region the variability that should be expected on the assumption that there is no correlation between the fluctuations in subregional yields.[2]

It may be seen from the table that the measures of variability—both absolute and relative—of the average wheat yields for the major wheat regions are always somewhat smaller than the averages of the same measures for the subregions of which the regions are composed. This indicates that in every case there is a certain degree of compensation of unrelated fluctuations in subregional yield. This is to be expected. It may be noticed, however, that for most of the major wheat regions this compensation is only slight, much smaller than would be expected in case of independent, uncorrelated fluctuations of subregional yields. It may be concluded that in all cases there exists a certain degree of positive correlation between the fluctuations of subregional yields. The ratios of the actual standard deviations computed for the regional yields series to those computed on the assumption that there is no correlation between the fluctuations of subregional yields (these ratios are shown in one of the columns of Table 2) give some indication of the closeness of correlations between subregional yields. For series of 35-year duration, as are most of the ones from which we have computed our standard deviations for regional yields, the ratios exceeding 1.20 point to a significant positive

TABLE 2.—MEASURES OF VARIABILITY OF THE *AVERAGE* WHEAT YIELD PER ACRE FOR MAJOR WHEAT REGIONS COMPARED WITH MEASURES OF VARIABILITY OF WHEAT YIELD PER ACRE FOR SUBREGIONS, 1901–35*

Region	Number of subregions (1)	Standard deviation, σ (*bushels per acre*): Average of σ for subregions (2)	Actual for region (3)	Expected[a] for region (4)	Ratio of col. 3 to col. 4 (5)	Coefficient of variability, V (*per cent*): Average of V for subregions (6)	Actual for region (7)	Expected[b] for region (8)
Prairie Provinces, Canada	3	4.27	3.72	2.70	1.38	25.0	22.8	16.6
United States Spring Wheat[e]	2	2.92	2.60	2.10	1.24	26.3	23.6	19.1
Eastern North America[e]	3	2.12	1.55	1.14	1.36	13.3	10.4	7.7
United States Soft Winter[e]	2	3.48	3.28	2.46	1.33	22.9	21.7	16.3
United States Hard Winter[e]	3	3.21	2.65	1.87	1.42	29.4	23.0	16.3
Pacific[e]	4	2.79	2.41	1.76	1.37	15.5	13.5	9.9
Northern Europe[c]	6	2.74	1.70	1.15	1.48	8.9	6.7	4.5
Southeastern Europe	3	2.79	2.38	1.71	1.39	18.9	15.3	11.0
France	4	2.73	2.45	1.40	1.75	13.2	11.9	6.8
Italy	2	2.28	1.82	1.61	1.13	13.4	10.6	9.4
Western Mediterranean	2	1.45	1.37	1.17	1.17	14.2	12.0	10.3
Australia	4	2.90	2.76	1.64	1.68	26.2	25.1	14.9
India	3	1.23	.95	.72	1.32	11.1	8.6	6.5
South America[d]	2	2.06	1.94	1.94	1.00	19.6	17.3	17.3

* Data are computed from material given in Table I; see its footnotes *a* through *c* for period qualifications.

[a] Computed from standard deviations of average subregional yields on the assumption that the fluctuations of subregional yields are independent. See footnote 2.

[b] Percentage ratios of standard deviations, as given in column 4, to average yield for the respective regions as shown in Table I.

[c] Northern Europe, Western subregion, has been further divided into four new subregions: namely, British Isles, Scandinavia, Belgium, and Netherlands. Hence, for the purpose of this table, Northern Europe has six subregions rather than the three listed in Table I.

[d] Argentina is here considered as one subregion.

[e] Wheat yield per acre computed on sown-acreage basis.

[2] The expected standard deviations are obtained from the formula: $\sigma_Y{}^2 = \frac{\Sigma a_t{}^2 \sigma_{y_t}{}^2}{A^2}$, where σ_Y designates the expected standard deviation for a regional yield per acre, σ_{y_t} the standard deviation for yield per acre in any of the subregions composing the respective region, A the average wheat acreage (for 1901–35) in a given region, and a_t the average wheat acreage of any of the subregions. This means that $A = \Sigma a_t$. The above formula is developed on the assumption that variations of total wheat production are caused exclusively by variations of yield per acre. The assumption appears particularly appropriate when deviations of total production and of yield per acre are measured from their respective trends, as is our practice, and not from their averages. Changes in acreage are

correlation between the respective subregional yields.[3]

For all major wheat regions of North America (Table 2), the ratios of the actual standard deviations for regional yield to deviations expected on the assumption that there is no correlation among subregional yields exceed 1.20. This points to the existence of a significant correlation among fluctuations of subregional yields in all principal regions of North America. In 5 of the 6 major regions this correlation appears to be highly significant. In only 3 of the 5 major wheat regions in Europe are there indications that a significant correlation exists among subregional yields,[4] but in all of these it is highly significant. The ratio of the actual to the expected standard deviation is especially high for France. This may be explained partly by the fact that the wheat acreage is relatively large in the subregions where the absolute variability of yields is comparatively low (the Southern and West Central subregions), and it is small where the absolute variability is the highest (Northern subregion). There are also indications of a highly significant correlation among fluctuations of yields in the Australian wheat regions, for the variability of wheat yield in Australia as a whole (4 states) is about as large as it is on the average in the separate wheat regions of Australia. Fluctuations of wheat yields in various subregions of India also are related one to another, but those of Argentina and Uruguay do not show any correlation.[5]

usually more or less gradual, and consequently they are reflected mainly in the trend of total production rather than in its year-to-year fluctuations. By taking deviations of production from the trend, we thus remove the main component of variations in production caused by changes in acreage. By far the greater part of the remaining variation in production may be regarded as caused by variations in yield per acre. The relationship would also hold true, however, on the more general assumption that any acreage changes that occur are such that they have no influence on fluctuations in the average yield per acre.

The above formula is developed from the theorem that the variance of the sum of several *independent* variables is equal to the sum of the variances of these variables. If we designate by P the total production of wheat in a certain region; and by $p_1, p_2, \dots p_t, \dots p_n$, total productions in the subregions of that region, then

$$P = p_1 + p_2 + \dots p_t + \dots p_n, \text{ and}$$
$$\sigma_P^2 = \sigma_{p1}^2 + \sigma_{p2}^2 + \dots \sigma_{p_n}^2 = \Sigma\sigma_{p_t}^2$$

where σ_P^2 is the variance of P, and σ_{pt}^2 the variance of p_t. On the assumption that variation of production is caused exclusively by variations in yield, we may write that $\sigma_P^2 = A^2\sigma_Y^2$, and $\sigma_{p_t}^2 = a_t^2\sigma_{y_t}^2$, and consequently $\sigma_Y^2 = \frac{\Sigma a_t^2\sigma_{y_t}^2}{A^2}$, as given above. In case subregional wheat acreages tend to be equal, $\frac{\Sigma a_t^2\sigma_{y_t}^2}{A^2}$ tends to approach $\frac{\sigma_{y_t}^2}{n}$, but it will tend to be somewhat larger than $\frac{\sigma_{y_t}^2}{n}$ when regional acreages vary widely. But in case the acreages (which are used as weights in the above formula) correlate inversely with the variability of yield in the respective subregions, then $\frac{\Sigma a_t^2\sigma_{y_t}^2}{A^2}$ may happen to be smaller than $\frac{\sigma_{y_t}^2}{n}$.

The above formula was suggested by Professor A. L. Bowley, University of London, and it was used by de Hevesy, *op. cit.*, pp. 730–31.

[3] This criterion is obtained from Snedecor's Table of F (G. W. Snedecor, *Statistical Methods*, Ames, Iowa, 1940, pp. 184–87), by treating the problem as one of testing the significance of the difference between two variances, one based on data with *n–1* degree of freedom, the other given independently (degree of freedom infinite). It may be seen that the ratio of two variances (one based on 34 degrees of freedom and the other given independently) equal to 1.44 indicates a 5 per cent significant difference between two variances. Since a ratio of 1.44 in variances is equivalent to a ratio of 1.20 in standard deviations, ratios exceeding 1.20 indicate significant differences (5 per cent) between standard deviations. Similarly a ratio of standard deviations exceeding 1.28 indicates a highly significant difference (1 per cent) between them. For all specific conditions that we have investigated, this criterion, if it errs, leads to underestimating the significance of the correlation among yields in the subregions within a region.

[4] Our correlation analysis indicates, however, that there are also significant positive correlations between subregional yields in Italy and in the Western Mediterranean region. These discrepancies may perhaps be explained by the fact that our assumption that variations of total production of wheat are caused exclusively by variations of yield is not very satisfactory for these regions, since variations of wheat acreage in some portions of them are considerable and erratic, and are consequently responsible for substantial and sudden changes in total production. This is particularly true of French North Africa and Southern Italy. Moreover, the relatively great stability of total wheat outputs in these regions, when compared with the variability of yields per acre and acreages, points to a tendency for yields per acre and acreages to vary in the opposite direction (p. 190). This tendency may also be responsible for the above-mentioned discrepancies.

[5] This last fact is rather surprising because of the proximity of the wheat areas of Argentina and Uruguay and the considerable degree of similarity of their climatic conditions. But our correlation analysis confirms it.

The coefficients of variability measuring relative variability of yields are the same as standard deviations expressed as percentages of the average regional yields for the respective regions. Hence the relationship between the actual coefficient of variability for a region and that expected on the assumption that no correlation exists among subregional yields is practically the same as the relationship between the respective standard deviations, and does not require additional discussion. These coefficients show that relative variability of yield in most of the major wheat regions is only slightly smaller than the averages for the subregions composing them.

Variability of Wheat Yields by Continents and for the "World"

Interesting conclusions may be drawn also from comparisons of the measures of variability of average yields of wheat per acre for wide continental areas, or even for the wheat "world" as a whole,[6] with those for regions and subregions. It is necessary to repeat here that yields of wheat per acre computed for such wide areas as North America, Europe ex-Russia, and still more for the "world," are quite abstract values that are not representative of actual yields in any part of these wide areas. We are interested in the study of variability of such abstract yields, because variations of these yields represent by far the greater portion of the year-to-year variations of the wheat outputs for these wide areas (p. 189). Furthermore, comparisons of variability of yields for such wide areas with that for regions and subregions give the most general picture of the degree to which unrelated variations in wheat yields are progressively compensated for with the increase in the size of the areas under consideration.

These comparisons are summarized in Table 3, which shows for the North American wheat area, for the European area with the exception of Russia, and for the wheat "world" as a whole (also exclusive of Russia), (1) the number of major wheat regions and subregions composing them, (2) the average wheat yield per acre, and (3) the measures of variability (absolute in bushels per acre and relative as a percentage of the average yields). Both measures of variability are shown for yields computed for the respective continental areas and for the "world," and (in the form of unweighted means) for wheat regions and subregions composing the respective areas.

Table 3.—Measures of Variability of Wheat Yield per Acre in the Major Continental Areas and of the Wheat "World" Compared with the Measures of Variability of Wheat Yield per Acre in Regions and Subregions, 1901–33*

Area	Number of major regions	Number of sub-regions	Average yield (*bushels per acre*)	Standard deviation σ (*bu. per acre*): Actual for region	Average of σ for major regions	Average of σ for sub-regions	Coefficient of variability V (*per cent*): Actual for region	Average of V for major regions	Average of V for sub-regions
North America[a]	6	17	13.3	1.40	2.70	3.10	10.5	19.2	21.4
Europe ex-Russia	5	17	17.5	1.20	1.94	2.56	6.9	11.3	12.8
"World"	14	43	14.2	.69	2.26	2.69	4.9	15.9	17.7

* Averages computed from data in Table I.

[a] Period 1901–35.

Unweighted averages of the measures of variability of regional and of subregional yields summarize only the data shown separately for each major wheat region in Table 2. A comparison of these averages does not add much to what has been said in the preceding paragraphs. It shows that variability of wheat yields averaged by major wheat regions is only a little smaller than that of

[6] The wheat "world" is understood here as the territory of all wheat regions included in the previous analysis, excluding the Russian regions. Data for Russia cover a somewhat different period than we have used for other regions, and in addition statistics for years following the 1917 revolution are not fully comparable to those for earlier years. Hence it was found advisable not to include them in the summary picture.

wheat yields averaged by subregions. Indeed, in North America the coefficients of variability of wheat yields for the 6 major wheat regions average 19.2 per cent, while similar coefficients for the 17 subregions average 21.4 per cent. In Europe the respective figures are 11.3 per cent and 12.8 per cent. As these two continental areas represent the greater portion of the wheat "world," as defined here, the respective figures for the "world" are just between those for North America and Europe ex-Russia. As explained earlier, a relatively small decline of the variability of yields in the major wheat regions as compared with that in the subregions composing them indicates that fluctuations of subregional yield are positively related among themselves.

A quite different situation is revealed by comparisons of the measures of variability of wheat yields in the major wheat regions with those for the wide continental areas in which the regions lie. It appears from the table that the variability of the average wheat yield for North America, as a whole, is only about half of the average variability for the principal wheat regions of the United States and Canada. The situation in Europe is about the same, though the difference between the variability of yield for Europe ex-Russia, as a whole, and the average level of variability for the major European wheat regions is proportionally a little smaller than it is for North America and its regions.

Such a great decline in the variability of yields averaged for large areas points to a high degree of compensation of unrelated variations in regional wheat yields, and indicates that there is practically no significant direct correlation among fluctuations of regional yields. That this is true in relation to the major North American wheat regions is evident from the fact that the standard deviation, computed for the average yield of wheat per acre for North America as a whole, only slightly exceeds the expected standard deviation for the same average yield on the assumption that fluctuations in regional wheat yields in North America are independent of each other.[7] The actual standard deviation is 1.40 bushels per acre, the expected is 1.30, and their ratio is only 1.08.

Since the difference between the variability of the average wheat yield for the whole area of Europe ex-Russia and the average variability of yields for the major European wheat regions is proportionally somewhat smaller than it is for North America, it must be expected that regional wheat yields in Europe fluctuate in somewhat closer direct relationship than they do in North America. Indeed, the standard deviation for the average wheat yield for Europe ex-Russia significantly exceeds the expected standard deviation computed on the assumption that no correlation exists among wheat yields for the major wheat regions of Europe ex-Russia. The former is 1.20 bushels per acre; the latter .93 bushels per acre, and their ratio, 1.29, indicates a highly significant positive correlation among fluctuations of regional wheat yields in Europe.[8] Thus, it may be concluded from the relatively marked stability of

[7] Following the formula developed in footnote 2.

[8] Our correlation analysis also indicates that wheat yields for the major wheat regions of Europe fluctuate in closer direct relationship than do wheat yields in major wheat regions of North America. But it must be remarked that a high degree of compensation of variations in regional yields may result not only when fluctuations of regional yields are independent but also, even to a greater extent, when they correlate inversely. When yields in some regions tend to fluctuate systematically in the same direction, while in other regions they tend to fluctuate in the opposite direction, the compound effect of such fluctuations on the variability of yield for the whole area composed of all these regions may be the same as if there were no significant correlation among the fluctuations of regional yields. Our correlation analysis indicates that such a situation exists to a certain extent in North America. Significant positive correlations were established among fluctuations of wheat yields in some of the major wheat regions of North America, for instance between yield of United States spring wheat and that for spring wheat in the Prairie Provinces of Canada, as well as between yield in the eastern United States and the yields in the Soft Winter and Hard Winter wheat areas. But it was established also that wheat yields in some North American regions tend to fluctuate in the opposite direction. This is particularly characteristic of the relationship between wheat yields in the eastern United States and in the United States Spring wheat regions. Yield of spring wheat in Canada also tends to fluctuate inversely with the yield of hard winter wheat in the United States, although this last correlation is hardly significant.

Similar tendencies appear also in Europe, but to a much smaller extent. No significant negative correlation has been established for the major European wheat regions, though wheat yields in France and the British Isles, on the one hand, and in Rumania, on the other, indicate certain tendencies to fluctuate in the opposite direction.

average wheat yields for North America and for Europe ex-Russia, when compared with the variability of yields in their major wheat areas, that there is a considerable degree of diversity among fluctuations of regional yields in the major wheat areas, particularly of North America.

Since variations of wheat yields in the major wheat regions of North America show greater diversity than those of Europe ex-Russia, there is less contrast between the variability of average wheat yields for these continental areas taken as a whole than between the variabilities of yields in their respective regions. The average yield in North America fluctuates more than that in Europe, but not as much more as would be expected on the basis of the great variability of wheat yields in most of the major wheat regions of North America. Although the total wheat acreages of these two continental areas (average for 1901–35) are about equal, the area in North America is dispersed over a much greater total territory than in Europe ex-Russia. This may partly explain the differences between the two continents with regard to variability of yields, but full explanation requires additional study of climatic characteristics of the two continents and their effects upon wheat yields.

From Table 2 (p. 174), we know that variability of wheat yields for the Australian and South American continental areas[9] continues to be large even when all wheat regions are combined. It was natural to expect this, since the total wheat acreage of these continents is much smaller than that of North America or Europe, and since most of this acreage is concentrated in a relatively limited territory of the two continents.

In spite of the fact that our wheat "world" includes these two continental areas with great variability of wheat yields and India, in addition to North America and Europe ex-Russia, the average wheat yield for the "world" as a whole shows a high degree of stability. The coefficient of variability for the average wheat yield computed for the "world" as a whole (about 5 per cent) must be contrasted with the unweighted mean of the coefficients of variability for the 43 subregions (about 18 per cent), and with that of the coefficients of variability for the 14 major regions (about 16 per cent).

The relatively small difference between the average variability of wheat yields in the 14 major wheat regions of the "world" and that in the 43 subregions composing them points once more to a relatively close direct relationship among variations of wheat yields within the major wheat areas, while the great difference between the variability of the "world" wheat yield and the average variability of wheat yields in the 14 major wheat areas points to a great diversity among the variations of wheat yields in these major wheat areas. The actual standard deviation for the average "world" wheat yield (.69 bushel per acre) exceeds the expected computed from the standard deviations for regional yields on the assumption that variations of the regional yields are independent (.64 bushel) so little that it is possible to infer that these last variations are not related at all among themselves. A similar conclusion must be drawn also in relation to variations of the average wheat yields for the continental areas. But are they really unrelated, or are some of them related directly and others inversely? This can be answered only by a detailed correlation analysis. Here it must be emphasized only that yield of wheat per acre computed for the "world" as a whole, for one reason or another, shows a high degree of stability while regional wheat yields fluctuate widely.

V. CHANGES IN VARIABILITY OF YIELDS FROM 1901–18 TO 1919–35

The study of the variability of regional wheat yields throughout the world is completed in this section by analysis of the changes in variability of regional yields that took place between two groups of years, 1901–18 and 1919–35.[1] Information necessary for this is

[9] The South American wheat area is less fully covered by available crop statistics than is the North American or Australian.

[1] Since, in our measures of variability of wheat yields, we average deviations of annual yields from the trends represented by 9-year moving averages,

given in Table I, where measures of absolute and relative variablity of regional wheat yields are shown not only for the whole period used in the interregional comparisons, 1901–35, but also for its two parts, the latter of which covers most of the interwar period.

For series of 18 and 17 years duration, as are ours, the change in the variability of yields may be regarded as significant only when the measure of absolute variability (standard deviation) has increased by about a half, or decreased by about a third, of its value at the earlier period.[2] Smaller changes in the measures of variability could be caused by a chance combination of usual variations in annual yields. In the light of these standards for significant changes, increases or declines in the variability of wheat yields from the earlier period to the later have been sufficiently large to be significant in only a few wheat regions (or subregions) of the world, while in most the changes are not large enough to require particular explanation. Furthermore, some changes that might be viewed as significant in the light of the standards just mentioned must be regarded as purely statistical rather than as real changes in the variability of wheat yields, for they are explainable by changes in the methods of obtaining, or in the precision of, crop estimates.

In the following paragraphs we shall mention *all* regions in which changes in the variability of wheat yields appear to be significant, and we shall attempt to indicate the reasons for these changes. We shall also mention regions with fairly large changes in variability of wheat yields, which, though formally insignificant, may show some tendencies that appear real in the light of the known facts.

EUROPE EX-RUSSIA

In the regions of this continent, hardly any real change in variability of wheat yields took place from 1901–18 to 1919–35. There are, however, indications of several significant differences between the measures of variability of wheat yields in the two periods, practically all of which point to an increased variability of yields in the later period.

The variability of wheat yields appears to be significantly larger in the later period in Northern Europe as a whole and in all its subregions: Western, Germany, and Eastern.[3] The same is indicated for the East Central subregion of France; but the variability of wheat yield substantially increased during the later (interwar) period also in West Central France, and in France as a whole. The only large, though still not significant, decline in the variability of wheat yield from 1901–18 to 1919–35 apparently took place in the Eastern subregion of Southeastern Europe (see Table I).

It is difficult to offer reasonable explanations of these changes in the variability of wheat yields in European regions. Consequently, we must first explore the possibility that the

crop statistics used in the computation of these trends extend from 1897 to 1939, that is, to the last prewar year for which crop statistics are more or less complete. For some regions, as indicated in the footnotes to Table I, crop statistics are not available for 1939, or even for 1938. In the computation of trends, data from 1897–1900 are also used. For some regions these are less reliable than statistics for the following years but they were used in computation of trends in order to extend the period under study. For the United States crop series, it was not possible to approximate yields of winter wheat per *sown* acre prior to 1901 (see Appendix Note to Part I of this study, WHEAT STUDIES, April 1942, XVIII, 333). Yields on harvested acreage were therefore used for 1897 to 1900 in the computation of the respective trends for these series.

[2] More exactly, a 51.3 per cent increase of standard deviation, or a 34.4 decline, indicates a significant difference (at 5 per cent level of significance) between the standard deviations for two periods. If standard deviations are computed for periods shorter than these mentioned above, the percentage increase (or decline) indicating significant changes would be larger. The test of significance in our case is complicated to a certain extent, because the absolute variability and average level of yield tend to be in direct correlation (pp. 162–63). An increase in absolute variability of yield (measured by the respective standard deviations) accompanied by a simultaneous increase in the average level of yield may be explained, at least partly, by this correlation. In such cases it would perhaps be safer to apply the above-indicated standards for significant percentage-changes to the measure of relative variability expressed as a percentage of the average yields for the respective periods, rather than to the standard deviations themselves.

[3] For the last subregion, a significant difference between standard deviations is indicated only when the war years are omitted, and when the standard deviations are computed for 1901–14 and 1921–35 respectively. Omission of war years is justified for several European countries because of abnormal agricultural conditions during those years. This relates particularly to northeastern Europe.

changes are statistical rather than real. Indeed, wheat acreage did not change much in Northern Europe between 1901–18 and 1919–35; and, if it changed appreciably in France, it declined rather than increased. Consequently, the increase in the variability of wheat yields in this area cannot be explained by expansion of wheat cultivation on poor lands, less fitted for successful production of wheat. Agricultural practices in wheat production also could not have changed radically between the first two decades of the twentieth century and the later (interwar) period. Increased level of the average wheat yield per acre in these regions in the later period points, however, to a further improvement of these practices. Under such circumstances, a smaller stability of wheat yields could hardly be expected. The known facts also do not indicate significant changes of the climatic condition of northwestern Europe.

Since the Western subregion of Northern Europe, according to our definition, consists of several countries collecting and publishing their own crop statistics, it seemed advisable to study the variability of wheat yields in these smaller areas in order to obtain some clue to the explanation of the increase in variability of wheat yield in this region as a whole. The information on the measures of variability of wheat yields for these countries is given in the accompanying tabulation.[4]

Area	Standard deviation (*bushels per acre*)		Ratio of col. 2 to col. 1	Coefficient of variability (*per cent*)	
	1901–18	1919–35		1901–18	1919–35
British Isles	2.10	2.47	1.18	6.4	7.4
Scandinavian countries	2.90	3.95	1.36	9.0	11.2
Belgium	3.49	3.24	.93	10.4	8.4
Netherlands	3.13	4.25	1.36	9.2	9.9
Northern Europe, Western subregion	1.67	2.62	1.57	5.1	7.5

It may be seen from the ratios of the standard deviations for regional wheat yields computed for 1919–35 to those computed for 1901–18 that in none of the smaller areas composing the Western subregion of Northern Europe has the variability of wheat yields increased significantly; in Belgium it has even declined. This indicates that the "significant" increase of the absolute variability of wheat yield in the subregion as a whole is spurious. The variability for the larger area increased more than those of the smaller areas composing it, simply because in the later period variations of wheat yields in the smaller areas tended to fluctuate in closer direct correlation among themselves, while in the earlier period they varied more diversely. The latter resulted in a greater compensation of unrelated variations of wheat yields for smaller areas in the earlier period and, consequently, in greater stability of wheat yield for the subregion as a whole. Indeed, during the period 1901–18, the coefficient of variability of yield for the larger area was only 5.1 per cent, while similar coefficients for the smaller areas ranged from 6.4 per cent to 10.4 per cent. Such a degree of compensation indicates that variations of yields in individual countries were unrelated among themselves, while in the later period there was significant direct correlation among them. This relationship may serve as a good example of the various pitfalls that analysis of the dynamics of yield series encounters, particularly when yield series are for wide and not sufficiently homogeneous areas.

For somewhat similar reasons we dismiss without much discussion the significant increase in the variability of wheat yields in the Eastern subregion of Northern Europe, when crops in the war years 1915–20 are omitted. The change in the variability of wheat yield in this area may be real, since the war and the following revolutions and agrarian reforms have greatly affected agriculture there. But it may equally be the result of lack of comparability of respective crop statistics. During 1901–18 this area was divided between the two Empires—Austro-Hungary and Russia—which were responsible for uniform crop statistics in their respective areas, while during 1919–35 the same area was divided among more than half a dozen independent states, which estimated their crops independently, following methods different from those

[4] Sources of statistics of yield as indicated in the Appendix Note to Part I (WHEAT STUDIES, April 1942, XVIII, 333).

used in the earlier years. Furthermore, the areas covered by crop statistics for 1901–18 and 1919–35 are not always exactly the same because of boundary shifts.

The reality of the increased variability of wheat yields in Germany during the interwar period may be regarded as more probable. At least, one investigator has built a theory to explain it. Finckenstein[5] says that the intensive agriculture in Germany has exhausted its yield-raising potentiality even in the prewar period. According to him, every agricultural system has limited potentialities in the raising of yields; when these limits are passed, the system is liable to a crisis that finds expression in large fluctuation of yields; and German agriculture in the interwar period was in such a situation. This explanation may appear plausible. However, Finckenstein did not bring many empirical facts to substantiate his theory. Furthermore, he suggested this explanation of the increased variability of yields in Germany before he had sufficiently explored a possible statistical explanation of this increase.

To us it seems probable that increased variability of wheat yields during the interwar period in Germany, and in other countries of northwestern Europe including France, must be regarded as a statistical phenomenon rather than as a real fact. During World War I, all these countries had the opportunity to ascertain their bread-grain consumption with a greater degree of precision than they had done before, since all of them experienced some shortage of bread grain during the war. Better knowledge of grain consumption contributed, in turn, to a greater precision in estimating postwar crops. But the more precise postwar crop estimates could show greater variability than the less precise prewar ones. Indeed, it is quite conceivable that, because crop statistics for the earlier period are less precise, the crop estimates for that period may cluster more closely around the average than do the more precise crop estimates for the later period. Of course, this must be regarded as only a hypothesis, but it appears more reasonable than a real increase in the variability of wheat yield in such countries as the British Isles, Germany, and France.[6]

It is equally difficult to recognize the reality of a large, though not significant, decline in the variability of wheat yields in the Eastern subregion of Southeastern Europe. We are also inclined to explain this decline more as a result of the imperfection of crop statistics than as a real change.

The wheat area in Rumania was reduced somewhat in the period 1919–35. This was partly because of the radical agrarian reform, since peasants who obtained land from the large estates preferred to plant more corn than wheat.[7] But this did not mean that the smaller wheat crops were concentrated on better lands or that cultivation methods were improved. On the contrary, the tendency appears to have been in the opposite direction, for the average yield of wheat per acre was lower in the later period than in the earlier. Hence it is difficult to explain why the wheat yield in this area should have been more stable, especially because there was no tendency to greater stability of wheat yields in the adjacent Western and Southern (Bulgaria) subregions of Southeastern Europe.

[5] H. W. Finck von Finckenstein, *Die Getreidewirtschaft Preussens von 1800 bis 1930* (*Vierteljahrshefte zur Konjunkturforschung*, Sonderheft 35, Berlin, 1934), pp. 35–37.

[6] It must be added, however, that the significant increase in the variability of wheat yield in East Central France, which was mentioned earlier, may result from another kind of defective comparability of statistical data. The area of this region is not quite the same for 1901–18 and 1919–35. For the later period it includes Alsace-Lorraine, which during the earlier period was part of Germany. The difference in the territory covered could be responsible for the difference in the variability of wheat yields in the two periods. However, it must be mentioned that variability of wheat yield in Germany as a whole is lower than in France, and that French crop statistics indicate considerable increase in the variability of wheat yields during the interwar period not only for East Central France, but also for West Central France, which experienced no change in frontier, and for France as a whole.

[7] Corn requires more labor than wheat, and labor resources are greater in relation to land on small peasant farms than on large estates. Moreover, corn is the principal food of the peasantry in Rumania, and consequently it was produced chiefly by peasants before the postwar agrarian reform, while wheat as a cash crop was grown mainly on large estates. For details, see V. P. Timoshenko, "The Danube Basin as a Producer and Exporter of Wheat," WHEAT STUDIES, March 1930, VI, 218.

North America

We encounter similar difficulties in explaining some of the significant changes in the variability of regional wheat yields in the North American wheat regions. Absolute variability of wheat yield increased significantly in 4 of the 17 North American subregions. Variability of wheat yields tended to increase in most of the other American subregions, particularly when relative variability is considered (Table I). Indeed, coefficients of variability of wheat yield computed for 1919–35 exceeded similar coefficients for 1901–18 in 13 of the 17 subregions and in 5 of the 6 major wheat regions of North America.[8] Coefficients of variability declined from 1901–18 to 1919–35 in only 4 subregions and in only one major wheat region. However, most of these changes were not large enough to be regarded as significant.

Significant increases in the absolute variability of wheat yield took place in two subregions of Eastern North America—the Northeastern[9] and the Southeastern subregions—and in two subregions of the Pacific Northwest—Oregon and Idaho.

It is difficult to explain satisfactorily why variability of wheat yields has significantly increased in Eastern North America. The situation there is similar to that in northwestern Europe. In both the northeast and the southeast of the United States, acreage under wheat decreased, while the average yield per acre tended to increase. This may indicate that in both regions wheat retreated to better land and that agricultural practices in wheat growing were improved.[10] Hence it is difficult to understand why yield per acre in this area appears to be less stable in the later period. Variability of wheat yield in the third subregion of Eastern North America—Ontario—tended to decline, and in the adjacent Soft Winter wheat area of the United States the variability of wheat yield showed no definite tendency to increase.[11] Consequently, we are inclined to believe that the significant increase in the variability of wheat yield in Eastern United States, similar to that in northwestern Europe, must be explained by statistical factors rather than be regarded as real. Wheat is a secondary crop in Eastern United States, and this may explain to a certain degree the lack of precision of the wheat statistics.

No difficulty arises in explaining the significant increase in the variability of wheat yield in the two subregions of the Pacific Northwest. In both Oregon and Idaho cultivation of wheat was much expanded in the later period in the dry areas with low, unstable yields. This is particularly true of Idaho, where the proportion of wheat grown on nonirrigated land in the total wheat acreage greatly increased in the later period. This, of course, had to increase the variability of the average wheat yield computed for irrigated and nonirrigated wheat combined.

Cultivation of wheat on dry, low-yielding land, where wheat yields tend to vary greatly from year to year, also expanded greatly during World War I and in the years following in the major regions of hard winter and spring wheat, both in the United States and in Canada. Hence it would be natural to expect that variability of wheat yields should increase also in these regions. Under such circumstances, even those increases in the variability of wheat yields that are not large enough to be regarded as significant may serve as indicators of real tendencies. As mentioned earlier, such tendencies are better revealed by the coefficients of variability of wheat yields expressed in percentages of the average yield, than by the measures of absolute variability. This may be explained by the fact, established earlier (p. 162), that absolute variability and level of yield tend to be directly correlated. Consequently, expansion of wheat in low-yielding areas might result in a greater relative varia-

[8] The Pacific Northwest and Pacific Southwest are treated here as one Pacific region.

[9] In the Northeastern subregion only has the absolute variability of wheat yield on *harvested* acreage increased significantly. The variability of wheat yield on *sown* acreage also shows a substantial increase—the respective standard deviations are 1.38 and 1.99 bushels per acre and the coefficients of variability 8.4 and 10.9 per cent—but the changes are not sufficiently large to be regarded as significant.

[10] This is also the conclusion of Bennett. See Wheat Studies, November 1937, XIV, 96–97.

[11] In the United States Soft Winter region as a whole, both the absolute and the relative variability of wheat yield declined slightly; but in its Eastern subregion—adjacent to the eastern United States—the absolute variability slightly increased, while the coefficient of variability declined.

bility of wheat yields, while the measures of absolute variability — standard deviations — might remain without change. Such a situation happens to exist in the spring-wheat areas both in the United States and in Canada. For all subregions except Manitoba, where no net expansion of the wheat acreage took place between 1901–18 and 1919–35, the relative variability of wheat yields substantially increased (by more than 30 per cent), while absolute variability—reflecting lower average yields of wheat per acre—remained without substantial change. A similar development occurred in the United States Hard Winter region, where the average wheat yield per acre declined from 1901–18 to 1919–35. Here too the relative variability of wheat yield per sown acre increased substantially for the region as a whole and for two of its subregions, particularly for the Southern subregion, where the wheat area expanded most. But the absolute variability of wheat yields did not change at all in the Northeastern subregion and even declined in the Northwestern subregion, where wheat acreage more than doubled from 1901–18 to 1919–35. In the Northwestern subregion, the relative variability increased only slightly (9 per cent) and the absolute variability declined. This is rather surprising, since wheat cultivation here expanded greatly on dry, low-yielding land. If our measures of variability reflect correctly real tendencies existing in this particular region, they point to a substantial improvement in the technique of wheat growing, which contributed to a greater stability of yields.

In the light of increased variability of regional wheat yields in the great majority of the North American wheat regions during 1919–35, it is rather surprising to learn that variability of the average wheat yield for North America as a whole substantially declined from 1901–18 to 1919–35. Indeed, the standard deviation measuring absolute variability of average wheat yield per sown acre in North America declined from 1.63 bushels for 1901–18 to 1.16 bushels for 1919–35, or about 30 per cent, while the coefficient of variability indicating relative variability declined from 11.6 to 9.3 per cent, or about 20 per cent. This indicates that variations of regional wheat yields in North America were much more diverse during the interwar period of 1919–35 than they had been during the earlier period.

AUSTRALIA

In contrast to North America, the variability of regional wheat yields in Australia tended to decline significantly from 1901–18 to 1919–35. Once more this tendency is better revealed by coefficients of variability, measuring relative variability in percentages of average yield, than by measures of absolute variability. The latter indicate a significant decline in the variability of wheat yields in only one of the four principal wheat areas of Australia (Western Australia), while coefficients of variability show that, with the possible exception of New South Wales, wheat yields became definitely more stable in all the principal wheat regions of Australia. This development may appear surprising in view of the fact that, between 1901–18 and 1919–35, wheat acreage expanded in Australia even more than in North America.[12] Apparently expansion of wheat acreage was not always in the direction of areas less favorable for wheat growing, or else the expansion in this direction was compensated for by improvement in wheat-growing practices. Indeed, the average yield of wheat per acre increased from 1901–18 to 1919–35 in all the principal wheat regions of Australia, while it declined in all North American wheat regions producing hard wheats (Table I).

It is, perhaps, most surprising that the clearest evidence of significant decline in the variability of wheat yield is for Western Australia, where expansion of wheat acreage was greatest. Significant decline in the variability of wheat yield in this area is indicated by much smaller measures of both absolute and relative variability of wheat yield in 1919–35, as compared with those for 1901–18. In the earlier period, wheat growing in this region was still very little developed. Hence, there was still much room there for expansion of wheat in new areas that were not less favor-

[12] In North America west of the Mississippi, however, expansion of wheat acreage from 1901–18 to 1919–35 was greater than that in Australia.

able for wheat growing than older ones,[13] and for an improvement of agricultural practices.

Summer fallowing must perhaps be regarded as the most effective practice stabilizing wheat yields in the Australian climate,[14] though it means a less intensive use of land. Table 4 shows that the practice of summer fallowing has become more and more general in all wheat regions of Australia, and particularly in Western Australia. The proportion of summer-fallowed land to the total crop area in the later period (1919–35) was much greater in Australia as a whole, and in Western Australia in particular, than in the period 1901–18. Undoubtedly this was an important factor explaining the greater stability of wheat yield in Australia.

Special investigation of droughts, undertaken in Western Australia by the Public Works Department, suggests that severe droughts were much more prevalent during 1900–16 than during 1916–35.[15] This helps to explain why the decline in the variability of yield in Western Australia was more pronounced than in other Australian wheat regions.

The relatively small decline in the variability of wheat yields in New South Wales, on the other hand, suggests that wheat expansion in this region, second only to that in Western Australia, was mainly on dry, low-yielding land, where wheat yields fluctuate widely.

TABLE 4.—SUMMER FALLOWING IN AUSTRALIA AND WESTERN AUSTRALIA IN SELECTED YEARS 1901–02 TO 1935–36*

Year	Australia			Western Australia		
	Area under crops	Fallow	Per cent of total crop area	Area under crops	Fallow	Per cent of total crop area
	Thousand acres			*Thousand acres*		
1901–02.....	8,414	1,653[a]	19.6	217	58	27
1907–08.....	9,354	2,205	23.6	494	152	30
1913–14.....	14,683	4,595	31.3	1,538	755	49
1915–16.....	18,528	3,967	21.4	2,189	686	31
1918–19.....	13,332	4,198	31.5	1,605	726	45
1925–26.....	16,794	7,082	42.2	2,932	1,595	54
1929–30.....	21,930	8,873	40.5	4,566	2,598	57
1930–31.....	25,164	9,208	36.6	4,792	2,821	59
1935–36.....	19,974	9,763	48.9	3,754	2,319	62

* Australia, Bur. of Census and Statistics, *Summary of Australian Production Statistics . . . . 1925–26 to 1935–36* (Production Bull. 30 [1937]), pp. 140–41.

[a] No information for New South Wales before the year 1907–08.

Very little can be said concerning changes in the variability of wheat yields in other wheat regions, namely South America, India, and Russia. In some of the subregions of these regions, variability of wheat yields tended to increase, in others to decrease; but in none were the changes large enough to be regarded as significant. All could result from chance combination of variations of yield characteristic of these regions. Definite conclusions concerning the Russian series are also precluded by the nature of available statistics, for changes in the methods of crop estimation make those for the later period poorly comparable with the earlier. However, the increase of variability of yields of winter and particularly of spring wheat in the North Caucasus are larger than for other regions. This may indicate a real tendency. Cultivation of wheat in this region, particularly of spring wheat, was much expanded on arid land in the eastern direction.

[13] Our analysis of the expansion of wheat acreage in Western Australia during the war and in the years following, up to 1930–31, indicates that this expansion proceeded not only and not mainly in the direction of the arid, low-yielding land in the northeastern margin of the western wheat region, but to a great extent also in the Northern Agricultural Division, which is not particularly arid, as well as in the Southeast, where wheat yields are usually above the average for Western Australia and where they do not vary greatly from year to year. Furthermore, much of the acreage newly planted to wheat on marginal land before 1930 was abandoned during the following years. Consequently, the territorial distribution of the much larger wheat acreage of Western Australia in the later period was not necessarily less favorable for wheat growing than it was in the earlier period. For details on the dynamics of regional wheat acreages in Western Australia, see *Statistical Register of Western Australia* for various years; also J. Gentilli, *Atlas of Western Australian Agriculture* (University of Western Australia, Crawley, 1941), particularly map on p. 9, showing territorial distribution of high-, medium-, and low-yielding lands of the Western Australian wheat area, as well as regions with various degrees of variability of wheat yields.

[14] A. E. V. Richardson, *Wheat and Its Cultivation* (Victoria Dept. Agr. Bull. 55, New Ser., Melbourne, 1925), p. 186.

[15] Wadham and Wood, *op. cit.*, pp. 46–48.

VI. TYPES OF VARIABILITY OF YIELDS

By "type of variability" we mean the character of distribution of deviations of annual yields from the "normal" or average yield according to the size of these deviations. Are positive and negative deviations—that is, good and poor crops—equally frequent and symmetrically distributed around the average? Or, perhaps, do crops above the normal appear more frequently than small crops, or vice versa; and are the distributions consequently asymmetrical? Do small and large deviations of yield occur with equal frequency? Or do small deviations occur more frequently, larger deviations less frequently, and very large ones only seldom? Such information may be obtained from the frequency distributions of the deviations of annual yields from the trend values for the respective years, represented in this study by the 9-year (weighted) moving average.

Various types of such frequency distributions are conceivable. As yields may be regarded as the result of a multitude of independent factors, it is possible to expect that variations in yields may follow the law of normal distribution. But it is also quite possible, and perhaps probable, that the distribution of variations of yield from its normal or average value may be skew or asymmetrical, as is commonly characteristic of many other biological phenomena. It is conceivable also that deviations of annual yields from their normal value may, within certain limits, be equally frequent, independent of the size of these deviations. In such case, we shall have a rectangular distribution of these deviations.

In order to obtain objective information on the types of variability of wheat yields in various regions of the world, such frequency distributions of the deviations of yield were prepared for the 25 regional series in wheat yield used in Part I of this study for the detailed analysis of the "cycles" on wheat yields.[1] These series are relatively long, and, consequently, the numbers of items in the frequency distributions of the variations of yield obtained from them are sufficiently large to make them more or less regular. On the other hand, these series represent the wheat "world" fairly well.[2]

These frequency distributions for all 25 regions are given in Table II. As our interest in this section is concerned mainly with the form of these frequency distributions, rather than with the measure of dispersion of yield, the class intervals in the frequency distributions are expressed not in bushels per acre but in units of standard deviations for the respective distributions. This makes it possible to combine data for several regional series into larger groups representing wider geographical areas. Frequency distributions for these larger groups are also shown in Table II.

Such a grouping is desirable, since the number of items in the frequency distributions for even the longest of our regional series is still not large enough to make these distributions sufficiently regular. For some of our regions, the number of items is as small as 35 (North Caucasus) or 44 (Volga region and Ukraine). For most of the North American wheat regions it is 66, and for Australia 72. For only one region (France) does the number of items in the frequency distribution exceed 100. Hence, when the number of classes selected is sufficiently large to give a detailed picture of distribution, the frequency distributions for individual regions inevitably become irregular. This is well illustrated by Chart 3, in which several such frequency distributions for individual wheat regions are presented graphically. Since the number of items in the distributions varies from one region to another, it seemed advisable to present in this chart frequencies not in absolute numbers but as percentages of the total number of items in the respective frequency distributions.

The chart shows that the character of the distributions of variations of annual yields varies considerably from one region to another, and that only a few of them appear more or less regular. It must be mentioned, however, that in the selection of regions for the graph we attempted to pick extreme samples of certain types of distributions, rather

[1] WHEAT STUDIES, April 1942, XVIII, 310–11.
[2] *Ibid.*, p. 312.

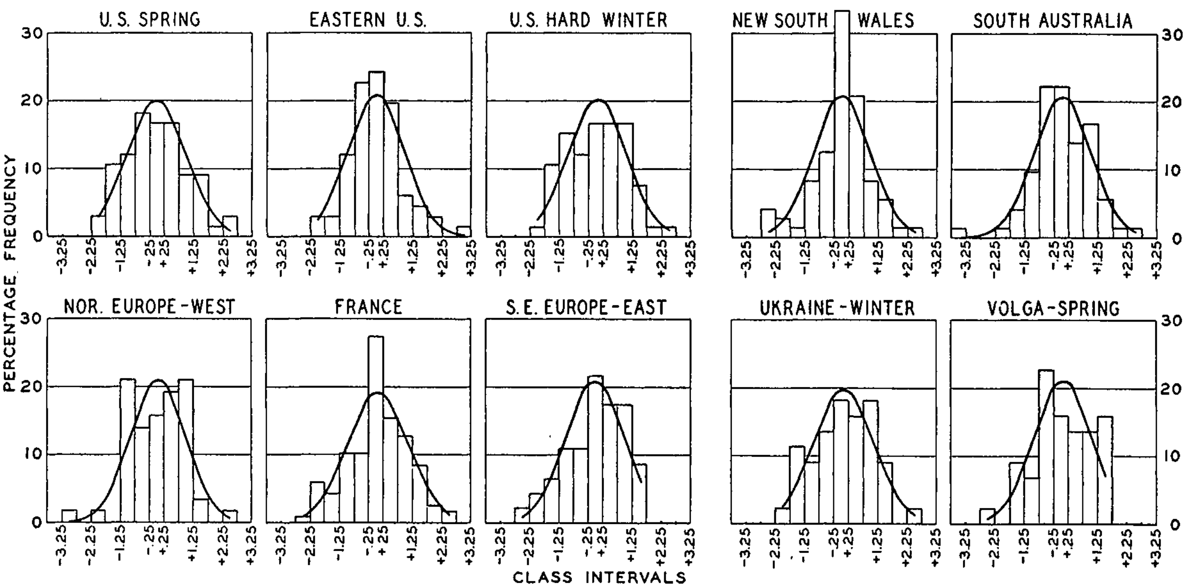
than to give a representative sample of our 25 regions. We picked those regions for which frequency distributions of the deviations of annual yields from the trend lines apparently differed most from the regular bell-shaped curve characterizing the so-called normal distribution. Our purpose was to test the hypothesis that variations of yield follow the law of normal distribution. For this reason, it appeared advisable to apply such a test to those distributions that apparently deviated most from the normal distribution.

Indeed, frequency distributions for two of the regions represented in Chart 3, those for the United States Hard Winter wheat and for the Western subregion of Northern Europe, appear to be closer to a rectangular distribution than to a bell-shaped curve. This is particularly true of the variation of yield in the Western subregion of Northern Europe, where frequencies in the five central class intervals, represented by the heights of rectangles, are fairly large and nearly equal, while in the classes to the right and left they fall abruptly to very small values.

In two other regions—France in Europe and New South Wales in Australia—an excessively large number of items are concentrated in the middle class interval. This indicates that yields very close to the average are reported abnormally frequently, while yields deviating moderately from the average are reported less frequently than would be expected for a normal distribution of the variations of yield. In order to show these deviations from the normal distribution, frequencies for the normal distributions are shown in Chart 3 by the normal curves fitted to the actual frequency distributions.[3]

From comparisons of the heights of columns of the frequency distributions shown in Chart 3 with the positions of the normal curve in the middle of respective columns, it may be concluded, for instance, that in the Eastern United States variations of yield also deviate noticeably from the normal distribution. In this region also yields deviating little or only moderately from the average, i.e., those represented by the three central classes, are

CHART 3.—FREQUENCY DISTRIBUTIONS OF DEVIATIONS OF ANNUAL YIELD FROM THE LINES OF TREND, ACCORDING TO THEIR MAGNITUDE (EXPRESSED IN UNITS OF STANDARD DEVIATIONS), FOR SELECTED WHEAT REGIONS*



* Data in Table II.

[3] For the tracing of the normal curves, ordinates for the middle columns in the frequency distributions were computed in the usual manner of curve fitting. Consequently, the imperfect appearance of the curves in Chart 3 must not affect our comparisons of the actual distribution with the curves.

substantially more frequent than would be reasonable to expect if the variation of yields followed the normal distribution. On the other hand, yields deviating from the average to a greater extent, those represented by the two classes to the left and two classes to the right of the three in the middle, are substantially less frequent than in the case of the normal distribution. The frequency distribution of the variations of wheat yield in the Volga region also deviates noticeably from the normal distribution and is quite irregular.

On the other hand, variations of yields in such regions as the United States Spring wheat area, the Eastern subregion of Southeastern Europe, South Australia, and winter wheat in Ukraine, represented in Chart 3, though irregular, conform better to the type of the normal distribution. Scrutiny of the frequency distributions of the variations of yield for other wheat regions, included among the 25 given in Table II but not presented graphically in the chart, indicates that most of them, in spite of their irregularity, do not show systematic deviations from the normal distribution.

In view of this it appeared reasonable to undertake a statistical test of the hypothesis that variations of yield follow the law of normal distribution, in spite of the apparent diversity of the frequency distributions of these variations presented in Chart 3.

The results of this test indicate that for none of the ten regions selected for the test was the probability of the hypothesis smaller than .05, the least exacting level of significance of the deviation usually applied in such tests. For two of the ten regions, this probability was below .10 but it exceeded .05; for one, it was below .20 but above .10; for two others it was below .30 but over .20; and for the remaining five regions it exceeded .50. The probability that the ten frequency distributions shown in our chart, taken together, may be regarded as a sample drawn from the normally distributed population is larger than .20 but smaller than .30.[4] It may be concluded, therefore, that there is not sufficient indication to warrant the inference that types of variability of wheat yields vary significantly from one region to another, or that they are significantly different from the variability of a phenomenon that is subjected to the influence of a multitude of independent factors.

This conclusion may be applied also to all 25 regions included in Table II, since, as mentioned earlier, the frequency distributions of variations in yields in the ten regions selected for the test appeared to be in smaller agreement with the hypothesis tested than variations in yields in other wheat regions.

It follows from the above conclusion that the information which we have at our disposition does not warrant saying that in one or another region large crops tend to occur more frequently than small ones, or vice versa, though a skew frequency distribution, as for instance that for the Eastern subregion of Southeastern Europe, may suggest this. It would also be wrong to affirm that there is a definite tendency in the Western subregion of Northern Europe for crops considerably above and below average to occur as frequently, or even more frequently, than average crops, though the rectangular character of the frequency distribution of yields of various size may suggest this.

It must be mentioned here that wheat yields, as reported in the crop statistics, represent estimates of yields and that their variations depend not only on the variation of real yields

[4] The following tabulation shows the probabilities indicating the degree of goodness of fit of the actual frequency distributions of the deviations of yield from the trends to the normal distributions in ten wheat regions:

Region	Probability
U.S. Spring wheat	.693
Eastern United States	.274
U.S. Hard winter	.687
Northern Europe, West	.085
France	.082
Southeastern Europe, East	.618
New South Wales	.213
South Australia	.549
Ukraine (winter wheat)	.781
Volga (spring wheat)	.181

By applying the combination of probabilities for the ten individual regions, following the method developed by R. A. Fisher (*Statistical Methods for Research Workers*, 4th ed., London, 1932, Sec. 21.1), we obtained a probability equal to .279 that the ten frequency distributions shown in Chart 3 may be regarded as drawn from the normally distributed population.

but also on the errors in estimates of those yields. Consequently, it is conceivable that some of the systematic deviations of the frequency distributions of variations of yield from the normal distribution mentioned in our earlier discussion may be caused by the systematic character of the errors of the crop estimates. For instance, it is quite conceivable that excessive frequency of yields close to the average for some of the regions may simply indicate a tendency to report a crop near to the average, when information on the actual yield is not very clear.

For these reasons it appears desirable that some of the striking "abnormalities" shown by the distributions of regional yields according to their size should be studied attentively by statisticians responsible for the organization of crop statistics in the respective countries. Although they are within the limits of chance variations, they may suggest also certain systematic errors in crop estimates, the elimination of which would result in more accurate estimates.

The conclusion that the distribution of variations of yields do not differ significantly from a normal distribution is of interest by itself, and is of importance also in justifying the application of certain statistical techniques to crop statistics. For instance, it may justify, to a certain degree, the application of the correlation technique in the analysis of fluctuations of regional yields. The use of correlation analysis for a comparison of the fluctuations in regional yields is still more justified by the fact, established in Part I of this study, that the time sequence of the variations in yields does not show significant difference from that for variations in random series. Under such circumstances, significant correlation coefficients between the fluctuations of regional yield may be regarded as appropriate measures of the closeness of the relationship between the fluctuations of these yields.

VII. VARIABILITY OF WHEAT OUTPUTS

The purpose of the study of the variability of total wheat outputs is, to a considerable extent, different from that which we had in view in studying the variability of wheat yields per acre. There we regarded variability of yields as a consequence of certain factors, and efforts were made to explain differences in the degree of variability of regional yields, or changes in the variability from one period to another, by geographical characteristics of the regions, or by technological or meteorological changes. Our interest in the variability of wheat outputs, on the other hand, lies in the fact that variations in total outputs must be regarded as important factors in the causation of variations in other phenomena, mainly of an economic character, such as wheat prices and size and distribution of trade in wheat. Here we are relatively little interested in the explanation of variability of total outputs, or in finding factors determining differences and changes in the degree of their variability. In this respect, we shall limit our task by showing only that variability of wheat yields per acre is the major factor determining the variability of total wheat outputs, at least for the relatively short periods studied here.

The difference in purposes determines the selection of regional units that are appropriate. The regions for study of variability in yields were delimited mainly with respect to their geographic and climatic characteristics. Consequently, homogeneity in these respects and (following from this) relatively small size were the main requirements in the selection of those regions. The basis for selection of regions for study of the variability of wheat outputs is quite different. Economic characteristics, such as economic unity of a region or its position in the wheat trade, must be the principal features. Because of this, and because we are interested mainly in the macro-dynamic problems of the wheat "world" rather than in local diversities, regions selected for study of variability of wheat outputs are represented by the major wheat-importing and wheat-exporting countries or by groups of such countries. Since the variability of wheat outputs in these regions is an important factor in world trade in wheat and in the determination of wheat prices, it appeared advisable to present here certain measures of this variability.

The character of problems to be considered determines also the choice of measures to be used in the analysis of the variability of wheat outputs. As explained elsewhere (p. 156), it is preferable to use measures of relative variability—cofficients of variability expressed in percentages of the average outputs—for comparison of variability of wheat outputs. Furthermore, since we are interested in the study of variability of wheat outputs more as a factor affecting various economic phenomena than as a consequence to be explained by other factors, it seems desirable to measure variations of total outputs not only from their respective trends but also from the mean average output for a given period. This is true in spite of the difficulties encountered in interpreting the latter measure (p. 155). As explained earlier, when we measure variations from the mean output, we measure total variability of outputs, while by measuring variations around the trend, we measure only a part of the variability, separating elements of trend from the total.

Table III gives, for the five major wheat-importing areas of Europe and for the eight major wheat exporters, measures of relative variability (coefficients of variability) of wheat outputs for the period 1901–35 and for the two subperiods, 1901–18 and 1919–35. Variations are measured from trends and from mean outputs. In order to show to what extent the variability of wheat outputs depends on the variability of wheat yields per acre for the same areas, the table also shows the coefficients of variability of wheat yields per acre for the same areas. Data on the average outputs, acreages, and yields of wheat, shown in the same table for these 13 areas, make it possible to determine the measures of absolute variability of outputs and yields in the respective areas from the coefficients of variability shown in the table.

Variability of Outputs and Yields

From a comparison of the coefficients of variability measuring variations of wheat outputs and yields per acre from their respective trends, it may be seen that variation of yield per acre is the major factor determining short-term variations of outputs. This is evident if we rank the regions according to the size of the coefficients of variability of their total wheat outputs and according to the size of the coefficients of variability of their wheat yields. The order is very much the same. Total outputs vary widely in regions in which yields per acre fluctuate greatly, and vice versa.

The variability of output is greater than that of yields in all regions except Russia. This is to be expected, since variability of total outputs depends on variations of acreage as well as of yield per acre. However, from a comparison of the respective coefficients of variability it must be concluded that the effect of variations of acreage upon the variability of outputs is of only secondary importance, at least when variations are measured from the respective trends. Data in Table 5 indicate that, on the average for all 13 regions, the variability of regional wheat outputs exceeds the variability of regional wheat yields by about 15 per cent. This may serve, to a certain extent, as a measure of the influence of

Table 5.—Relative Variability of Wheat Outputs and Yields per Acre, in Thirteen Regions, 1901–35*

Area	Coefficient of variability		Percentage ratio
	Total output (*per cent*)	Yield per acre (*per cent*)	
Northern Europe, West	10.4	6.3	165
Germany	10.9	8.0	136
France	13.1	11.9	110
Italy	10.6	10.6	100
Spain	13.3	12.5	106
Total importing areas	7.8	7.3	107
United States	13.3	11.9	112
Canada	25.7	20.3	127
Argentina	23.2	18.2	127
Australia	28.5	24.7	115
India	11.3	8.6	131
Southeastern Europe	15.6	15.3	102
French North Africa	16.2	15.9	102
USSR	15.6	15.7	99
Total exporting areas	7.9	7.0	113
Total all areas	6.0	5.4	111

* Data from Table III.

the variation of acreage upon the variability of total output.[1]

The same table shows, however, that the variability of wheat outputs in various regions exceeds that of yields per acre to a different extent. The percentage ratios vary from 165 for the Western subregion of Northern Europe, to 99 for Russia, and indicate that total production in the latter country is even more stable than yield per acre. The variability of wheat outputs is substantially greater than that of yield per acre in such relatively new wheat-exporting countries as Canada, Argentina, and, to a certain degree, Australia also. This is easily explained. In these countries wheat acreage varies widely, and these variations show not only a growth, reflected by the trends, but also sudden and erratic movements. In India the variability of wheat outputs exceeds the variability of yield per acre by an even greater percentage than in the above-mentioned three countries. This also is easily explained, because we know that in India wheat acreage is affected not less by variations in rainfall than is yield per acre.

It is somewhat more difficult to explain why the variability of wheat outputs in the Western portion of Northern Europe and Germany so much exceeds the variability of the respective yields of wheat per acre. The total crop acreage in these countries, with dense populations and old agricultures, cannot vary greatly. However, in both these regions wheat is not the major crop, as it is in France, Italy, or Spain; consequently, wheat acreage may and does vary substantially without great variation in total crop acreage. We know that the relative variability of wheat yields in these two areas is the smallest of all regions included in our analysis. Under such circumstances, erratic variations in the wheat acreage, even of a moderate size, might affect the variability of wheat outputs in these areas to a relatively great extent, as they did.[2]

We experience certain difficulties also in explaining why, in some regions such as Italy, Southeastern Europe, and French North Africa, the variability of wheat outputs exceeds the variability of wheat yields so little, and why variability of outputs in Russia is even smaller than variability of yields. The situation appears particularly surprising in relation to French North Africa, where erratic variations in wheat acreage are considerable. In this respect, that area has characteristics in common with the new wheat exporters or with India. The only explanation of such a relationship may be found in the tendency of acreage and yield per acre in these regions to fluctuate in the opposite direction. This tendency is possible in a country where there are wheat regions with quite different levels of yield per acre and where the acreage of the low-yielding areas fluctuates greatly. Then a reduction in the low-yielding acreage may tend to raise the average yield per acre for the country as a whole. Such a situation is quite possible in French North Africa, where wheat acreage in the southern low-yielding area may vary greatly with weather variations, while wheat acreage on the better-yielding lands may be relatively stable. Crop statistics for Italy for 1909–38 clearly indicate that variations of wheat acreage in the low-yielding area of Southern Italy are substantially greater than those in the high-yielding area of Northern Italy. A similar situation is possible also in Russia, where the wheat area is distributed among several regions with quite different climatic characteristics.[3] In spite of all these regional differ-

[1] When the variability of the total wheat output for all 13 areas is compared with the variability of the average wheat yield computed for all regions combined, the difference appears even smaller, as may be concluded from the respective coefficients of variability of 6.0 and 5.4 per cent and their percentage ratio, which is 111.

[2] The variability of total wheat output in the Western portion of Northern Europe is further strengthened by a certain tendency for wheat acreage and yield per acre to fluctuate in the same direction. But additional research would be necessary to answer the questions to what extent this tendency may be regarded as a significant one, and what is its explanation.

[3] The series for total production, acreage, and yield per acre of wheat in the territory of the USSR, as adjusted by Bennett (WHEAT STUDIES, April 1933, IX, 265), used in this study, reveals a certain tendency for wheat acreage and yield per acre to fluctuate in the opposite direction. Additional research is necessary, however, to determine to what extent this tendency may be regarded as "real." Incomplete and not always comparable crop statistics for Russia, which required several adjustments, may account, at least partially, for this relationship.

ences in the relationship between the variability of outputs and yields, it is possible to conclude that, broadly speaking, a greater proportion of the short-term variations in total wheat outputs are determined by variations in yield per acre.

Variability of Regional Outputs

Variability of total wheat ouputs, like that of wheat yield per acre, differs much from one area to another. As more appropriate for the purpose, we shall use for this comparison coefficients of variability measuring fluctuations of output around their respective trends (shown in columns 4 to 6 of Table III). It may be seen from this comparison that, generally speaking, total wheat production fluctuates much more widely in the wheat-exporting countries than in the principal wheat-importing areas of Europe. Only in India, which can hardly be classified as a major wheat exporter during the interwar period, did total wheat production fluctuate less than did wheat outputs in some of the importing countries of Europe. This is true in spite of the fact that in India wheat output fluctuates substantially more than wheat yield per acre.

Wheat outputs vary most in Australia, Canada, and Argentina, the three major non-Eupean wheat exporters. Variability of wheat outputs in these countries tended to be smaller in the later (interwar) period, but coefficients of variability of their wheat outputs continued to exceed 20 per cent even in this later period.[4] A much smaller variability of total wheat production was characteristic of the United States the fourth major non-European wheat exporter. As we know from the preceding analysis, this does not mean that regional wheat outputs in the United States vary little, but that they vary diversely. Consequently, the variability of the total wheat output of the United States (the coefficient for 1901–35 is 13.3 per cent) was not larger than that for some of the European importing regions. The variability of wheat outputs in the European and North African wheat-exporting areas occupies an intermediate position; it is larger than in the United States but substantially smaller than in the three other chief exporters of wheat.

Wheat outputs in the European importing countries, on the other hand, vary relatively little. It is true that variability of outputs in the Western portion of Northern Europe and Germany is substantially larger than that of yield per acre, but the coefficients of variability of wheat outputs for both these areas are only slightly above 10 per cent, and they do not reach 14 per cent for any of the importing areas of Europe. The simple average of the coefficients of variability of wheat outputs in the eight exporting areas (18.7 per cent for 1901–35) is about 60 per cent larger than the similar average for the five European importing areas (11.7 per cent). The difference would be still greater if India were excluded from the group of exporters.

Since total wheat production varies more in the wheat-exporting countries than in the wheat-importing countries, the burden of necessary adjustments must be heavier for the exporters. However, variations of wheat outputs in the exporting countries, though larger on the average than in the European importing countries, are also more diverse.[5] Consequently, the relative variability of total wheat output for the eight wheat exporters combined is not larger than the relative variability of the total wheat output for the five wheat importers, because of greater compensation of unrelated variations in outputs of exporting countries. This is evident from the coefficients of variability of the total wheat outputs for these two groups of countries during 1901–35, which are 7.9 and 7.8 per cent respectively. The coefficients of variability of the average wheat yields per acre, computed for the same period and the same groups of countries, are respectively 7.0 and 7.3 per cent, only slightly

[4] In Canada the decline of the coefficient of variability of wheat output from 32.0 per cent in 1901–18 to 22.7 per cent in 1919–35 must be contrasted with an increase of the coefficient of variability of wheat yield per acre for the same two periods from 18.6 to 22.8 per cent. From the previous discussion, we know that, with the exception of Manitoba, the relative variability of wheat yields in the Canadian Prairie Provinces has also substantially increased during that time. We shall not attempt to explain this discrepancy here.

[5] It is easy to explain this, since all principal wheat importers included in this analysis are in Europe, while exporting areas are dispersed throughout all continents.

smaller than the coefficients of variability of outputs.

When these coefficients of variability for the two groups of areas are compared with similar coefficients for individual areas composing them, it may be concluded that there is much closer direct relationship among the fluctuations of wheat outputs (and yields) in the wheat-importing countries of Europe than among the fluctuations of wheat outputs in the wheat-exporting countries. This suggests the existence of a significant positive correlation among the former. It appears, on the other hand, that outputs in the latter group of countries fluctuate without much systematic relationship among themselves (the same as yields), and this tends to stabilize the total wheat production in exporting countries taken together.

The same relative variability of total wheat outputs for the two groups of countries does not mean, however, that absolute variations of their total wheat outputs are about equal. Since wheat output for the eight exporting areas during 1901–35 averaged about three times as large as that for the five importing areas (Table III), the absolute variations of their respective outputs are in about the same proportion. Consequently, the burden of the necessary adjustments of wheat supplies is still carried mainly by the wheat-exporting countries.

The stability of "world" wheat production, as represented by the total production of the 13 major wheat-importing and -exporting areas, is only slightly smaller than the stability of average "world" wheat yield per acre. Indeed, the coefficients of variability of "world" wheat output and of "world" yield per acre for 1901–35 are respectively 6.0 and 5.4 per cent; that is, variability of total production is only 11 per cent larger than that of yield per acre. The latter coefficient is very close to that obtained for the variability of the "world" yield in the preceding section, in which the effect of the size of regions upon the variability of regional yields were analyzed, though the "worlds" in these two analyses are not identical. The principal difference is that here wheat production in the territory of the USSR is included, while the Russian series were excluded from the summary comparisons in our previous analysis.

It is of interest to observe that stability of "world" wheat production was greater during the later (interwar) period than during the earlier period of 1901–18. However, the tendencies were different for exporting and importing countries grouped separately. As may be seen from the coefficients of variability of wheat outputs for 1901–18 and 1919–35, shown in Table III, total wheat production of the exporters fluctuated less in the interwar period than during 1901–18, while wheat outputs of the European importing area show the opposite tendency. Our previous analysis of the changes in the variability of wheat yields from 1901–18 to 1919–35 (pp. 179–83) revealed the same tendency, but there we questioned the reality of the increase in the variability of wheat yields in several European regions.

Total Variability of Outputs

Coefficients of variability of wheat outputs in the principal wheat-importing and -exporting countries, measuring variations of annual wheat outputs from the average outputs for the respective periods, 1901–18, 1919–35, and 1901–35, are shown in columns 10, 11, and 12 of Table III. As explained earlier, these coefficients measure total variability of wheat outputs, including the elements of the trend, while the coefficients of variability used in the preceding paragraphs measure only partial variability of outputs, excluding gradual changes represented by the respective trends. Such measures of total variability of wheat outputs may be useful for certain purposes. Chart 4 of Part I of this study shows that trends of wheat outputs are not only very different for various countries, but that for some countries they are very irregular.[6] For certain periods the growth or decline of wheat outputs represented by trend lines is so rapid in one country or another that the effects upon total supplies of wheat can hardly be distinguished from the effects of annual fluctuations in outputs. These changes are caused mainly by sudden expansion or contraction of acreage.

[6] Wheat Studies, April 1942, XVIII, 308.

In this respect, they are economically different from usual variations in annual outputs, for the latter are caused mainly by fluctuations of yield per acre, which, to a greater extent, do not depend on the will of the farmer. However, because of the peculiar nature of agricultural production, not all expansions or contractions of acreage can be regarded as motivated by changes in market conditions; hence, effects of changes in acreage on the market and trade would hardly differ from variations caused by exterior factors that do not depend on the will of the farmer. In this we see reasons why measures of total variability of wheat outputs are of practical importance and deserve to be analyzed briefly.

Table 6, covering the principal wheat-importing and -exporting regions, shows that variability of wheat outputs from the mean averages, or total variability, is always larger than variability of the same outputs from the trends, which may be called partial variability. Steep rising trends in total wheat outputs in many regions, or irregular trends first rising and then declining—or vice versa—in others,[7] explain why the variability of wheat outputs from the mean average for the period 1901–35 is so much larger in several countries than the variability from the trend.[8] On the average for all 13 regions, variability of wheat outputs from their means exceeds the variability from the respective trends by nearly 60 per cent. However, these differences vary greatly from region to region. In some countries they do not exceed 25 per cent (Spain, United States, India, and French North Africa); in others, the variability from the means is about or more than twice as large as the variability around the trend (Germany, Italy, and Canada).

TABLE 6.—RELATIVE VARIABILITY OF WHEAT OUTPUTS IN THIRTEEN REGIONS, 1901–35, ACCORDING TO TWO DIFFERENT MEASURES*

Area	Coefficient of variability: From mean (*per cent*)	Coefficient of variability: From trend (*per cent*)	Percentage ratio
Northern Europe, West	18.0	10.4	173
Germany	23.9	10.9	219
France	19.5	13.1	149
Italy	20.1	10.6	190
Spain	15.4	13.3	116
Total importing areas	14.0	7.8	179
United States	16.6	13.3	125
Canada	51.1	25.7	199
Argentina	32.7	23.2	141
Australia	47.5	28.5	167
India	13.5	11.3	119
Southeastern Europe	22.8	15.6	146
French North Africa	20.3	16.2	125
USSR	27.0	15.6	173
Total exporting areas	15.5	7.9	196
Total all areas	13.0	6.0	217

* Data from Table III.

Such great variations from one area to another cannot be explained simply by differences in the steepness of trends of the respective wheat outputs, though this is one of the factors. The effect of the trend on the total variability of outputs depends also on the degree of variability of these outputs from their trends. Hence, if output varies only slightly around the trend, a trend would have relatively greater effect upon the total variability of output than a trend of the same steepness would have if the output varied greatly around the respective trend. This may be illustrated by comparison of the ratios of two measures of variability of outputs, shown in Table 6 for Germany and Canada and for Northern Europe and Australia. In Canada, the trend of wheat output during 1901–35 was much steeper than in Germany; similarly it was much steeper in Australia than in Northern Europe. However, effects of these steep trends on the total variability of wheat outputs in Canada and Australia are smaller than they are on the total variability of the wheat outputs in Germany and Northern Europe, because the variability of wheat outputs around the trends in the two former countries is two or three times as large as it is in the two latter areas.

Because total variability of outputs (meas-

[7] Chart 4, WHEAT STUDIES, April 1942, XVIII, 308.

[8] From Table III, it may be seen that the differences between the two measures of variability computed for the two parts of the whole period, 1901–18 and 1919–35, continue to be large, though on the average somewhat smaller than for the whole period 1901–35. The effect of a regular rising (or declining) trend on the total variability increases with the length of the period.

ured from the average outputs) depends on so many factors, it is very difficult to interpret changes in that variability from region to region, or from period to period. As explained earlier (p. 156), it is better to use measures of variability from the trends for such a purpose. For this reason, we do not go into such interpretations here, but simply give them as measures that may be useful for some problems. Table 6 shows, however, that the coefficients of variability of wheat outputs, measuring their variations from the means, are on the average substantially larger for wheat-exporting countries than for the importing areas. But the variations of wheat outputs in Northern Europe, Italy, Germany, which are the smallest when measured from their respective trends, are not so small when measured from the mean.

We wish to emphasize one characteristic of the measures of total variability of wheat outputs. When regional outputs are combined into larger groups, the degree of compensation of variations in regional wheat outputs is smaller. This must be explained by the fact that there is more similarity in the movements of the trends of regional wheat outputs than in their fluctuations around their respective trends. Indeed, wheat outputs in most of the areas, particularly in the wheat-exporting countries, were increasing rapidly during 1901–35.

Consequently, total variability of the wheat outputs in the five importing countries, in the eight exporting countries, or in all 13 areas combined, is much greater than the partial variability, when only the variations from the respective trends are taken into consideration. For 1901–35 the coefficient of variability of the "world" wheat output, when measured from the mean average output, is 13.0 per cent, as against 6.0 per cent when measured from the trend. That is, total variability is more than twice as large as partial. Concurrent expansions or concurrent contractions of wheat outputs, particularly characteristic of the wheat-exporting countries, are responsible for great strengthening of the variability of the "world" wheat output. Variations in wheat outputs caused by exterior factors, independent of the will of farmers, are more diverse and tend to be compensated for to a greater extent than those variations of outputs that are caused mainly by farmers' decisions and that find expression in the general tendencies of the trends in regional wheat outputs. Thus, stabilization of the world wheat output might perhaps be easier if natural forces alone were responsible for the variability of world wheat production.

VIII. SUMMARY OF CONCLUSIONS

Our analysis of various aspects of variability in wheat yields and outputs has led us to certain conclusions. The more important of these may now be summarized.

Using measures of relative variability of regional yields, expressed as percentages of the average level of the respective yields, as the basis of classification, it was possible to segregate the wheat regions of the world into two distinct groups: (*a*) those with small relative variability, with coefficients of variability below 19.1 per cent (the average of the coefficients of variability for all 46 regions used in the study); and (*b*) those with large relative variability, with coefficients of variability exceeding 19.1 per cent.

It was established that within each of these two groups there exists a tendency for the measures of absolute variability (standard deviations of annual yields from trends) of regional yields to correlate positively with the average levels of regional yields. This tendency is concealed, however, when all wheat regions, those with small and with large relative variability of yield per acre, are mingled together. This problem requires, however, a further more detailed study for which it is preferable to use crop statistics of some one country, since such statistics are more comparable from one region to another.

It was also found that the distribution of the wheat regions between these two groups is, to a certain extent, systematic from the point of view of geographic (climatic) characteristics of the regions. The most general climatic characteristic of the regions with high relative variability of yields appears to be continentality of climate. This is particularly true of regions in the Northern Hemisphere. But certain characteristics of climate peculiar to the areas with continental climate are typical also of regions with large variability of yields in the Southern Hemisphere.

The second most general characteristic of climates peculiar to regions with large variability of yield must be recognized as aridity. However, aridity of climate is not common to all regions with large relative variability of yields; there are several humid regions, such as the United States Soft Winter wheat area, in which wheat yields vary greatly, particularly yields on sown acreage. On the other hand, there are several regions with semiarid climates where wheat yields vary relatively little. These are mainly regions with the winter regime of rainfall. Generally speaking, the winter regime of rainfall is favorable to stability of wheat yields, though average yields in regions with this type of climate are usually relatively low.

Concerning the effect of the size of wheat regions upon the variability of average regional yields, it was established that, generally speaking, average yields for wide areas are less variable than those for the smaller regions composing them. It was natural to expect this in view of the diversity in the fluctuation of local yields. It was found, however, that the variability of wheat yields for the major wheat regions used in this study is usually only slightly smaller than that for the subregions composing them.

This points to the existence of positive correlations among fluctuations of yields in subregions belonging to the same major wheat regions. But further grouping of the major wheat regions into still larger areas, covering large countries or even whole continents, results in a great reduction of the variability of the average yield per acre for these wide areas. This is particularly true of the major wheat regions of North America, and, to a certain extent, of Europe ex-Russia also. For Australia, however, the variability of wheat yield for the continent as a whole is nearly as large as for the several wheat regions.

This points to a diversity in the variations of yields among the major wheat regions of wide continents, particularly in North America. This diversity may indicate either an absence of any correlation among the fluctuations of regional yields, or positive correlations among some of them and negative among others. The last type of relationship appears to be characteristic of the North American wheat regions.

A still greater diversity in the fluctuations of wheat yields is characteristic of intercontinental relationships. Consequently, average wheat yield per acre for the "world" as a whole shows a high degree of stability. This is also true of the total world wheat production.

Generally speaking, short-term variations in wheat outputs are determined mainly by variations in yield per acre. However, in some regions—in most of the newer agricultural areas and in older areas where wheat is only a secondary crop—even short-term variations in wheat outputs are affected to a considerable extent by irregular variations in the wheat acreage. In spite of this, variability of regional wheat outputs fairly well reflects variability in regional wheat yields per acre. Broadly speaking, wheat outputs vary relatively more in the principal wheat exporting countries than in the importing countries of Europe. However, because the variations of outputs of exporting countries show greater diversity than do those of European importing countries, relative variability of total wheat output for all exporting countries is not greater than that of the total wheat production in the importing area of Europe as a whole.

These contrasts between the relative stability of the world wheat yield and output and the great variability of wheat yields and outputs within some of the wheat exporting countries, and diversity in this respect among the exporting countries themselves, must be taken into consideration and attentively studied by those who are responsible for planning under the new international wheat agreement. The great difference in the degree of variability of the total wheat outputs for Australia, Canada, and Argentina on one side, and for the United States on the other, may create certain frictions in the functioning of an agreement if export quotas for all exporters are fixed and nontransferable. It may also create difficulties in the fixation of appropriate price differentials for various kinds of wheat for the entire crop year early in the season, before the results of crops are sufficiently known, particularly for the countries of the Southern Hemisphere, where outputs vary widely. This is particularly true in view of the fact that the interchangeability of wheats of various origins is far from complete. Meanwhile, these features of the international wheat agreement are included in the Draft Convention, designed to be brought into operation at some future date.[1]

From the study of the types of variability of yields, little can be concluded except that interregional differences among the types of distributions of yields of various size around the regional "normal" yield can hardly be said to be significant. This conclusion stands in spite of the apparent diversity of these distributions.

It appears desirable, however, that this diversity in the distributions of yields according to their sizes, particularly some of striking "abnormalities" of distributions mentioned, should be studied attentively by those who are responsible for the organization of crop statistics in the respective countries, since these abnormalities may point to some systematic errors in crop estimates. In this respect, of special interest are those distributions which show too great concentration of crops around the normal or average crop (as in France, New South Wales and other Australian regions, eastern United States, and some others).

Only a few significant changes took place in the variability of wheat yields between 1901–18 and 1919–35, and some of these, though significant, may be regarded as results of changes in methods or precision of crop estimation rather than as real changes in the variability of yields. In particular, there is hardly sufficient reason to accept as significant the indication that variability of wheat yields actually increased from the prewar to the interwar period in some regions of northwestern Europe or in eastern United States. Crop statistics of these countries must be studied further in order to ascertain to what extent these changes in the variability from the earlier period to the late are real and to what extent they may be regarded as the results of unhomogeneity of the crop statistics for the two periods.

In relation to other continents, it may be said that, broadly speaking, *relative* variability of yields tended to increase in the North American wheat regions west of the Mississippi, presumably because of the expansion of wheat acreage on land with less favorable climatic characteristics. On the other hand, the variability of regional wheat yields in Australia tended to decline, in spite of considerable expansion of wheat acreage also on that continent; this may be explained in part by the fact that the yield-stabilizing practice of summer fallowing became much more common in Australia in the interwar period than it had been before World War I. The different tendencies in the variability of wheat yields on the two continents may serve in some degree as guides for future wheat policies in the respective regions. Increasing variability of wheat yield in the United States and the Prairie Provinces of Canada may serve as a danger sign pointing to overexpansion of wheat in these areas and call for a policy of reduction of wheat acreage on marginal land.

One conclusion of methodological character may be drawn from the study of changes in variability. Ten-year periods, usually regarded as sufficiently long for establishing the average level of yield per acre for a certain area, must be regarded as not long enough for establishing a measure of the average variability of yield per acre. Even the longer periods used in this study are not long enough to give conclusive results for most of the regions.

[1] J. S. Davis, "New International Wheat Agreements," WHEAT STUDIES, November 1942, XIX, 25–83.

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APPENDIX TABLES

TABLE I.—AVERAGE WHEAT ACREAGE, YIELD, AND VARIABILITY OF YIELD FOR SELECTED REGIONS*

(1901–35, except as noted)

Region	Average wheat acreage (*million acres*)			Average wheat yield (*bushels per acre*)			Measures of variability: Standard deviation (*bushels per acre*)			Measures of variability: Coefficient of variability (*per cent*)		
	1901–18	1919–35	1901–35	1901–18	1919–35	1901–35	1901–18	1919–35	1901–35	1901–18	1919–35	1901–35
Prairie Provinces, Canada	7.98	22.24	14.91	18.2	14.4	16.3	3.92	3.58	3.72	21.5	24.9	22.8
Manitoba	2.65	2.60	2.62	17.8	15.1	16.4	4.04	3.08	3.58	22.7	20.4	21.8
Alberta	1.11	6.36	3.66	21.1	16.5	18.8	5.20	5.48	5.26	24.6	33.2	28.0
Saskatchewan	4.22	13.28	8.62	18.3	13.3	15.8	4.03	3.98	3.96	22.0	29.9	25.1
United States Spring Wheat[s]	15.51	19.40	17.40	12.8	9.2	11.0	2.52	2.74	2.60	19.7	29.8	23.6
Minnesota and South Dakota[s]	7.19	5.31	6.28	13.1	9.7	11.4	3.09	3.05	3.05	23.6	31.4	26.8
North Dakota and Montana[s]	8.32	14.09	11.12	12.6	9.1	10.8	2.80	2.84	2.79	22.2	31.2	25.8
*Eastern North America	7.19	5.08	6.16	14.2	16.6	15.4	.89	1.88	1.43	6.3	11.3	9.3
*Eastern North America[s]	7.53	5.24	6.42	13.7	16.0	14.9	1.10	1.96	1.55	8.0	12.3	10.4
Northeastern subregion	2.54	2.07	2.31	17.0	18.7	17.9	1.25	2.02	1.65	7.4	10.8	9.2
Northeastern subregion[s]	2.63	2.13	2.39	16.5	18.2	17.4	1.38	1.99	1.68	8.4	10.9	9.7
Southeastern subregion	3.76	2.21	3.00	10.6	12.0	11.3	1.15	2.05	1.63	10.8	17.1	14.4
Southeastern subregion[s]	4.01	2.32	3.18	10.1	11.3	10.7	1.30	2.20	1.77	13.0	19.5	16.5
Ontario, Canada	.89	.80	.84	21.6	24.2	22.9	3.08	2.78	2.90	14.3	11.5	12.7
United States Soft Winter	10.85	9.78	10.33	15.8	16.8	16.2	2.48	2.44	2.43	15.7	14.5	15.0
United States Soft Winter[s]	11.99	10.61	11.32	14.6	15.6	15.1	3.40	3.25	3.28	23.3	20.8	21.7
Eastern subregion	5.25	4.58	4.93	16.1	17.7	16.9	2.91	3.21	3.03	18.1	18.1	17.9
Eastern subregion[s]	5.84	4.98	5.43	14.9	16.6	15.8	3.99	4.17	4.02	26.8	25.1	25.4
Western subregion	5.60	5.20	5.40	15.3	15.7	15.5	2.45	2.06	2.25	16.0	13.1	14.5
Western subregion[s]	6.14	5.62	5.89	14.2	14.7	14.4	3.23	2.69	2.94	22.7	18.3	20.4
United States Hard Winter	12.59	21.48	16.90	14.1	12.5	13.3	1.72	2.17	1.92	12.2	17.4	14.5
United States Hard Winter[s]	14.46	26.10	20.12	12.6	10.4	11.5	2.55	2.82	2.65	20.2	27.1	23.0
Northeastern subregion[s,a]	6.59	8.39	7.44	14.3	12.9	13.6	2.86	2.86	2.82	20.0	22.2	20.7
Northwestern subregion[s,a]	4.56	9.73	6.99	11.1	8.7	9.9	3.93	3.36	3.62	35.4	38.6	36.6
Southern subregion[s]	3.40	7.89	5.58	10.8	9.7	10.3	2.88	3.53	3.19	26.7	36.4	31.0
Pacific	4.15	5.17	4.64	18.3	20.1	19.2	1.96	2.30	2.10	10.7	11.4	10.9
Pacific[s]	4.50	5.67	5.07	17.1	18.5	17.8	1.81	2.97	2.41	10.6	16.1	13.5
Pacific Northwest	3.10	4.21	3.64	19.6	20.5	20.1	2.37	2.60	2.45	12.1	12.7	12.2
Pacific Northwest[s]	3.31	4.57	3.92	18.5	19.0	18.8	2.42	3.30	2.84	13.1	17.3	15.1
Washington	1.84	2.15	1.99	19.2	19.9	19.5	3.05	3.28	3.12	15.9	16.5	16.0
Washington[s]	2.00	2.36	2.17	17.8	18.3	18.1	3.29	3.98	3.60	18.5	21.7	19.9
Oregon	.77	.98	.87	19.0	20.2	19.6	2.23	2.53	2.35	11.7	12.5	12.0
Oregon[s]	.81	1.10	.95	18.1	18.5	18.3	2.12	3.55	2.86	11.7	19.2	15.6
Idaho	.49	1.07	.77	23.4	22.0	22.7	1.57	2.73	2.18	6.7	12.4	9.6
Idaho[s]	.50	1.11	.80	22.7	20.9	21.8	1.60	2.78	2.22	7.0	13.3	10.2
Pacific Southwest	1.05	.96	1.01	15.8	18.7	17.2	1.73	2.00	1.84	10.9	10.7	10.7
Pacific Southwest[s]	1.19	1.10	1.15	14.2	16.6	15.4	2.03	2.97	2.49	14.3	17.9	16.2

* For definition of regions and sources of statistics, see Appendix Note to Part I of this study, WHEAT STUDIES, April 1942, XVIII, 331–33. A few changes and additions have been made to various regions. The sources of statistics for these additions, unless otherwise noted, are M. K. Bennett, "World Wheat Crops, 1885–1932," WHEAT STUDIES, April 1933, IX, 265–74; and J. S. Davis, "The World Wheat Situation, 1939–40," *ibid.*, December 1940, XVII, 201–04.

In this part of the study EASTERN NORTH AMERICA consists of the subregions of Eastern United States, plus Ontario; for the added subregion, statistics are from Ontario Department of Agriculture, *Annual Report of Statistics Branch, 1927*, p. 40 and from the Dominion Bureau of Statistics, *Monthly Bulletin of Agricultural Statistics*, various issues. NORTHERN EUROPE, Eastern subregion, includes (*a*) for the years 1885–1918: prewar Kingdom of Austria, Congress Poland, other territories lost by Russia, and Finland; (*b*) for the years 1919–37: postwar Austria, Poland, Lithuania, Latvia, Estonia, Finland, Bohemia, Moravia, and Silesia. Statistics for Bohemia, Moravia, and Silesia are from official publications of the republic of Czechoslovakia. SOUTHEASTERN EUROPE now includes Bulgaria. The WESTERN MEDITERRANEAN in this study includes French North Africa (Algeria and Tunis) and Spain. The AUSTRALIAN series includes only the four states listed. SOUTH AMERICA is now represented by Argentina and Uruguay.

[a] Periods 1901–18; 1919–34; 1901–34.
[b] Periods 1901–18; 1919–33; 1901–33.
[c] Period 1913–34.
[d] Period 1913–35.
[e] Periods 1891–1915; 1916–30; 1891–1930.
[f] Periods 1896–1915; 1916–30; 1896–1930.
[s] Wheat yield per acre computed on sown-acreage basis.
[w] Computations made with the omission of the war years 1915–20 inclusive.

TABLE I—(*Concluded*)

Region	Average wheat acreage (*million acres*)			Average wheat yield (*bushels per acre*)			Measures of variability					
							Standard deviation (*bushels per acre*)			Coefficient of variability (*per cent*)		
	1901–18	1919–35	1901–35	1901–18	1919–35	1901–35	1901–18	1919–35	1901–35	1901–18	1919–35	1901–35
*Northern Europe[b]	11.78	12.35	12.05	24.5	26.4	25.4	1.27	2.14	1.70	5.2	8.1	6.7
Western subregion	2.78	3.08	2.93	32.9	35.1	34.0	1.67	2.62	2.15	5.1	7.5	6.3
Germany	4.54	4.29	4.42	26.5	30.5	28.5	1.82	2.76	2.29	6.9	9.0	8.0
Germany[w]	4.65	4.42	4.53	26.6	31.2	29.0	1.75	2.93	2.39	6.6	9.4	8.2
Eastern subregion[b]	4.47	5.20	4.81	16.9	19.1	18.0	1.50	2.02	1.74	8.9	10.6	9.7
Eastern subregion[wb]	4.76	5.56	5.15	17.7	19.7	18.7	1.08	2.14	1.64	6.1	10.9	8.8
*Southeastern Europe[b]	18.86	18.43	18.67	15.5	15.6	15.6	2.72	1.98	2.38	17.5	12.7	15.3
*Southeastern Europe[wb]	19.08	19.19	19.13	15.9	15.8	15.9	2.76	2.07	2.41	17.4	13.1	15.2
Western subregion[b]	10.02	11.00	10.46	16.6	16.7	16.7	2.19	2.38	2.24	13.2	14.3	13.4
Western subregion[wb]	10.27	11.41	10.81	17.1	17.2	17.2	2.38	2.50	2.39	13.9	14.5	13.9
Eastern subregion[a]	6.41	4.84	5.67	14.0	13.0	13.5	4.26	2.87	3.62	30.4	22.1	26.8
Eastern subregion[wa]	6.38	5.10	5.74	14.4	13.0	13.7	4.12	2.87	3.49	28.6	22.1	25.5
Bulgaria[a]	2.42	2.65	2.53	14.5	16.0	15.2	2.53	2.58	2.51	17.4	16.1	16.5
Bulgaria[wa]	2.42	2.72	2.57	15.1	16.2	15.7	2.71	2.69	2.66	18.0	16.6	16.9
France	15.16	13.16	14.19	19.5	21.8	20.6	2.17	2.78	2.45	11.1	12.8	11.9
France[w]	16.11	13.30	14.66	20.2	22.3	21.3	1.93	2.89	2.43	9.6	13.0	11.4
Northern subregion[a]	2.98	2.74	2.87	26.3	30.2	28.2	3.24	3.27	3.22	12.3	10.8	11.4
Southern subregion[a]	4.42	3.45	3.96	15.5	16.4	16.0	1.97	2.18	2.04	12.7	13.3	12.8
West Central subregion[a]	5.03	4.50	4.78	19.6	21.1	20.4	2.42	3.41	2.89	12.3	16.2	14.2
East Central subregion[a]	2.73	2.37	2.56	18.3	21.0	19.6	2.18	3.40	2.78	11.9	16.2	14.2
East Central subregion[wa]	2.97	2.41	2.69	19.0	21.3	20.2	1.86	3.60	2.82	9.8	16.9	14.0
Italy	11.68	11.84	11.76	15.1	19.2	17.1	1.56	2.11	1.82	10.3	11.0	10.6
Southern Italy[c]	....	....	6.12	...	...	13.5	...	...	2.07	...	...	15.4
Northern Italy[c]	....	....	5.61	...	...	21.9	...	...	2.50	...	...	11.4
*Western Mediterranean	14.17	16.09	15.10	11.5	11.3	11.4	1.43	1.34	1.37	12.4	11.9	12.0
French North Africa	4.66	5.32	4.98	8.2	7.5	7.9	1.13	1.41	1.26	13.8	18.8	15.9
Spain	9.50	10.78	10.12	13.1	13.2	13.1	1.78	1.52	1.64	13.6	11.5	12.5
*Australia	7.32	12.00	9.59	9.9	12.1	11.0	3.27	2.21	2.76	33.1	18.3	25.1
New South Wales	2.17	3.56	2.84	10.5	12.7	11.6	3.91	3.39	3.62	37.2	26.7	31.2
Victoria	2.43	2.92	2.67	10.5	13.4	12.0	4.12	2.93	3.54	39.2	21.9	29.5
South Australia	2.06	3.03	2.53	8.9	10.8	9.8	3.01	2.13	2.58	33.8	19.7	26.3
Western Australia	.67	2.49	1.55	10.1	11.1	10.6	2.36	1.21	1.88	23.4	10.9	17.7
India	28.44	31.10	29.73	11.2	10.9	11.1	.95	.98	.95	8.5	9.0	8.6
Northwestern subregion[a]	10.18	11.45	10.78	11.9	12.0	12.0	1.32	1.50	1.40	11.1	12.5	11.7
Northeastern subregion[a]	8.22	8.54	8.37	14.1	13.5	13.8	1.47	1.15	1.31	10.4	8.5	9.5
Southern subregion[a]	10.04	10.89	10.44	8.1	7.8	8.0	1.11	.85	.98	13.7	10.9	12.2
*South America	15.23	19.29	17.20	10.3	12.0	11.2	2.00	1.94	1.94	19.4	16.2	17.3
Argentina[d]	....	....	16.35	...	...	12.3	...	...	1.50	...	...	12.2
Argentina[e]	14.47	18.31	16.34	10.4	12.0	11.2	2.10	2.03	2.04	20.2	16.9	18.2
Southern subregion[ed]	....	....	8.93	...	...	11.2	...	...	2.23	...	...	19.9
Northern subregion[ed]	....	....	8.52	...	...	11.4	...	...	2.88	...	...	25.3
Uruguay	.76	.98	.87	9.2	10.6	9.9	2.28	1.89	2.07	24.8	17.8	20.9
Ukraine (winter wheat)[e]	1.97	7.57	4.07	11.6	13.1	12.2	2.78	2.25	2.57	24.0	17.2	21.1
Ukraine (spring wheat)[e]	7.21	6.26	6.85	7.9	9.3	8.5	1.77	2.10	1.87	22.4	22.6	22.0
Volga (spring wheat)[e]	9.48	13.80	11.10	7.1	7.8	7.4	2.65	2.24	2.47	37.3	28.7	33.4
North Caucasus (winter wheat)[f]	4.42	5.58	4.92	10.8	10.9	10.9	1.97	2.81	2.33	18.2	25.8	21.4
North Caucasus (spring wheat)[f]	2.10	4.66	3.20	10.0	8.2	9.4	1.97	2.56	2.21	19.7	31.2	23.5

TABLE II.—FREQUENCY DISTRIBUTIONS OF DEVIATIONS (EXPRESSED IN UNITS OF STANDARD DEVIATION) OF ANNUAL YIELD FROM THE LINE OF TREND FOR 25 SELECTED REGIONS

Region	Period	−3.75 to −3.26	−3.25 to −2.76	−2.75 to −2.26	−2.25 to −1.76	−1.75 to −1.26	−1.25 to −.76	−.75 to −.26	−.25 to +.24	+.25 to +.74	+.75 to +1.24	+1.25 to +1.74	+1.75 to +2.24	+2.25 to +2.74	+2.75 to +3.24
Prairie Province, Canada	1885–1939	0	0	0	2	1	8	9	11	7	2	5	1	1	0
U.S. Spring Wheat[a]	1866–1939	0	0	0	2	7	8	12	11	11	6	6	1	2	0
Eastern United States	1866–1939	0	0	0	2	2	8	15	16	13	4	3	2	0	1
U.S. Soft Winter[a]	1866–1939	0	2	0	2	0	10	10	14	13	11	3	0	0	1
U.S. Hard Winter[a]	1866–1939	0	0	0	1	7	10	8	11	11	11	5	1	1	0
Pacific Northwest	1869–1939	0	0	1	3	3	6	13	11	17	3	0	4	1	1
Pacific Southwest	1866–1939	0	0	1	4	2	6	15	14	10	8	5	1	0	0
7 American series	....	0	2	2	16	22	56	82	88	82	45	27	10	5	3
Northern Europe, West	1875–1939	0	1	0	1	0	12	8	9	11	12	2	0	1	0
Germany	1878–1939	0	0	1	3	2	2	12	12	11	6	2	3	0	0
Southeast Europe, West	1885–1937	0	0	0	3	4	5	2	10	13	4	3	1	0	0
Southeast Europe, East	1885–1938	0	0	1	2	3	5	5	10	8	8	4	0	0	0
France	1815–1939	0	0	1	7	5	12	12	32	18	15	10	3	2	0
Italy	1885–1939	0	0	1	0	5	7	6	6	12	4	5	1	0	0
Algeria	1875–1939	0	0	1	2	3	8	5	11	15	6	3	2	0	1
7 European series	....	0	1	5	18	22	51	50	90	88	55	29	10	3	1
New South Wales	1860–1939	0	0	3	2	1	6	9	24	15	6	4	1	1	0
Victoria	1860–1939	1	0	1	2	2	6	13	14	20	8	3	2	0	0
South Australia	1860–1939	1	0	0	1	3	7	16	16	10	12	4	1	1	0
Western Australia	1868–1939	0	1	0	0	0	8	16	14	13	10	2	0	0	0
4 Australian series	....	2	1	4	5	6	27	54	68	58	36	13	4	2	0
India	1885–1939	0	0	1	1	4	3	8	10	9	3	4	3	1	0
Argentina[a]	1885–1939	0	0	1	1	2	4	9	10	10	6	3	0	1	0
20 series	....	2	4	13	41	56	141	203	266	247	145	76	27	12	4
Ukraine (winter wheat)	1883–1934	0	0	0	1	5	4	6	8	7	8	4	0	1	0
Ukraine (spring wheat)	1883–1934	0	0	0	1	3	6	7	9	6	6	4	2	0	0
Volga (spring wheat)	1883–1934	0	0	1	0	4	3	10	7	6	6	7	0	0	0
N. Caucasus (winter wheat)	1892–1934	0	0	1	2	1	5	5	8	5	4	2	2	0	0
N. Caucasus (spring wheat)	1892–1934	0	0	0	4	0	3	7	6	9	4	0	1	0	1
5 Russian series	....	0	0	2	8	13	21	35	38	33	28	17	5	1	1
Total 25 series	....	2	4	15	49	69	162	238	304	280	173	93	32	13	5

[a] Wheat yield per acre computed on sown-acreage basis.

TABLE III.—AVERAGE WHEAT ACREAGE, OUTPUT, YIELD PER ACRE, AND COEFFICIENT OF VARIABILITY FOR OUTPUT AND YIELD PER ACRE FOR MAJOR IMPORTING AND EXPORTING AREAS, 1901–35

Area	Average acreage (*million acres*)	Average[a] output (*million bushels*)	Average[a] yield (*bushels per acre*)	Variations from trend (*per cent*)						Variations from mean (*per cent*)		
				Total output			Yield per acre			Total ouput		
				1901–18	1919–35	1901–35	1901–18	1919–35	1901–35	1901–18	1919–35	1901–35
	(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)	(9)	(10)	(11)	(12)
Northern Europe, West	2.9	103.6	34.0	10.3	10.7	10.4	5.1	7.5	6.3	13.5	18.0	18.0
Germany	4.4	130.7	28.5	10.7	11.4	10.9	6.9	9.0	8.0	15.8	30.0	23.9
France	14.2	294.1	20.6	12.1	14.5	13.1	11.1	12.8	11.9	21.6	17.2	19.5
Italy	11.8	203.9	17.1	10.3	11.0	10.6	10.3	11.0	10.6	10.7	20.3	20.1
Spain	10.1	132.0	13.1	14.1	12.8	13.3	13.6	11.5	12.5	15.5	13.0	15.4
Total importing areas	43.4	859.0	19.8	7.2	8.5	7.8	6.3	8.3	7.3	9.8	16.1	14.0
United States	59.8	750.8	12.5	15.1	12.0	13.3	12.4	11.5	11.9	16.5	16.2	16.6
Canada	16.0	249.5	16.4	32.0	22.7	25.7	18.6	22.8	20.3	49.9	28.8	51.1
Argentina	16.3	182.3	11.2	24.5	22.5	23.2	20.2	16.9	18.2	28.8	23.5	32.7
Australia	9.8	112.6	11.0	45.5	20.8	28.5	32.4	17.9	24.7	52.6	28.4	47.5
India	29.7	328.3	11.1	12.4	10.4	11.3	8.5	9.0	8.6	15.7	10.9	13.5
Southeastern Europe[b]	18.7	312.8	15.6	18.7	12.7	15.6	17.5	12.7	15.3	21.8	24.6	22.8
French North Africa	5.0	39.5	7.9	14.8	17.7	16.2	13.8	18.8	15.9	14.3	25.5	20.3
USSR[c]	70.3	756.4	10.2	16.8	14.8	15.6	15.4	16.1	15.7	19.4	34.3	27.0
Total exporting areas	223.6	2,643.4	11.8	8.8	7.2	7.9	7.3	6.9	7.0	13.0	13.7	15.5
Total all areas	266.8	3,491.3	13.0	7.2	4.9	6.0	6.0	4.7	5.4	10.0	12.2	13.0

[a] The period 1897–1939 was used in the computations of average output and yield, which are given in columns 2 and 3; these averages are the ones used in the computations of the coefficients of variability as given in columns 4–6 and 7–9.

[b] Period for columns 1, 5, 6, 8, 9, 11, and 12 ends in 1933; for columns 2 and 3, in 1937; and for columns 4, 7, and 10, as indicated.

[c] Period for columns 1, 5, 6, 8, 9, 11, and 12 ends in 1934; for columns 2 and 3, in 1938; and for columns 4, 7, and 10, as indicated.

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