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TRENDS OF YIELD IN MAJOR WHEAT REGIONS SINCE 1885

PART I. GENERAL CONSIDERATIONS AND RISING TRENDS

M. K. Bennett

This study is the first of two which constitute a moderately comprehensive survey of trends of average yield per acre in most regions of the world outside of Soviet Russia, China, and Turkey and neighboring Asiatic countries. The objectives are to describe trends of yield in each of fourteen more or less homogeneous wheat-growing areas, and to offer explanations of the strikingly diverse slopes and conformations of trends in these regions.

In the issue of *WHEAT STUDIES* for March 1937, a map was presented showing the geographical distribution both of wheat acreage and of wheat yield per acre throughout practically all of the wheat-producing world. There the basic data took the form of average yield and acreage, typically for the period 1920-34, and certain climatological data were utilized to explain differences in levels of 1920-34 average yields per acre between different areas. Here attention is directed toward the influences that have caused regional trends of yield since 1885 to rise, remain about stable, or fall.

The present inquiry cannot cover a territory so far-flung as the earlier one. Not only are the major wheat-producing regions of Russia, China, and Turkey excluded here, but also minor regions such as Egypt, Mexico, Japan, New Zealand, South Africa, Switzerland, South American countries other than Argentina and Uruguay, and some others. Some of these countries fail to provide adequate statistics extending back to 1885; others are relatively unimportant producers or produce wheat under climatic conditions far different from those prevailing in the principal wheat belts of the world.

National boundaries are in large degree ignored in definition of the fourteen regions

here considered. Little attention is given, for example, to trend of yield in the United States or in Canada as a whole. The emphasis falls on trends in each of six separate regions lying within these countries. In Europe, we group into a single region as many as sixteen countries, and sometimes throw parts of a country into different regions. So far as feasible, this study deals with developments in fairly homogeneous wheat-producing regions, several of which may lie in one country or one of which may include several different countries.

In explanation of regional trends, a large body of data is presented, in the form of yield averages within administrative subdivisions of countries. Moreover, trends of wheat acreage proved to be so important in explaining trends of yield that these two sets of values needed to be studied simultaneously. Consequently the number of statistical series employed in the analysis became so large that space limitations preclude their publication in tabular form.

The regional statistics suggest several topics other than trend of yield that might warrant investigation. A glance at the charts will reveal wide differences among regions and sub-regions in the variability of yield per acre; some degree of correlation, either positive or negative, seems to exist between certain regional yields; and the geographical occurrence of exceptionally good or bad years is also striking. From this inquiry, however, we exclude systematic consideration either of relative variability of yields, of regional inter-correlations, or of the history of notably good or bad years except as these affect regional trends.

In the present part of the study, we first illustrate the diversity of regional trends of

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yield, define the regions, and classify the regional trends as rising, irregular, and stable or declining. There follows a generalized discussion of the influences that must be kept in mind when one attempts to explain the trend of yield in any region. Finally, the attempt is made to isolate and appraise the influences that have actually operated upon

rising trends of yield in five regions since 1885. In the second part of the study, scheduled for publication in March 1938, it is proposed to continue this analysis with reference to regions characterized by irregular trends and by stable or declining trends; and to conclude with a general analysis of "world" trend of yield since 1885.

I. DIVERSITY OF REGIONAL TRENDS

The present section emphasizes the great diversity among trends of wheat yield per acre in different wheat-producing regions since 1885. We first summarize briefly the statistical evidence concerning trend of yield over longer periods of time than the half-century here considered; and then define the fourteen wheat-producing regions here studied, present the basic statistical data pertaining to them, and classify the regions according to type of trend.

YIELDS IN HISTORICAL PERSPECTIVE

In some parts of the world wheat has been grown for much more than two thousand years. But only in France do continuous statistical records of average wheat yield per acre in substantial land areas cover more than a century. Chart 1 presents the five oldest available series applicable at once to large territorial areas and to nearly the same territory throughout the period covered. Data for France begin with 1815, for Prussia with 1846, the British Isles with 1852, Australia with 1860, the United States with 1866.¹

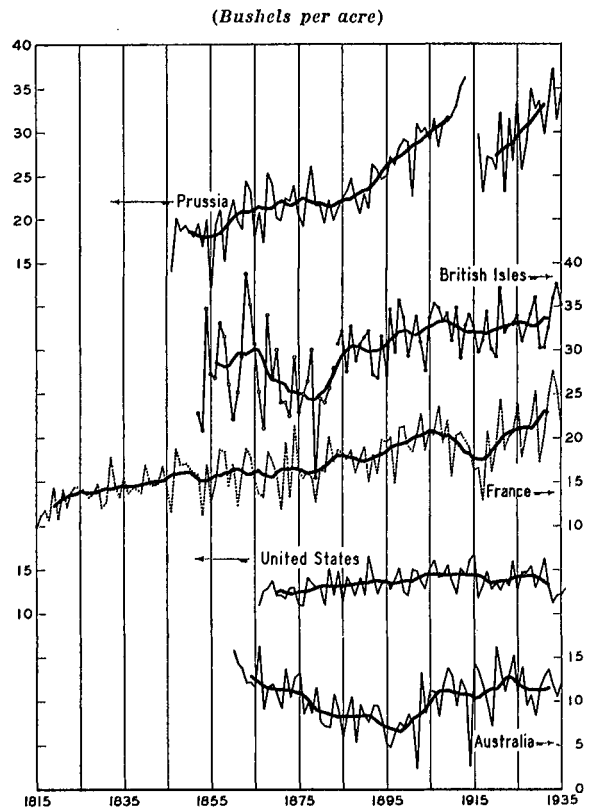
Only for the British Isles has it been possible as yet to formulate a reasonably well founded quantitative appraisal of the trend of average wheat yield per acre over several centuries.² Scattered yield records from medieval farms, together with occasional guesses by well-qualified men of the time, provide the

¹ Other available series antedating 1885, not shown in the chart because for one reason or another they are not useful in the present inquiry, are prewar Rumania (beginning with 1862), Sweden (1865), the Netherlands (1875), Denmark (1875), Algeria (1875), Japan (1877), Germany (1878), and prewar Hungary (1881).

² See M. K. Bennett, "British Wheat Yield per Acre for Seven Centuries," *Economic History* (Supplement of *Economic Journal*), February 1935, III, 12-29.

basis for such a broad appraisal from 1200 to around 1850, when annual statistics first become available. This appraisal suggests a

CHART 1.—LONGEST AVAILABLE CONTINUOUS SERIES ON NATIONAL TRENDS OF WHEAT YIELD PER ACRE*



* The sources of data in this and the following charts will be indicated in Part II of this study, to be published in March 1938. Trend-lines are weighted nine-year averages of annual yields (see text, p. 71).

trend rising slowly from 8 bushels per acre to about 15 bushels in the five and a half centuries from 1200 to 1750; a very rapid rise from 15 to about 27 bushels per acre in the century 1750-1850; and again a slower

rise to about 34 bushels in the 85 years since 1850.

The half-century following 1885 appears, in the British Isles, to have been characterized by relatively slow increase of wheat yield per acre as compared with any of perhaps three or four of the immediately preceding half-centuries. On the other hand, in Prussia particularly, but also in France, this recent half-century appears to have been one of relatively rapid increase in yield, at least if it be assumed that medieval yields in these countries were on about the same level (around 8 bushels) as in Britain. Such contrasting developments are to be expected. The countries of the world wherein wheat production is of long standing have always differed in climate, stage of culture, and place of wheat among other crops. Hence different upper limits to wheat yield exist, agricultural innovations working toward those limits have been diversely timed, and wheat acreage has in places retreated to superior locations and in other places expanded to inferior locations. In the world at large, the past half-century has probably witnessed more widespread adoption of improved agricultural techniques than in any other half-century; but this probability does not establish the presumption that, in the older wheat-producing countries generally, this half-century has also witnessed relatively rapid increase of wheat yield per acre.

When one considers trend of wheat yield over several centuries, "trend" may be taken to represent a tendency so broad and general that reversals of direction extending over ten or twenty years or even more may perhaps be disregarded. This study is concerned with trend over a shorter period, only fifty-two years; and descriptions of trend ought not to be so highly generalized as to eliminate from consideration reversals persisting for as short a period as a decade. Here we use the term "trend" of wheat yield per acre to mean simply the course of a weighted¹ nine-year moving average of annual yields in any region over the period considered. Trends so measured fit the annual data closely enough to throw into relief significant but fairly short-term changes in direction and slope. This is illustrated in Chart 1 by the drop and recovery

of yield in the British Isles during the period 1865-85, in France during 1905-25, in Australia during 1885-1905. At the same time, these moving averages are stable enough to be little affected by variations in weather except under extreme conditions.

Diversity of trend conformation, not similarity, is the prominent characteristic of the five series shown in Chart 1. If comparisons are restricted to the period 1866-1935, we find a relatively flat trend in the United States, rising slowly to about 1905, stable or irregularly declining thereafter. The Australian trend declines rather steadily to 1898, rises rapidly to 1907, and thereafter "tables out" with a bulge centering in 1922. The French trend rises irregularly to 1905 after 15 initial years of flatness, declines to 1917, rises thereafter. The British trend declines to 1879, rises steeply to 1887, rises more slowly and irregularly to 1908, and shows in milder degree the decline and recovery centering in 1917. The Prussian curve shows little increase up to 1885, rises to 1910 more steeply than any of the other series, and suggests (though broken) a sharper war-time decline and post-war recovery than any of the other series.

Since these various trends move at different numerical levels, *percentage* changes in trend would afford different comparisons: in particular, the Prussian, British, and French curves would appear flatter as compared with the United States, and the Australian even more variable. Diversity of trend, considered either in absolute terms or in percentages, will be found characteristic of the fourteen wheat-producing regions with which the two parts of this study deal.

THE REGIONS

Of these fourteen regions, six lie in North America, five in Europe and Northern Africa,

¹ The weights of successive years are 1, 2, 3, 3, 3, 3, 3, 2, 1. The results were obtained by first calculating seven-year moving averages, and then taking three-year moving averages of these. In the charts each average is plotted against the central year of the nine included.

Moving averages covering shorter periods yielded trends too particularized for this inquiry; those covering longer periods, and likewise trends fitted by mathematical formula, proved too highly generalized; and trends fitted freehand seemed to rest too heavily upon personal judgment.

one in Asia, and two in the Southern Hemisphere.

The North American regions are (1) "Prairie Provinces" of Canada—the provinces of Manitoba, Saskatchewan, and Alberta; (2) "United States Spring Wheat" region—the states of Minnesota, the Dakotas, and Montana; (3) "Eastern North America"—the Province of Ontario in Canada, and the states of Maine, Vermont, New York, New Jersey, Pennsylvania, Maryland, Delaware, Virginia, West Virginia, Kentucky, Tennessee, North Carolina, South Carolina, Georgia, Alabama, Mississippi, Arkansas,¹ Utah, Nevada, Arizona, and California;² (4) "United States Soft Winter" region—the states of Michigan, Ohio, Indiana, Illinois, Wisconsin, Iowa, and Missouri;³ (5) "United States Hard Winter" region—the states of Nebraska, Wyoming, Kansas, Colorado, Oklahoma, Texas, and New Mexico; and (6) "Pacific Northwest"—the states of Washington, Oregon, and Idaho.

The five European regions are (7) "Northern Europe," including the territory now covered by the British Isles, Belgium, the Netherlands, Germany, Denmark, Norway, Sweden, Finland, Lithuania, Latvia, Estonia, Poland, Austria, and the western half of Czechoslovakia; (8) "Southeastern Europe," including territory now covered by the eastern half of Czechoslovakia, and Hungary, Rumania,

Bulgaria, Yugoslavia, and Greece; (9) France; (10) Italy; and (11) "Western Mediterranean"—Spain and Portugal in Europe, and Morocco, Algeria, and Tunis in French North Africa.

Other regions are (12) India; (13) Australia; and (14) "South America," including only Argentina and Uruguay.

It was sought to define these regions so that the wheat statistics of each applied to the same territorial boundaries throughout the period from 1885. This was particularly difficult; it could not be fully achieved with regard to the eastern part of "Northern Europe" and "Southeastern Europe"; nor are the territorial boundaries of France and Italy identical in all years. But for study of trend in wheat yield per acre the territorial discrepancies are insignificant as compared with other statistical discrepancies, such as changes in systems of crop estimating within identical territories, or estimations made necessary by lack of official data.⁴ Indeed, territorial discrepancies are less significant in the present inquiry than shifts of wheat acreage within some of the regions of which the boundaries have remained unchanged since 1885.

The attempt was made to define wheat regions in such a way that each region would be fairly homogeneous with regard especially to type of wheat grown, climate, place of wheat in agriculture, magnitude of wheat acreage, and direction of trend of wheat acreage. Nothing more than a moderately consistent approximation proved feasible; not one of the fourteen regions is truly homogeneous in these respects. Thus "Eastern North America" is a far-flung territory, extending from coast to coast across the southern United States and from eastern Canada as far south as Alabama. In this extreme illustration of heterogeneity, climate is far from homogeneous in the several parts of the region, but decline of wheat area and relative unimportance of wheat in agricultural operations are common to most parts. India is too large a territory to be homogeneous in climate. Italy and France, though much smaller in territory, have climates widely different in north and south. The most that can be said is that these fourteen regions differ one from the other too widely to justify

¹ Neighboring states in this group—New Hampshire, Massachusetts, Connecticut, Rhode Island, Florida, and Louisiana—do not produce enough wheat to be reported in official statistics.

² These four Western states grow too little wheat to be regarded as a major wheat region but enough to warrant inclusion of them within some larger region. With reference to geographical location and climate, they might reasonably be grouped with the Pacific Northwest; but because they are wheat-deficiency areas and exhibit trends of acreage and yield similar to trends in the eastern part of the United States, we have chosen to group them under the regional heading "Eastern North America."

³ This designation "Soft Winter region" is one of convenience; soft winter wheat is produced elsewhere in the United States, notably in the region "Eastern North America"; and the Soft Winter region produces some hard wheat.

⁴ The extent to which we have resorted to estimates is set forth in M. K. Bennett, "World Wheat Crops, 1885-1932," *WHEAT STUDIES*, April 1933, IX, especially p. 245. In the present study certain of these estimates have been slightly revised.

combination; each is a fairly homogeneous region at least from some points of view; and further subdivision designed to achieve a larger degree of homogeneity would result in an unwieldy number of statistical series.

CLASSIFICATION OF TRENDS

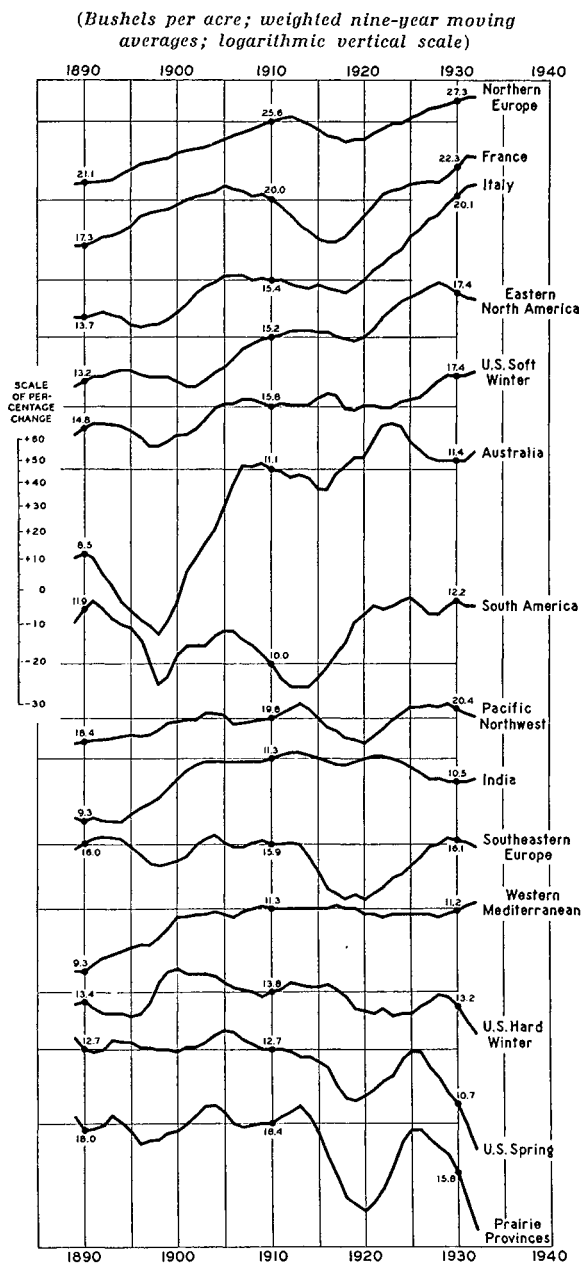
Chart 2 displays the trends (weighted nine-year moving averages) of wheat yield per acre in each of the fourteen regions, on a logarithmic vertical scale which affords a direct visual comparison of relative changes. This chart at once emphasises the diversity of trend in the several regions, and represents a broad threefold classification of trends according to type. The scale at the left affords a measure of percentage change applicable to any of the curves.

No two of the regional trends are identical, though there are fairly close resemblances between certain pairs—Northern Europe and France, India and the Western Mediterranean region, the United States Spring region and the Prairie Provinces, the Pacific Northwest and Southeastern Europe. No single trend moved without interruption either upward, horizontally, or downward. The interruptions to the broad drift over the whole period were in the main diversely timed. In some regions they were large and in others small (e.g., Australia and Eastern North America). In several regions the general drift in the second half of the period (after 1910) was about the same as the drift in the first half; whereas in several other regions (e.g., South America and India) the later drift was in the opposite direction from the earlier.

In eleven of the regions, the general average level of yield about in the decade centering in 1930 was higher than it had been 40 years before, in the decade centering in 1890; but in three areas it was lower. Increase of yield was a more widespread phenomenon in the 20 years between 1890 and 1910, when only three regions failed to show increase (South America, Southeastern Europe, and the United State Spring region) than it was between 1910 and 1930, when decline occurred in five regions. Percentage increases in yield tended to be larger, or percentage decreases smaller, between 1890 and 1910 than between 1910 and

1930; but Italy, Eastern North America, the United States Soft Winter region, and South America were exceptions.

CHART 2.—TRENDS OF WHEAT YIELD PER ACRE IN FOURTEEN REGIONS, FROM 1885*



* Regions defined in text, p. 72.

In view of this diversity of trend behavior, satisfactory classification of the fourteen regions according to type of trend is difficult. Five regions, however, show trends in which

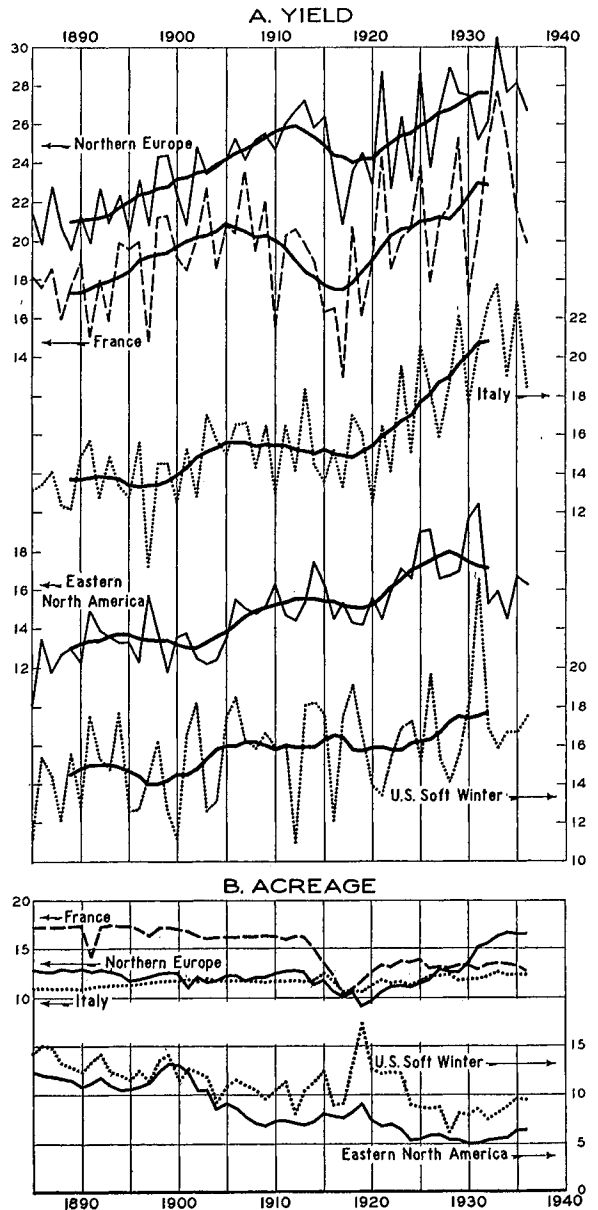
a rather well defined upward tendency predominates over the period as a whole. These are Northern Europe, France, Italy, Eastern North America, and the United States Soft Winter region, for which the trend lines appear at the top of Chart 2. Five regions show trends in which a rather well defined tendency toward either stability or downward drift predominates over the period as a whole, though not continuously. These are South-eastern Europe, the Western Mediterranean region, the United States Hard Winter region, the United States Spring region, and the Prairie Provinces of Canada, for which trend lines appear at the bottom of the chart. In the other four regions—Australia, South America, the Pacific Northwest, and India, shown in the middle of the chart—the trends of yield fall into an intermediate category, showing either reversal of direction over the period as a whole (South America and India), or a highly erratic course (Australia, South America), or a course that might be described as either predominatingly stable or predominatingly upward (Pacific Northwest). The first group we describe as “rising trends”; the second as “declining trends”; the third as “irregular trends.” This classification, though in some respects inadequate, seems serviceable for orderly discussion.

Charts 3, 4, and 5 show for each of the fourteen regions described above, on arithmetic scales, both the trend of yield per acre as measured by weighted nine-year moving averages, the annual yields from which the moving averages were computed, and (in the lower portions of each chart) annual wheat acreage. These three charts successively display the rising trends of yield, the irregular trends, and the stable or declining trends.

Extended comment upon the significant features need not be attempted here; indeed, it must be postponed until after analysis of the influences that determine trends, and of developments within different parts of each of the fourteen regions. It suffices here to mention briefly the general relationship between trend in yield and trend in acreage, and the frequency with which prominent depressions or “troughs” of yield occurred, centering in the years 1895–1902 and 1913–20.

The five regions wherein trends of yields have been predominantly increasing (Chart 3) are areas characterized by either decline, stability, or very slight increase in acreage.

CHART 3.—RISING REGIONAL TRENDS OF WHEAT YIELD PER ACRE, AND YIELD AND ACREAGE ANNUALLY, FROM 1885
(Bushels per acre; million acres)



The five areas with stable or declining trends of yield (Chart 5) are areas wherein the wheat acreage has expanded either tremendously or substantially. This suggests the generali-

zation that yield per acre tends to rise with decline or stability of wheat acreage, but to decline with substantial or large expansion of wheat acreage. The data in regions of irregu-

CHART 4.—IRREGULAR REGIONAL TRENDS OF WHEAT YIELD PER ACRE, AND YIELD AND ACREAGE ANNUALLY, FROM 1885
(Bushels per acre; million acres)

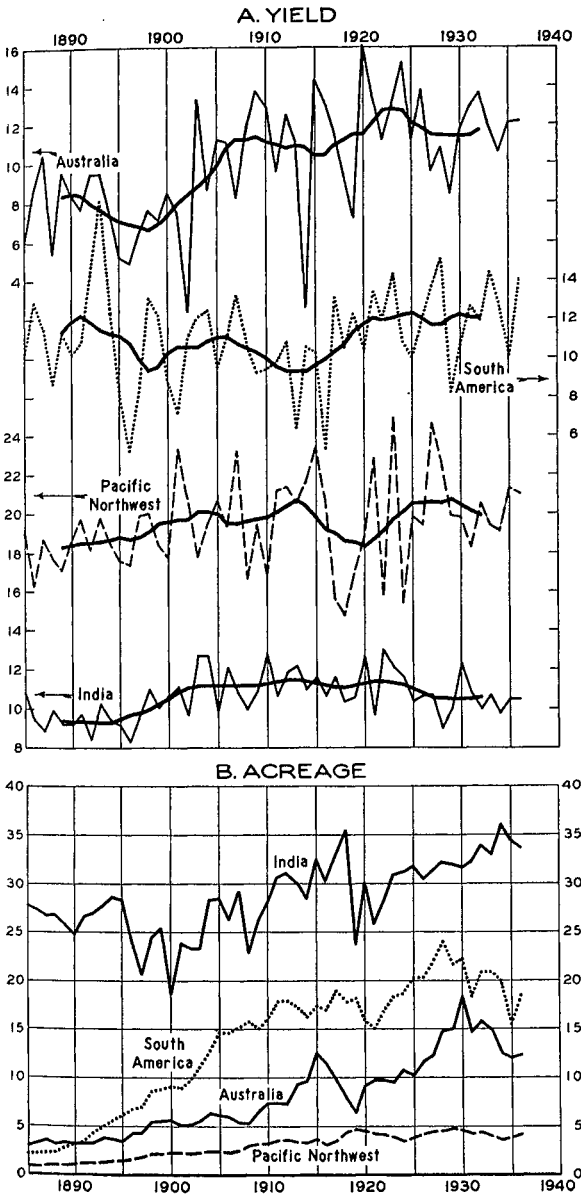
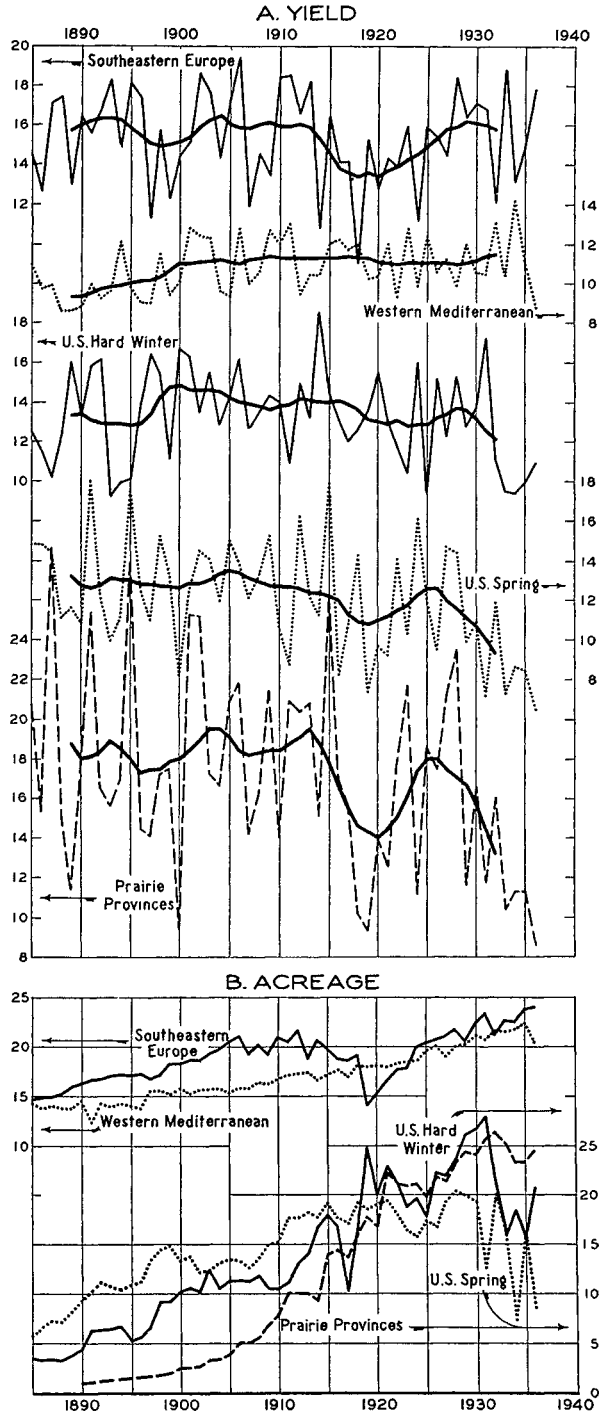


CHART 5.—STABLE AND DECLINING REGIONAL TRENDS OF WHEAT YIELD PER ACRE, AND YIELD AND ACREAGE ANNUALLY, FROM 1885
(Bushels per acre; million acres)



lar trend of yield tend partly to confirm the generalization (India) and partly to invalidate it. Yields have been well maintained in the Pacific Northwest in spite of substantial

expansion of acreage (more marked in percentage than in absolute terms), and in some parts of the period have increased in South

America and Australia in spite of large expansion of acreage. Numerical appraisal is unnecessary to indicate that change of yield in either direction is not associated with *proportional* change of acreage in the opposite direction. But since change in acreage tends so often to be associated with opposite change in yield per acre, it has seemed necessary to study yield and acreage concurrently, and to present statistical data on each in practically all charts.

The data do not apply consistently to yield per acre and acreage either *harvested* or *sown*, but are in some regions one, in some regions the other. It is impossible to compile data for all fourteen regions on either basis. This would be important in study of relative variability of regional yields, for greater variability is to be expected of yield per acre sown, especially as between two regions where abandonment of acreage is heavy in both but the statistics are based on sown area in one, harvested area in the other (e.g., Prairie Provinces and United States Hard Winter region). It is less important in analysis of trend. Most of the fourteen series shown in Charts 3-5 are of *harvested* yield per acre and acreage;

the Prairie Provinces, South America, India, and Australia are exceptions.

Striking features of the trend of yield in these fourteen regions (best shown in Chart 2, p. 73) are temporary "troughs" commonly centering (*a*) in one or another of the eight years 1895-1902 and (*b*) in one or another of the eight years 1913-20. In all regions except Northern Europe, France, the Pacific Northwest, India, and the Western Mediterranean region, the average yield per acre as measured by the smoothed curves fell lower sometime between 1895-1902 than it had been in 1890; decline and recovery of yield per acre around the turn of the century occurred widely though not universally. Decline and recovery of yield centering sometime in the period 1913-20 was even more common; in every one of the regions, average yield centering on one or another of these years fell more or less below the average level of 1910. Some interesting problems of causation are suggested by these two "troughs" of yield per acre—the relative effects in particular of weather, of shifts in acreage, and of change in methods of wheat culture. These problems receive some attention below.

II. COMPLEXITY OF TREND INFLUENCES

The present section deals, in general terms and not exhaustively, with the several typical influences that ought to be borne in mind in attempting to explain the trends of wheat yield per acre summarized above in Charts 2-5. The conformation of these trend lines may be affected by one or more of six distinguishable influences: (1) inaccurate statistics; (2) geographical shifts of wheat acreage within the region; (3) the initial general level of yield per acre; (4) changes in the environment of the wheat plant due to natural causes; (5) changes in the environment of the wheat plant due to man; and (6) changes in the wheat plant itself.

This classification is not designed to distinguish between favorable and unfavorable influences; nor is its purpose to list influences that are strictly independent of each other. It is designed to be nearly inclusive, covering practically all influences that may affect trend

of yield;¹ and to provide a basis for orderly discussion.

INACCURATE STATISTICS

Inaccuracy of yield-per-acre statistics, perhaps of major import or perhaps insignificant, is reasonably to be expected especially if the statistics cover large territorial areas and long periods of time. Yield-per-acre statistics almost invariably are obtained as a basic part of procedure in estimating production; acreage statistics are the complementary part. The typical procedure, in a particular year and country, is to appraise the wheat acreage and the yield per acre independently in each of a large number of "crop-reporting districts," deriving the production in each district by multiplication of estimated yield and estimated area. Yield per acre in a region

¹ Not included is improvement of machinery whereby harvesting losses may be minimized.

(or country, state, or province) may then be calculated from total production in the included districts divided by total acreage in the same districts.

Yield-per-acre statistics for large territorial areas thus are invariably *weighted averages*—that is, estimates of yield in many smaller areas (themselves either weighted or not) weighted by acreage in each small area. The whole procedure reflects familiar facts. Yield per acre of wheat may vary widely from year to year on a particular farm; of two adjacent small areas, one may characteristically and persistently give high yields and the other low; localized developments (e.g., flood, hail, locusts) may cause yields even in adjacent small areas to fluctuate unsystematically in amount, or even in direction, from year to year; and acreage may be contracting in the high-yield part of a region and expanding in the low-yield part, or conversely. It would obviously be prejudicial to the main objective—appraisal of annual national wheat crops—to treat either yield or acreage developments in a small locality as typical of national developments, unless national production happened to be confined to very narrow geographical limits.

In most countries, therefore, the process of crop estimating calls for maintenance of many local agents as well as a central statistical organization; for revision of procedures as time passes; and, especially in pioneer countries, for expansion of the crop-estimating organization as the agricultural area expands. This is expensive. It has naturally been undertaken almost always on a small scale at the outset, and has been begun at different times in different countries. Subsequent improvement has perhaps not been universal, but is more typical than deterioration. General governmental disorganization, and revision of national boundaries such as occurred in Eastern Europe during and after the war, inevitably disturbed the continuity and reliability of statistics. Acreage statistics are peculiarly subject to question in pioneer areas where expansion proceeded rapidly; and if the acreage statistics are in error, some degree of error may have crept into the weighted averages of regional yields. Even in older

areas, initial attempts to appraise crops sometimes failed to cover part of the national territory. Systems of measuring both area and yield have changed in some countries where territorial boundaries and general organization of governments remained unaltered; and the history and import of these changes are obscure. For some parts of some wheat-producing regions, we have been forced to rely upon our own estimates of yield in early years.

In short, the annual yield statistics for the fourteen regions dealt with here are by no means equally dependable; but it is not usually feasible to differentiate sharply or to “correct” the data except in a general way, mainly qualitative. Here we summarize pertinent statistical defects that bear upon interpretation of the trends of yield in the fourteen regions, without pretending to cover the whole field.

North America.—The indicated trend of yield in the Prairie Provinces of Canada (Chart 5, p. 75) probably runs a little too high in the period 1906–16, on account of official overestimation of the crops of 1909 and 1911–13. Statistics of stocks, railway movement, and domestic disposition indicate the overestimation of the crops, and it seems probable that some part of the error arose from overestimation of yields.

Statistics applying to some or all of the five wheat-producing regions lying mainly within the United States (Eastern North America, United States Soft Winter, United States Hard Winter, United States Spring, and Pacific Northwest) may perhaps show either somewhat too large an increase or somewhat too small a decline in average yield per acre as between the earlier and later parts of the period 1885–1936. This assertion rests upon study of domestic disposition and exports in the early and the later parts of the past half-century. The recent *crop* statistics appear dependable as to general level, with a presumption that levels of both *acreage* and *yield* statistics are dependable for recent years. The early *crop* statistics, even as recently revised upward,¹ appear on the contrary too low to

¹ See U.S. Department of Agriculture, *Revised Estimates of Wheat Acreage, Yield and Production, 1866–1934* (Washington, mimeographed, September 1934).

cover exports and domestic utilization appraised independently of crop estimates for early years. We are not in a position to say whether the understatement of crops in the early part of the period 1885-1936 pertains to yield, acreage, or both, or whether it applies to any one of the five regions here considered more than to another. There is merely a presumption that one or another or all of the five trends of yield per acre for regions of the United States shown in Charts 2-5 may somewhat overstate increase of yield or understate decline of yield; this seems to be the direction of such bias as exists in the data. The magnitude of the bias, however, seems unlikely to be significant here, unless it would suffice to make the trend of yield in the Pacific Northwest rise less and appear more stable than it does in Chart 5.

Europe and Northern Africa.—The region "Northern Europe" includes many countries, and our knowledge of the crop statistics of most of these is far from comprehensive. No reason appears at present to question the data for territory now lying in Belgium, the Netherlands, the three Scandinavian countries, or Finland. Venn believes that the British official statistics which we use understate trend increase of yield in Britain, as well as the amplitude of annual fluctuations; but Vigor and others find them credible.¹

German official statistics of yield per acre seem generally to be accepted at face value

Reissued May 1937). These revised statistics show an increase of yield per harvested acre in the United States, 1885-89 to 1920-24, of 7 per cent; whereas the older estimates (see U.S. Department of Agriculture, *Wheat and Rye Statistics*, Statistical Bulletin 12, January 1926) showed an increase more than twice as large, or 19 per cent.

¹J. A. Venn, "An Inquiry into British Methods of Crop Estimating," *Economic Journal*, September 1926, XXXVI, 394-416; H. D. Vigor, "Crop Estimates in England," *Journal of the Royal Statistical Society*, XCI (new series), 1928, Part I, 1-48.

²See M. K. Bennett, "Per Capita Wheat Consumption in Western Europe," *WHEAT STUDIES*, March 1935, XI, 274-75; also N. Jasny, "Wheat Problems and Policies in Germany," *ibid.*, November 1936, XIII, 127-29.

³Jasny, *loc. cit.*

⁴See Holbrook Working, "The Changing World Wheat Situation," *WHEAT STUDIES*, September 1930, VI, 450; and M. K. Bennett, "World Wheat Crops, 1885-1932," *ibid.*, April 1933, IX, 260-61.

only for the years 1885-92 and 1928-36. In 1893-1913 they were too high, and here we have felt justified in reducing them by 10 per cent, though without assurance that this adjustment factor is the best to use every year.² In 1914-27, official German yield statistics were apparently too low;³ but no correction has been made. Consequently the trend of yield per acre for "Northern Europe," so far as it is affected by inaccuracies of German statistics, shows too large a decline to the war-time low and too steep a postwar rise.

Overstatement of the war-time trough and the steepness of the early postwar rise also seems to be contributed by changes in methods of appraising crops in Poland and Czechoslovakia around 1925 or 1926. The prewar data for territory now covered by Poland and the Baltic states (except Finland) contain a substantial element of our estimation, based however upon prewar official Russian statistics by regions; and territorial boundaries east of Germany in the region "Northern Europe" have changed enough to preclude strict comparability of yield statistics over the whole period 1885-1936. The principal statistical defect of the trend of yield in Northern Europe appears to be its exaggeration of the war-time trough and early postwar recovery.

The basic data for Southeastern Europe contain, up to 1919, an appreciable element of our estimation; but except for Greece—where the acreage was only a small fraction of the total—the basis of estimation seems fairly secure prior to 1914. The war-time and early postwar statistics, whether official or estimated, can hardly be more than approximate, and may be too low. Statistical methods in Czechoslovakia were changed about 1926 and in Greece about 1932, the later estimates showing higher yields than the earlier. Hence in general the regional trend in Southeastern Europe (Chart 5), like that in Northern Europe, may indicate a war-time level too low and a postwar rise too steep.

Italian statistics during the periods 1885-99 and 1904-08 seem to require correction and estimation.⁴ In the earlier period, official estimates of production are almost certainly too low, and acreage estimates are available only for the years 1890-92. We have estimated the

acreage in other years, raised the production estimates by 22 per cent in all years of the early period (1885-99), and arrived at appraisals of yield per acre by division, thus in effect attributing the underestimation of production to underestimation of yield per acre. In the later period, 1904-08, the official acreage statistics appear far out of line with the estimates for 1900-03 and after 1909, and these we have reduced with the effect of raising calculated yield per acre during 1904-08. Strict reliance upon official data would thus produce a trend of yield rising persistently and rather steeply from 1889 to about 1910; but such a trend we believe to be spurious. Our correction, if in error, seems likely to be too conservative, so that the general drift of trend up to the war as shown in Chart 3 may overstate the amount of increase in yield per acre. The remarkably steep postwar rise of yield has often been questioned, but seems credible in the light of disposition estimates.

French official statistics appear to have been subjected to no fundamental criticism until very recently; but procedures of estimation introduced (with the 1936 crop) under the new Wheat Board are now tending to suggest that at least the postwar official data overstated French wheat production. A few years must elapse before it can be seen whether the new procedures are the more dependable, and if so whether the older estimates err in appraisal of acreage or of yield per acre.

Official statistics of Spanish wheat acreage show an increase hard to credit between 1896 and 1897. Different sources disagree substantially with one another concerning Spanish production up to 1900, and indeed all through the period. We have had to rely upon insecure evidence in appraising early yields in Tunis (to 1901) and Morocco (to 1914). Hence the trend of yield in the "Western Mediterranean" region as shown in Chart 5 is probably partly spurious, especially so in the early part of the period 1885-1936. The amount of increase prior to 1900 seems likely to be more or less overstated; and even the later statistics may not be reliable.¹

Other regions.—Three defects seem to characterize the official crop statistics of India:

(a) the acreage statistics progressively cover more and more territory;² (b) the general level of yield per acre, at least in postwar years, is officially understated;³ and (c) the system of estimation was apparently revamped in 1891,⁴ so that earlier statistics may not be properly comparable with later data. We make no attempt to interpret the early estimates. The level of yield may well be too low throughout the period 1885-1936; but the trend after 1891 may not appreciably misrepresent the facts unless official understatement of yield has become progressively larger—a development not yet confirmed so far as we know.

The official statistics from which the trends of yield in South America and Australia (Chart 4) are calculated seem credible in the light of crop disposition statistics. These cannot, however, be applied to Uruguay, a relatively unimportant contributor to trend of South American yield.

In summary, it appears that the statistical data providing the bases for the fourteen regional trends of yield per acre shown in Charts 2-5 are frequently defective enough to produce significant mistaken indications of trend. Commonly, the possibilities of error seem in the direction of showing either too steep advance or too little decline during the first half of the past half-century, as in the six North American regions, Italy, and the Western Mediterranean. Less frequently the trends may show too large a decline and subsequent advance from late prewar to war-time and then to postwar levels, as in Northern Europe and Southeastern Europe. In two regions—

¹ See R. del Caño García, *Producción y mercado del trigo* (Madrid, 1933), pp. 97-98. Here are given charts which compare official estimates of Spanish wheat production and acreage, 1900-32, with unofficial estimates by the newspaper *El Norte de Castilla*. The latter gives lower estimates of production throughout the period, with a less steeply rising trend; and the trends of acreage in the two series are radically different.

² C. P. Wright and J. S. Davis, "India as a Producer and Exporter of Wheat," *WHEAT STUDIES*, July 1927, III, 398.

³ *Report on the Marketing of Wheat in India* (Delhi, 1937), especially p. 9.

⁴ Inferred from *Agricultural Statistics of India . . . 1901-02 to 1905-06* (Calcutta, 1907), I, 1.

France and India—there is some slight ground for questioning the conformation of trends derived from the official statistics, but the basis for appraising the effect of the statistical inaccuracies is not secure; this applies also to the Western Mediterranean region after 1900. South America and Australia are the regions wherein the indicated trends of yield appear to be most trustworthy throughout their course.

GEOGRAPHICAL SHIFTS OF WHEAT ACREAGE

The trend of wheat yield per acre in any large region may be determined, independently of all other influences, by internal shifts of wheat acreage. If a region consists of two parts wherein natural conditions determine that the level of yield must be respectively 10 and 20 bushels per acre, and the respective wheat areas happen to be 5 million acres, then the regional level of yield will be 15 bushels. If in the high-yield part of the region the acreage declines to 2 million acres in the course of time and in the low-yield part rises to 8 million acres, without change in the level of yield in either part, the regional average level of yield will fall to 12 bushels. If the change of acreage is reversed as between the two parts of the region, the regional level of yield will rise to 18 bushels. If, however, the initial levels of yield were identical in the two parts of the region and this identity persisted while acreage shifted from either part to the other, there would be no change in the regional level of yield.

Tremendous shifts of wheat acreage have actually occurred from one part to another of many of the fourteen wheat-producing areas considered here. Sometimes these shifts have involved mainly change in the proportion of the wheat acreage lying in the several parts of a region, the total acreage changing little. Sometimes the shifts have involved change both in the proportional distribution of acreage between parts of the region, and change also in the total regional acreage. In Charts 3-5 we have presented the changes in total acreage of each region from 1885 to 1936; and subsequent charts show the changes in acreage within parts of each region, so as to give an idea of the extent to which the changes

in internal distribution of acreage may have affected the course of the regional trends of yield. Often, however, there is no way to indicate important shifts of acreage—for example, in political subdivisions where the wheat acreage has expanded onto drier and drier land, but statistics are available only for the subdivision as a whole.

Changes either in the total wheat acreage of a region or in the distribution of acreage between parts of a region can seldom be expected, however, to proceed independently of other factors that influence trend of regional yield per acre. Thus enlargement of total acreage, and of the fraction lying within a droughty part of a region where the level of yield would normally be lower than in the more humid part, may proceed simultaneously with improvement of agricultural technique that tends to enlarge yields in both parts. The improvement of technique may suffice either to restrain decline of regional yield that would otherwise occur, or to offset it, or indeed to overbalance it and thus give rise to an increase. Similarly, the unfavorable effects of expansion of wheat acreage to low-yield parts of a region may be masked for a considerable period by a succession of several good years following several bad ones in the low-yield part of the region; or accentuated by opposite weather developments. A decline in total wheat acreage within a region, even without change in the proportional geographical distribution, is particularly likely to occur concurrently with change in agricultural technique. Such a decline, unless it results from war or other catastrophe, is likely to imply a regional tendency toward diversification of crops, involving improvement in the supply of plant nutrients available to the wheat; and it may often but not invariably imply that wheat retreats to naturally superior locations.

Interpretation of regional trends of wheat yield per acre accordingly resolves itself largely into an attempt to appraise the relative importance of effects produced respectively by internal shifts of wheat acreage, changes in weather or climate, and changes in farm practice in wheat-growing. Geographical shifts of acreage will be found to be a dominant influence in some regions, usually adversely

affecting the trend of yield, but relatively unimportant in others.

LEVEL OF YIELD

Trend of yield may be said to be determined in some degree by the initial level of yield in any region. Abstracting from irregularities of weather, inaccuracies of statistics, and shifts of acreage, one expects to find less increase of yield over half a century in that one of two regions closely similar in climate wherein the initial level of yield is the higher. If the climates and soils of the two regions are closely similar, the difference in level of yield must reflect mainly difference in the arts of cultivation. There will be an upper limit to yield in each region—probably numerically about the same if the regions are in fact climatically alike. If initially the yield is near this limit in the one, far below it in the other, there is much more room for improvement in the arts of cultivation and of yields in the latter, even if farmers in the former continue to be as “progressive” as farmers elsewhere over a particular period. One may therefore interpret a steeply rising regional trend as representing relatively greater improvement of the arts than occurred in a region where the trend rose less steeply, without in the least implying stagnation of the arts in the latter region. The farmers in the latter region may merely have been nearer to the point of “diminishing returns” at the outset of the period.¹ The significance of this emerges particularly when one compares, for example, the very large increase of yield since 1885 in northern Italy or in Japan with the much smaller increase in several parts of North-western Europe.

If two regions where initial levels of yield are far apart differ widely in climate, the divergent initial levels assume little importance in interpretation of trends of yield. Since we lack precise differentiations of regional climates, it will be found difficult to say in what contrasts of trend the initial level of yield is important or unimportant.

¹ The general principle is well stated and illustrated from experimental data in G. Frecheville, “Higher Farming,” *Journal of the Royal Agricultural Society of England*, 1926, LXXXVII, 1-18.

EXTERNAL CHANGE OF ENVIRONMENT

Trend of wheat yield in some regions may be strongly affected by change in the environment of the wheat plant brought about by developments over which man has little or no control. Such developments are represented by changes in climate or weather, and by large-scale infestations of pests or diseases of the wheat plant (which may themselves be associated with unusual weather conditions).

It will be remembered that “trend” in this study is measured by weighted nine-year moving averages. This method practically eliminates all fluctuations of trend that might be due to *alternating* and *regularly recurrent* spells of weather respectively good and bad for wheat, provided these spells were not of a duration exceeding four or five years. But even one or two extraordinarily bad years for wheat, if occurring in the midst of a substantially longer period of ordinary or exceptionally good weather, can cause a trend of yield measured by weighted nine-year averages to dip appreciably during the period in which the two bad years center. If nine relatively bad years are followed by nine ordinary years which in turn are followed by nine good years, then the line of trend must move upward steeply. The occurrence of exceptionally good or bad groups of years, enduring for several seasons in the midst of or before or after a longer spell of ordinary years, is bound to affect the conformation of the trend of yield. The same can be said of serious infestations of rust or locusts, or (perhaps a hypothetical illustration) of a stretch of years during which chronic sources of infestation happen to be absent.

So far as we can judge, the dips and bulges in the regional trends of yield shown in Charts 2-5 are in fact largely due to these rather protracted stretches of unusual weather. These are considered below. It can seldom be said with assurance, however, that no other influences were operating at the same time and in the same direction.

In the middle and late 'nineties, for example, there were depressions of yield in many regions. But there was also a severe depression of wheat prices followed by sharp

recovery; acreage changes were in some regions substantial; and it would be expected that price depression in humid areas where wheat was intensively cultivated might have tended to curtail the application of labor and fertilizer to wheat, with adverse effects upon yield, as farmers sought to cut down their costs of production.

The many depressions of yield centering in the war and early postwar periods represent especially difficult problems of interpretation; for these occurred not only in regions where war-time conditions inevitably reduced the available supplies of fertilizer, draft power, and human labor, but also in areas where wheat was cultivated under an extensive system and the depressions of yield seem more likely to have been chiefly due to weather developments and acreage changes.

An exhaustive and thorough explanation of the prominent depressions and bulges of yield per acre shown in the fourteen curves in Chart 2 would involve close examination of weather records. This is not attempted, partly because of the labor involved but also because understanding of precisely what weather factors most strongly affect yield is far from adequate. Annual or even monthly rainfall and temperature records, the more readily available sorts, might not suffice.¹

Here we are not concerned with questions of periodically recurrent cycles either in wheat yield or in weather conditions—subjects to which a voluminous literature is devoted.² The problem is to explain regional trends of yield; and dips and bulges in the several trends can be discussed in terms of probable weather influence without commitment as to the periodicity of weather influ-

ence. It is clear that the conformation of yield trend is inevitably affected by stretches of good or bad weather persisting over periods of more than four or five years, whether recurrent or not.

Possibly the trends may be affected also by changes in climate operating over periods so long that they are not well described as "stretches" of years. For example, Enquist has sought to show that the climate of Northwestern Europe tended to become more maritime (warmer winters, cooler summers) during the larger part of the nineteenth century and up to about 1915, thereafter tending again toward greater continentality (colder winters, hotter summers); and to this apparent change in climate in prewar years, Enquist ascribed a considerable part of the concurrent rise in trend of cereal yields in this area.³ Van Royen speaks of "wide borderland areas between humid and arid regions . . . always . . . subject to recurrent droughts of varying duration and intensity . . . in historical times," and of prehistoric droughts "some of which were brief, others evidently very long."⁴

Although few investigators have directed attention to transition periods from a long period of abundant rainfall and cool temperatures to a long period of scanty rainfall and high temperatures or the reverse, the possibility ought not to be overlooked that such transitions have occurred (perhaps with reference to other climatic factors) and might occupy as much as half a century. Depending on the extremes between which transition is made and the aspects of climate involved, the trend of wheat yield in any region over half a century might be determined at least partly by such very long-term variation in climate as well as by the more readily perceptible phenomena involving the succession of shorter stretches of good or bad weather. For present purposes, however, we assume that transitional change of climate is not likely to have affected the trend of yield materially in any of the regions considered here.

MAN-MADE CHANGE OF ENVIRONMENT

If in any region for fifty years the statistics of yield were trustworthy, the internal geographical distribution of wheat acreage un-

¹ See C. L. Alsberg, "Forecasting Wheat Yields from the Weather," *WHEAT STUDIES*, November 1928, V, especially pp. 20-23, 31.

² See, for example, H. S. Jevons, "The Causes of Fluctuations of Industrial Activity and the Price-Level," *Journal of the Royal Statistical Society*, XCVI (new series), 1933, Part IV, especially pp. 568-77.

³ Fredrik Enquist, "Om Klimatets Inverken på Skördevariationer," *Svensk Geografisk Arsbok*, 1932 (Lund, 1932), pp. 122-46.

⁴ William Van Royen, "Prehistoric Droughts in the Central Great Plains," *Geographical Review*, October 1937, XXVII, 637.

disturbed, and the climate stable, the trend of wheat yield per acre would be affected by man-made changes in the environment of the wheat plant. Such changes are of many types, and would inevitably differ from region to region if only in reflection of differences in climate. In general, changes made by man in the environment of the wheat plant involve either control of pests and diseases (independently of the development and cultivation of resistant varieties), or change in the supply and balance of plant nutrients.

Illustrations of pest and disease controls are systematic eradication of such hosts of rust as the common barberry; the destruction of grasshoppers trapped in trenches flung far across the countryside or by the distribution of poisoned bait; the erection of barriers against rabbits; systematic destruction of certain noxious weeds; and introduction of insect species that prey upon other insect species injurious to wheat. These controls are usually exercised by governmental organizations. Farmers themselves combat diseases and pests in various ways, notably by chemical treatment of wheat seed to prevent crop damage from bunt or stinking smut, and by seeding winter wheat late enough to prevent damage from the Hessian fly. Sometimes pest control involves no conscious effort; for example, merely the transformation of raw prairie into plowed land as settlement extends will gradually reduce hazards of damage from grasshoppers.

Change in the supply and balance of plant nutrients available to wheat may be in either direction. Everywhere there is a race between exhaustion of soil fertility on the one hand, and restoration or enhancement of soil fertility on the other. In newly settled areas, agriculture tends to be extensive and exhaustive of soil fertility for a period of years, until yield falls so low that farmers feel impelled either to alter their methods, or to abandon farming. In older areas the forces tending to exhaust soil fertility are always present, but their effects tend to be offset or more than offset by cultural methods.

The methods whereby farmers can improve the supply and balance of plant nutrients available to wheat may be classified under

four heads: crop rotation, fertilization, mechanical means, and regulation of the water supply.

Systems of crop rotation wherein wheat has a place are very numerous and very different, and have diverse histories. At one extreme, perhaps, lies a system whereby wheat is grown continuously for six or seven years, on land that has either never been cropped before or that, formerly in wheat, has been allowed to return to its natural vegetative cover in the course of a decade or longer. Or wheat may be the sole crop in a two-course rotation, occupying every year land that has been left fallow the year before. Or wheat may be part of a three-course rotation: fallow, winter wheat, spring grain; roots, winter wheat, spring grain; or corn, winter wheat, grass. It may be part of a four-course rotation such as wheat, barley, oats, clover; or of a five-course rotation like sugar beets, wheat, oats, clover, wheat. At the other extreme, wheat may occupy land only once in eight or ten years, other crops being produced in each of the intervening years; an eight-course rotation practiced in parts of Denmark is fallow, wheat, sugar beets, barley, fodder beets, barley, clover, oats.¹

In general, crop rotations involving wheat have tended to become progressively more effective and complex in the past fifty years, more so in some regions than in others. Normally, such developments mean enhancement of the yield per acre of wheat; for the objective in changing a crop rotation is to increase the productivity of the soil, and wheat may ordinarily be expected to share in the increased productivity. A relatively valuable crop, wheat occupies a favorable position in many crop rotations.

Rotations seldom become more complex without involving additional application of fertilizer and labor; consequently man-made changes in the supply of plant nutrients usually represent joint contributions from several distinguishable sources, and it would be impossible (except experimentally) to appraise independently the effect of change in

¹ Royal Danish Agricultural Society, *A Short Survey of the Danish Agriculture* (Copenhagen, 1913), p. 33.

crop rotation on yield of wheat. Yet if one considers such a change in rotation as substitution of a cultivated root crop for pastured fallow in a three-course rotation—fallow, winter wheat, oats—there would be reason in a sufficiently wet climate to anticipate enhancement of wheat yield without much change in labor and fertilizer assignable to the wheat. The yield of wheat would tend to be enhanced by being grown, after the change, on a field more free than formerly from weeds, better worked and aerated, and hence probably better supplied with available plant food. Still larger effects might follow a change from pastured fallow, wheat, oats to roots, wheat, oats, leguminous forage.

In many instances, increasing complexity of the crop rotation would accompany reduction of both total arable acreage¹ and wheat acreage, with retreat of wheat to naturally superior locations; and enhancement of wheat yield might then be attributable partly to its better location. This would probably tend to occur if wheat continued to be the most valuable cash crop: then the rotation would be designed primarily with a view to improve the yield of wheat. But in some circumstances wheat might decline in esteem and importance; livestock production based on grass or productive feed crops like corn might become the major objective; and wheat might retreat to inferior locations and decline in yield.

We make no thorough and systematic attempt here to trace, region by region, the changes that have actually occurred in crop rotations involving wheat. It suffices to say that rotations in most regions have become more complex, with favorable effects upon yield; that the changes cannot be supposed to have occurred simultaneously in different regions or to have been spread evenly over time in any region; and that change of crop rotation usually implies change in other factors that improve the supply and balance of plant nutrients.

Appropriate fertilization of the soil ordinarily

¹ Arable land includes land customarily sown to crops or temporarily lying idle or in fallow, but not land in so-called permanent meadow and pasture or in orchards or vineyards.

enhances wheat yields, and may do so independently of change in crop rotations. Without much doubt, the trend in the past half-century in several regions has been toward increase in the quantity of barnyard manure and commercial fertilizer used per acre of arable land, and in such regions wheat has shared the benefit with other crops. These are mainly humid regions, where the rainfall suffices to dissolve and make available to plants the nutrients in the heavier applications of fertilizer. But even in some dry regions (like Australia), where little or nothing would be gained by heavy application of complete fertilizers, substantial increases in wheat yields may follow moderate quantitative use of a commercial fertilizer rich in a particular nutrient like phosphorus, if the soil happens to be deficient in this particular element.

Even today, however, very little fertilizer—whether barnyard manure or commercial preparations—is employed in the agriculture of most of the wheat regions with which we deal here. It plays a minor or an insignificant role in India, most of Southeastern Europe, most of the Western Mediterranean region, the four regions of central and western North America, and South America. It is used most, and has contributed most toward yield of wheat, in Northern Europe, France, Italy (especially the northern part), Eastern North America, the eastern part of the United States Soft Winter region, and Australia. Expansion of its use in these regions has not been timed synchronously.

Minor mechanical methods of improving wheat yields by enlarging the supply of available plant nutrients pertain especially to preparation of the seed bed, partly to preservation or improvement of soil structure. Emphasis falls on frequency of plowing (which promotes nitrification and helps to control weeds), depth of plowing, depth and spacing of seed (the drill versus broadcast sowing), and—particularly in dry regions—appropriate timing of plowing and seeding. Mechanization of agriculture has contributed to all of these, most notably since about 1925, and perhaps most significantly to timeliness of plowing and seeding.

The principal devices whereby man controls

the supply of water, and hence conditions the supply and balance of plant nutrients available to wheat, are drainage, irrigation, and fallowing. Of minor importance are terracing and contour plowing. Drainage may improve wheat yields in humid regions, mainly by eliminating thinness of stand and by facilitating control of weeds. Irrigation has been most important in India and the Western Mediterranean region (as well as in Egypt, which is not here considered), and in small portions of the western United States falling into three separate regions.

Fallowing in humid regions has as its objective not control of the water supply, but primarily control of weeds and secondarily restoration of soil fertility. In arid regions, on the contrary, the primary objective is often said to be increase of the available water supply, sometimes weed control, with restoration of fertility commonly regarded as a subordinate objective.¹ Fallowing is more or less practiced almost everywhere but has lost importance in humid regions, where cultivated crops or leguminous forage have tended to displace fallow in the rotation; and this displacement has extended into the drier regions. Fallowing remains a very important moisture-conserving device particularly in Australia, the Prairie Provinces, the Pacific Northwest, the western fringe of the United States Spring and the United States Hard Winter regions, India, and most of the Western Mediterranean region. In some of these places the fallow is not cultivated so as to retain as much moisture as possible in the soil, but is used for pasture. A peculiar fallowing system prevails in parts of India, where in the course of two years a piece of land may be occupied by two crops, the first sown in the spring for autumn harvest, followed by fallow nine or ten months long, followed in turn by a crop sown in the autumn for spring harvest, followed by a short fallow of about three months.

There appear to be only a few regions—

¹ Recent studies call in question the emphasis commonly put upon conservation of moisture as the main objective in fallowing.

² C. L. Alsberg, "The Objectives of Wheat Breeding," *WHEAT STUDIES*, June 1928, IV, 271. This process might be either helped or hindered by the common custom of exchanging seed with neighbors.

notably Australia—where introduction of a fallowing system, as distinguished from change in management or in prevalence of the fallow, actually assumes much significance for interpretation of trend of wheat yield; in most other regions where it is now important, the system existed fifty years ago. But it is the much wider use of cultivated fallow in the Prairie Provinces and the Pacific Northwest, as compared with the United States Spring region, that largely explains the persistently higher *levels* of wheat yield in the former regions.

Terracing is historically of little importance in explaining trend of wheat yield, being found mainly in Italy where it has probably not gained much in importance since 1885. Contour plowing, whereby furrows are run in sloping country in such a way as to permit absorption of moisture that would otherwise run off, is a moisture-conserving device recently stressed in connection with control of soil erosion in the United States. We are not aware that it is new in the wheat-growing world, or that it has come widely into use in the course of the past half-century.

CHANGE IN THE WHEAT PLANT

The trend of wheat yield per acre in any region may be affected by change in the type or in the variety of wheat grown in the region. For example, winter wheat may have tended to supplant spring wheat in regions where spring wheat occupied a large fraction of the wheat area in the early part of the past half-century; and, since winter wheat usually exceeds spring wheat in yield per acre wherever both are grown successfully, a shift from spring to winter type will ordinarily increase the regional yield per acre.

Shifts in the varieties of wheat commonly grown have probably occurred in every region. To some extent, perhaps, these shifts may represent accidental selection: if year after year farmers grow and sow their own seed without purposeful selection, the more prolific varieties tend eventually to dominate the fields.² The existence and effects of such automatic selection cannot be traced. In larger and more perceptible degree, shifts in the varieties grown have represented first the

purposeful development of new varieties, and then their dissemination throughout the farming community.

Plant breeders, when not seeking to develop varieties of superior *quality*, aim at *quantitative* enhancement of yield through improving one or several characteristics of the plant—for example, to shorten the growing season so as to avoid the hazards of frosts in some regions and hot winds in others; to promote resistance to low winter temperatures, rust, drought, lodging, or shattering; or to increase the ability to germinate, the extent of tillering (and thus the numbers of stalks and heads), the number of kernels per head, and the size of the wheat berry. Truly scientific wheat breeding has been possible only since 1900, when Mendel's laws of heredity were rediscovered and verified; but some of the most valuable varieties were selected earlier.¹ Without doubt discovery and adoption of new varieties have been occurring in practically all wheat-growing regions for centuries before 1885, with favorable effects upon wheat yields per acre. But, while discoveries might be traced chronologically from 1885 or thereabouts, the extent of adoption is ordinarily untraceable; hence precise appraisal of the specific influence of plant selection and breeding upon trend of wheat yield cannot be achieved.

CONCLUSIONS

Enough has been said to demonstrate that interpretation of trends of wheat yield per acre is far from a simple matter, and that close appraisal of the relative importance of trend influences is virtually impossible. A trend is likely to reflect opposing influences more or less throughout its course, or in one part of its course a combination of several influences that differ from the combination operating at another time. Decline of wheat yield per acre is not a dependable sign of agricultural retrogression, and increase of yield is not a dependable sign of progressive agriculture.

¹ Alsberg, *WHEAT STUDIES*, June 1928, IV, 284.

² *Die deutsche Volksernährung und der englische Aushungerungsplan* (Braunschweig, 1915), p. 99.

³ Quoted by Enquist, *op. cit.*, p. 131.

With reference strictly to the historical period 1885–1936, the preponderant effect of change in the geographical distribution of wheat acreage has been adverse to wheat yield per acre; but in some regions the redistribution has favored wheat yields. External changes of environment have sometimes been adverse, sometimes favorable, differing from region to region. Statistical inaccuracies in general, but not in all regions, have been of a sort to overstate the real increase of yield. Man-made changes of environment, and changes in the wheat plant itself, have affected trends of yield favorably over the period as a whole.

But these man-made improvements in the arts of cultivation have been interrupted at times and in some regions, notably by the war but also by the abnormally low wheat prices preceding 1897 and 1933. In countries profoundly affected by war, revolution, famine, or epidemic, such catastrophes are bound to curtail supplies either of fertilizer, human labor, or animal labor, and to react more or less unfavorably upon wheat yields. If war and revolution are followed by partition of large estates, as in much of Southeastern Europe, wheat yields may suffer because the peasants fail either to understand or to be financially able to follow the superior methods of cultivation previously practiced on the estates.

Occasionally, but rarely, one encounters rough quantitative appraisals of the relative importance of various factors in enlargement of agricultural yield per acre or total output. Thus the Eltzbacher Commission in 1915 explained increases in German harvests over a long period as due 50 per cent to use of commercial fertilizers, 30 per cent to use of more prolific varieties, and 20 per cent to other factors such as better cultivation of the soil accompanying mechanization of agriculture and the struggle against plant diseases.² Nilsson-Ehle explains the increase in yield per acre of winter wheat in Sweden during the 40 years preceding 1930 as due about 50 per cent to improved varieties, 50 per cent to all other causes.³ It is clear that such appraisals cannot be more than enlightened guesses.

Numerous experimental studies, in which

the relative merits of different wheat varieties and different methods of wheat culture are appraised quantitatively, contribute little to appraisal of the relative influence of different factors on trend of yield in large regions. In passing, it is perhaps worth noting that experiments in Ohio, Missouri, and Rothamsted (England) indicate that increase in yield ranging from 79 to 105 per cent can be obtained through good crop rotation without fertiliza-

tion, as compared with yields on plots where wheat was grown continuously unfertilized; and that increase, ranging from 84 to 151 per cent, can be obtained by complete fertilization on plots where wheat is continuously cultivated. Other experimental reports concerning time and depth of plowing, time of seeding, and the like can be cited. But all these experimental data on the whole scarcely illuminate the problem here considered.

III. RISING TRENDS

In five of the fourteen wheat-producing regions, the trends of wheat yield per acre were upward—not without interruptions, but steadily enough so that trend-averages centering respectively in 1890, 1910, and 1930 rose progressively. These several rising regional trends are discussed in the following pages, with special reference to developments in component parts of each region and to internal shifts in wheat acreage. Accompanying charts show both yield per acre and acreage annually, with weighted nine-year moving averages of yield, in two to four geographical subdivisions of each region; and they also show, for comparison and contrast, weighted nine-year moving averages of yield in the region as a whole. The discussion is designed to indicate, so far as seems feasible in so complex a field, the influences that were mainly responsible for the rising trend of yield in each region.

NORTHERN EUROPE

“Northern Europe” comprises the British Isles and a part of Continental Europe bounded on the west by France, on the east by Soviet Russia, and on the south by a line running approximately through the northern slopes of the Alps and the Carpathians. It is typically a region where the average level of wheat yield per acre is relatively high—higher than in any other of the fourteen regions considered here; where wheat occupies only a small fraction of the arable acreage and crop rotations are highly developed; and where (except in the eastern portion, and in Sweden in recent years) domestic production of wheat has long been smaller than consumption re-

quirements, so that net imports are customary. It is a region in general characterized by a maritime climate, with mild winters and cool summers, described by geographers as subhumid to humid, cool, with adequate rainfall in all seasons.¹ Winter wheat greatly predominates over spring, somewhat less markedly in the cooler east and north than in the warmer west and south. The total wheat acreage was fairly stable in prewar years, declined and recovered during and after the war, and rose substantially after 1930 in response to a wave of agricultural protectionism.

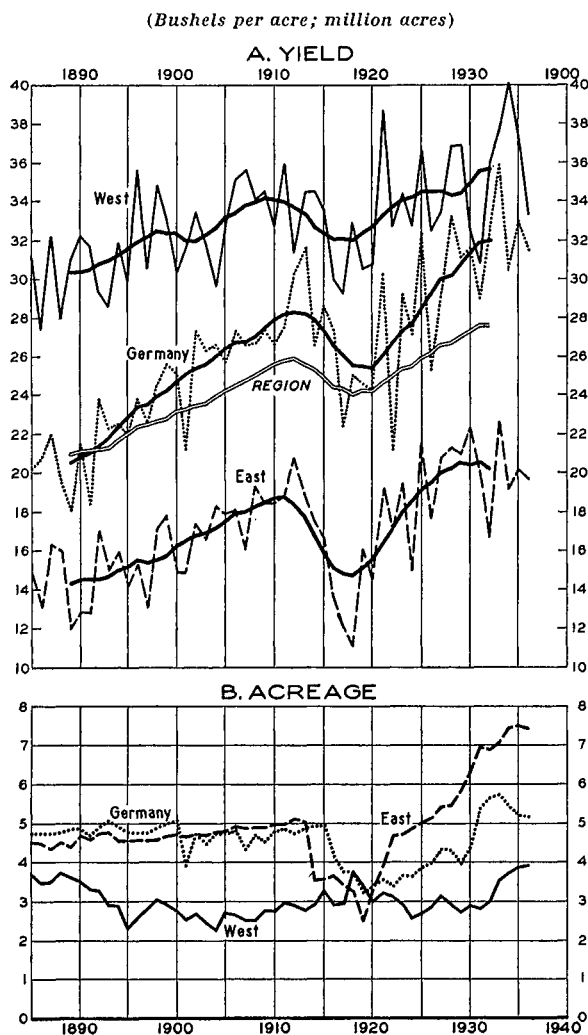
Regional wheat yields per acre have risen persistently except for a decline between 1912 and 1918–20 (Chart 3, p. 74, and the hollow line in Chart 6, p. 88). The increase from 1890 to 1910 was 4.5 bushels or 21 per cent; in an equal period of years, from 1910 to 1930, only 1.7 bushels or 7 per cent; over the whole period 1890–1930, 6.2 bushels or 29 per cent. These measurements are in terms of weighted nine-year averages centering in the years named. Statistical inaccuracies are not such as to throw much doubt upon the measured extent of increase between these particular periods, though one may question whether the war-time decline and the early postwar rise were as large as the data suggest (p. 78).

Levels and trends of yield differ in different parts of the region. We have subdivided it into three: the West, including the British Isles, Holland, Belgium, and the three Scandinavian countries; Germany; and the East, including postwar Austria, Poland, the four

¹ See maps in M. K. Bennett and H. C. Farnsworth, “World Wheat Acreage, Yields, and Climate,” *WHEAT STUDIES*, March 1937, XIII, following p. 308.

Baltic States, and Bohemia, Moravia, and Silesia in Czechoslovakia. Chart 6 shows, for each part, the trends and annual fluctuations of yield, and annual data on acreage. Since before 1885, the level of yield has been highest

CHART 6.—TRENDS OF WHEAT YIELD PER ACRE IN SUBDIVISIONS OF NORTHERN EUROPE, AND YIELD AND ACREAGE ANNUALLY, FROM 1885*



* Subdivisions defined in accompanying text. The hollow line represents trend of yield in Northern Europe as a whole, as in Chart 3.

in the western part, lowest in the eastern part, intermediate in Germany. The trend in the West moves between 30 and 36 bushels; in Germany between 20 and 32 bushels; in the East between 14 and 21 bushels.

The influence of internal geographical

shifts in wheat acreage has been to curtail increase of yield that might otherwise have occurred; for late in the period a larger proportion of the total acreage lay in relatively low-yield areas. If the proportional distribution of acreage among the three parts of the region had been the same around 1930 as it was around 1890, with yield per acre developing in the interval as it did, the regional yield around 1930 would have been about 1.2 bushels higher than it was; hence, the regional increase of yield trend from 1900 to 1930 would have been not 6.2 bushels or 29 per cent, but about 7.4 bushels or 35 per cent.¹

The sequence of favorable and unfavorable seasons, however, may have been such as to cause the regional trend of wheat yield in Northern Europe to rise somewhat more rapidly between 1890 and 1910 or between 1890 and 1930 than would have been the case with unvarying weather. Our impression is that the decade centering in 1890 contained a larger sprinkling of unusually bad years than the decades centering in 1910 and 1930; hence some small part of the recorded increase of yield may represent better weather. The decade centering in 1920 appears to have had a heavy sprinkling of bad years—1917, 1920, 1922, 1924. This may partly account for the dip in the regional trend of yield centering in 1918, though without doubt the war greatly curtailed application of labor and fertilizer and thus reduced wheat yields. We doubt if significant influence is likely to have been exerted, as Enquist suggests, by a tendency for winters in this region to become warmer up to about 1915, and then colder. In the main the sort of weather that seems to affect wheat yields in Northern Europe is not winter temperature so much as the amount and seasonal distribution of rainfall. The best years for wheat in most of the region seem to be those characterized by rainfall moderately below normal except perhaps in the spring.

In a sense, the sequence of weather and the

¹ This calculation is of course hypothetical; it assumes that trend of yield in each part of the region would have been what it actually was even if acreage did not change as it did. It is based on five-year averages of acreage centering in 1890 and 1930 and on weighted nine-year averages of yield centering in the same years.

changing geographical distribution of acreage were offsetting influences on the trend of wheat yield in Northern Europe, perhaps not far different in quantitative effect. If so, the recorded increases in yield between 1890 and 1910, 1910 and 1930, or 1890 and 1930 must be attributed mainly to improvement in agricultural technique. The forms which this improvement took were many: somewhat more effective rotations,¹ much larger applications of fertilizers, improved seed,² and better plowing, cultivation and weed control, seeding, drainage. Our impression is that enlarged use of fertilizers was probably the outstanding single favorable influence on wheat yields during the past half-century. The per-acre application of both barnyard manure (accompanying persistent rise in the livestock industry) and of commercial fertilizers (which were newer, dearer, and less well understood in the earlier years) has undoubtedly increased greatly. The major though not the full effects of improvement in crop rotations were probably achieved prior to 1885, in the transition from the medieval three-field system to modern agriculture. Relatively greater improvement of wheat yield since 1885 through better crop rotation, however, may have occurred in the eastern part of the region than in the western or in Germany.

Two subordinate questions of some interest present themselves with regard to Northern Europe: (1) why increase of wheat yield should have been so much larger in Germany than on the average in the group of adjacent countries to the west and north (the "western part" of northern Europe); and (2) why increase of yield in the region as a whole should have been so much larger between 1890 and 1910 than between 1910 and 1930.

German yields increased about 11 bushels (53 per cent) between 1890 and 1930 in terms of the averages centering in these years, whereas in the western part of Northern Europe the increase was only 4.5 bushels (15 per cent). This contrast appears in the main to reflect relative change or progress in the arts of cultivation. Presumably one important aspect of the explanation is that yields per acre in the western area in 1890 were already higher than in Germany, and hence had less

room to rise. This argument gains some support from study of yields in districts of Germany; of nine districts, the three where yields in 1890 were the *lowest* showed increases ranging from 46 to 55 per cent by 1910, while the three where yields in 1890 were the *highest* showed smaller increases, ranging from 33 to 38 per cent.³

Another credible explanation of the relatively steep increase in German yields lies in the effects of governmental policies of agricultural protectionism. In Germany, agriculture has been sheltered from overseas competition through the past half-century in substantially larger degree than in the British Isles, Holland, Belgium, or Denmark, wherein lies the bulk of the wheat acreage in the western part of Northern Europe. At least in Britain, which contains the largest wheat area, farmers may have suffered from chronic agricultural depression during so many years of the past half-century that greatly enlarged use of commercial fertilizers such as occurred in Germany could not be practiced as remuneratively as returning arable land to grass. This process may well have involved retreat of wheat to inherently inferior locations, though the facts are not clear. It is authoritatively asserted that maintenance of drainage in Britain was neglected, with unfavorable effects upon yields of wheat.⁴

¹ A common type of rotation was the "Norfolk system" (roots, winter wheat, spring grain, grass); in England during the early part of the period under review this was expanded by many farmers into the "wider shift," wherein grass occupied the land two successive years. See R. P. Stearns, "Agricultural Adaptation in England, 1875-1900, Part II," *Agricultural History*, July 1932, VI, 130-54.

² This implies improved varieties of winter wheat rather than extensive shift from spring to winter wheat. Prior to the last five years, there was probably some tendency for winter wheat to occupy an enlarging fraction of the wheat area in the eastern and northern parts of the region; but heavy protection of wheat since about 1930 has somewhat encouraged expansion of spring wheat at the expense of oats, enlarging the fraction of the wheat area devoted to spring wheat.

³ Calculated from data in H. W. Graf F. von Finckenstein, "Die Getreidewirtschaft Preussens von 1800 bis 1930," *Vierteljahrshäfte zur Konjunkturforschung*, Sonderheft 35 (Berlin, 1934), p. 58.

⁴ Sir Henry Rew ("Discussion on Mr. Vigor's Paper," *Journal of the Royal Statistical Society*, XCI, new series, 1928, Part I, 34) states: "During the past twenty

Higher initial yields of wheat and developments traceable to greater exposure to overseas competition can hardly be supposed, however, to afford more than a partial explanation of the smaller increase of wheat yield in the countries west and north of Germany than in Germany itself; other factors complicate the problem. In Holland, despite exposure to competition from abroad and a high initial level of yield, the increase of yield from 1890 to 1930 was 15.6 bushels, or 56 per cent—more than in Germany. But in Holland, where more commercial fertilizer is used per acre than in any other country, wheat is little grown and is almost a garden crop.

Not only in Northern Europe as a whole but also in each of eight separable parts, wheat yields per acre increased more rapidly in the two decades 1890–1910 than in the two decades 1910–30. It is natural to explain the relatively slow rate of increase of the later decades in terms of soil fertility lost during the war and the insufficient time to replace it in the decade 1920–30. Yet other factors probably exerted substantial influence: a gain due to better average weather in the period centering in 1910 than in the period centering in 1890 that was not repeated between the periods centering in 1910 and 1930; attainment by 1910 of a level of yield from which further gains could be obtained only with increasing difficulty; and probably in some areas a smaller increase in the per-acre application of fertilizer between 1910 and 1930 than between 1890 and 1910, or even a decline.¹

years, if not longer, drainage has been by general consent neglected in this country." Lord Bledisloe (*ibid.*, p. 37) added that ". . . there can be no question whatever that the land of this country has become in effect more and more water-logged and less well drained during the last fifty or sixty years. . . ."

¹ In Poland, artificial fertilizer used per hectare of land is said to have been 50.2 kg. in 1929 and 62.1 kg. in 1914. See V. Lésniewski and W. Ponikowski, "Polish Agriculture," in *Agricultural Systems of Middle Europe*, edited by O. S. Morgan (New York, 1933), p. 284. In Great Britain, less artificial fertilizer was used per acre of arable land in 1929 than in 1913; but in Holland, Belgium, Denmark, and Norway there was an increase. See Jean Sirol, *Les problèmes français du blé* (Paris, 1934), p. 78, and H. R. Smalley, "Recent Trends in Fertilizer Consumption in Europe," *Journal of the American Society of Agronomy*, March 1929, XXI, 271.

All told, Northern Europe seems to represent a wheat-producing region where substantial increase of yield reflects man-made improvement of the arts of cultivation much more than statistical errors or sequence of weather. Among improvements in methods of cultivation since 1885, fertilization seems to have contributed more than crop rotation, plant breeding, or minor mechanical methods.

FRANCE

Wheat plays a much more important role in France than in Northern Europe, even now occupying about a fourth of the arable area. It is the most prominent single crop in the rotation and usually holds the most favored position. Wheat is grown in practically every department of the country; but the acreage concentrates more in the west and north than in the south and east, largely in reflection of the geographical distribution of arable land. In the south and east, a larger fraction of the land is either forested and mountainous, or devoted to vines and orchards; and such land is not classified as arable. In many parts of the south and east, however, the place of wheat in the crop rotation—hence the fraction of the arable area in wheat—is even larger than in the west and north. Winter wheat occupies 95 per cent or more of the total wheat acreage almost everywhere; the spring wheat largely represents reseeded acreage damaged in winter. The climate ranges from the maritime type in the north and west to the Mediterranean type, with mild moist winters and hot dry summers, in the southeast.

Despite the prominence of wheat in French agriculture, the country is a net importer almost every year; and French farmers have long been sheltered from overseas competition by tariffs and other protective devices.

At the moment there appears to be insufficient ground for doubting the substantial accuracy of French official statistics, at least with reference to trends (see p. 79). The total wheat acreage (Chart 3, p. 74) tended to decline slowly before the war, was sharply reduced during the war, and subsequently failed by a considerable margin to rise to the immediate prewar level. Concurrently there was decline in the total arable area, in the

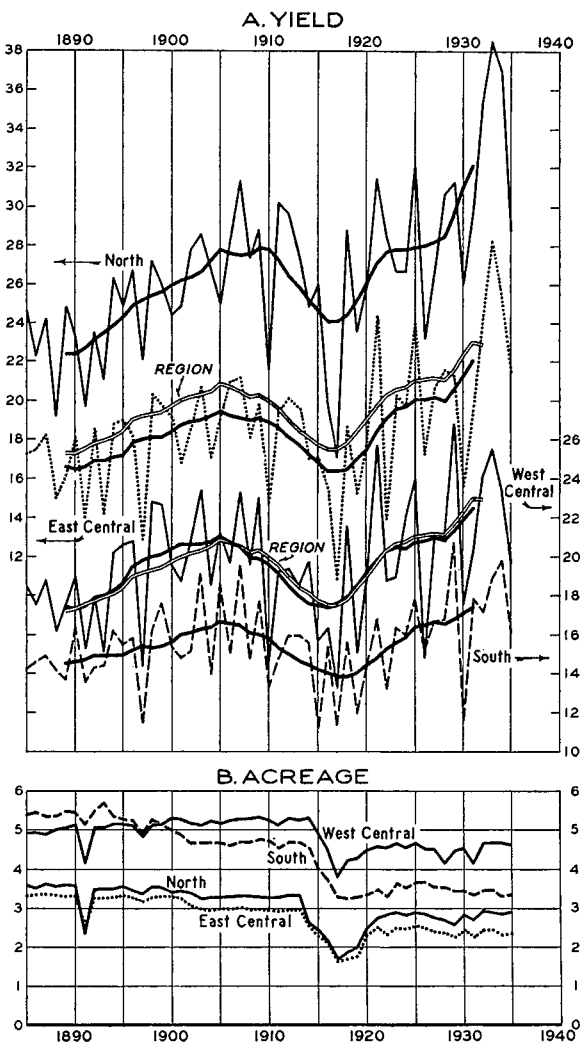
acreage devoted to other cereals as a group, and in bare fallow, with increase notably in the acreage devoted to cultivated root crops, legumes, and grasses, and to permanent meadow and pasture. These changes¹ imply heightened efficiency of crop rotations, which would be expected to benefit wheat unless in general wheat retreated to poorer land.

Between 1890 and 1930, French yields per acre increased about 5 bushels or 29 per cent. As Chart 7 shows, this national average increase was closely paralleled in two parts of the country—the west central and the east central²—where in general the levels of yield are similar and close to the national average. In northern France, however, yield increased more than in other parts (by 7.6 bushels or 34 per cent); while in southern France the increase was relatively small (2.5 bushels or 17 per cent). The substantially similar conformation of the trend of yield in the four districts—all rising to 1905, falling to 1916–18, then rising again—points to the probability of similarity of influences affecting yields throughout the country. The southern part, however, seems somewhat exceptional.

Internal geographical shifts of wheat acreage cannot significantly have affected the trend of yield in France as a whole. It is true that the proportion of the total acreage lying in the relatively low-yield districts, the south-

ern and east-central parts, has declined, but only from 51 to 45 per cent; and this shift of weighting has sufficed to elevate the national level of yield in 1930 only by about two-tenths of a bushel or 1 per cent. The internal shift

CHART 7.—TRENDS OF WHEAT YIELD PER ACRE IN SUBDIVISIONS OF FRANCE, AND YIELD AND ACREAGE ANNUALLY, FROM 1885*
(Bushels per acre; million acres)



¹ A broad impression of the significant changes can be obtained from the following data in million hectares:

Land use	1892	1910	1934
Wheat	7.2	6.5	5.4
Other cereals	7.6	7.1	5.5
Fallow	3.4	2.6	2.4
Other crops ^a	7.6	7.7	8.1
Total arable	25.8	23.9	21.4
Grassland ^b	6.2	10.1	11.3
Vines, orchards	2.7	2.8	2.1

^a Mainly hoed root crops, legumes and seeded grasses.

^b Permanent meadow and pasture, not cultivated.

The data for 1892 are calculated from *Statistique agricole de la France: Résultats généraux de l'enquête décennale de 1892* (Paris, 1897); for 1910 and 1934 from *International Yearbook of Agricultural Statistics*.

² The fourfold division of France as in Chart 7 represents a combination of eight regions specified in official statistics: *Nord* (our northern part); *Est, Est Central* (our east-central part); *Centre, Ouest* (our west-central part); and *Sudouest, Massif Central, and Midi* (our southern part).

* Subdivisions defined in accompanying text. The hollow lines represent trend of yield in France as a whole, as in Chart 3.

of acreage in France, however, was such as to strengthen the upward trend of national yield, whereas in Northern Europe the internal shift tended to weaken the rise of the regional trend.

Accidents of weather have exerted appreciable influence on the conformation of the national trend. The first decade following 1885 contained an unusually large sprinkling of bad years for wheat—1888, 1891 (when there was heavy winterkilling following a dry and very cold winter, reflected in the acreage statistics of Chart 7), and 1893—without offsetting exceptionally good years. This tended to steepen the upward slope of the prewar trend. The decade 1910–19 also contained an unusual proportion of bad years—1910 (very wet), 1915, 1916 (very wet), and 1917 (very cold winter)—with apparently only one exceptionally good year, 1918.¹ This distribution of seasons seems largely responsible for the fact that the trend of French yield, unlike that of Northern Europe (Chart 6), began to decline as early as 1905; and it was largely responsible also for the depth of the depression of yield centering in 1916–17. Shortages of labor, workstock, and fertilizer were not the only causes of the low level of French yields during and just after the war. Finally, there were three extraordinarily favorable years for wheat in 1932–34,² which contributed appreciably toward the upturn of trend from 1928 to 1931. The weather probably accounts for at least a fifth of the net increase in French yields between 1890 and 1930.

¹ See especially J. Sanson, *L'Atmosphère et l'agriculture* (Paris, 1932), pp. 104–21.

² M. Touzet, in *Le problème du blé en France* (Bordeaux, 1936), p. 37, states that the “splendides récoltes de 1932, 1933 et 1934 . . . ne sont donc que des ‘accidents’.”

³ In some districts, however, the shifts of arable acreage seem to have entrained allocation of the best land to grass. See M. Thiry, “La culture du blé dans la région de l'est de la France,” *Semaine nationale du blé* (Paris, 1923), p. 70.

⁴ French agricultural literature seems to contain only incidental discussion of the specific reasons for increase of yield. Use of fertilizer and of improved varieties are the factors most commonly mentioned, with emphasis sometimes on the one, sometimes on the other.

⁵ Sirol, *op. cit.*, pp. 77–78, gives statistics indicating per-hectare use of artificial fertilizers two or three times as large in northwestern districts of France as in southeastern districts; in France as a whole, about 60 per cent larger in 1929 than in 1913; and in 1929 lower in France (188 kg. per hectare of arable land) than in the neighboring countries, Great Britain (250 kg.), Germany (292 kg.), Denmark (310 kg.), Belgium (744 kg.), and Holland (1,591 kg.).

The major influences on increase of yield, however, must have been improvement in the arts of cultivation. More specifically, these were enlargement in the use of manure and commercial fertilizer per acre; the sowing of improved seed; more thorough cultivation of the soil; and improvement of crop rotations which in general may have involved retreat of wheat to superior land.³ Possibly the designated order suggests their relative importance.⁴ In the south, where the least improvement of yield occurred, the drier and warmer climate and the greater prevalence of subsistence farming hamper extensive use of fertilizer such as prevails in the north, where increase of yield has been most marked.⁵

If allowance is made for the effects of weather on trend of French yield, it appears that the tendency to increase was less between 1910 and 1930 than between 1890 and 1910—much as in Northern Europe. This may reflect either the general tendency for yield to increase more slowly as the level rises, even with constantly improving technique; or a special development involving lesser intensification of agriculture (especially use of fertilizer but also shortage of human labor) after 1910 than before.

ITALY

Wheat in Italy occupies over a third of the arable area, a larger fraction even than in France. Here also it is the favored crop in the rotation, but the proportion is so large that in some districts wheat follows wheat in the crop rotation, leaving inadequate room for soil-improving crops. Wheat is grown nearly everywhere by almost every farmer—on plain, hill, and mountain, and on tiny plots of terraced land and between the rows of vineyards and orchards. Practically all of the wheat is autumn-sown. Because the wheat acreage lies both in widely different latitudes, and at widely different elevations in the same latitudes, the crop is produced under widely varying climatic conditions. In general, however, the northern half of Italy is moister and cooler than the southern half, with more rainfall especially in the spring and summer. The climate thus ranges from a maritime-continental type in the north to a Mediterranean type in

the south and in the islands of Sicily and Sardinia. In most places the soils are inherently rather poor. Italy has long been a net importer of wheat, despite large domestic acreage and production.

The total wheat acreage (Chart 3, p. 74) has apparently risen slowly since 1885, with a war-time interruption and with the increase almost wholly in the south (Chart 8). In this chart, the "north" covers the northern half of the Italian Peninsula, the "south" the southern half and the islands of Sicily and Sardinia. If official statistics are taken at face value, the yield per acre of wheat in Italy as a whole increased spectacularly from 1890 to 1930, by 8.6 bushels or about 75 per cent, a percentage increase larger than occurred even in Germany. Our "corrected" statistics in Charts 3 and 8, however, evaluate the increase of Italian yield as 6.4 bushels (47 per cent); and this probably overstates the facts (p. 79). The data seem not to warrant close appraisal of trend in yield prior to about 1909, though it seems clear that moderate increase of yield, probably interrupted by several bad years in the 'nineties, characterized the period from 1885 to 1910 especially after the turn of the century.¹

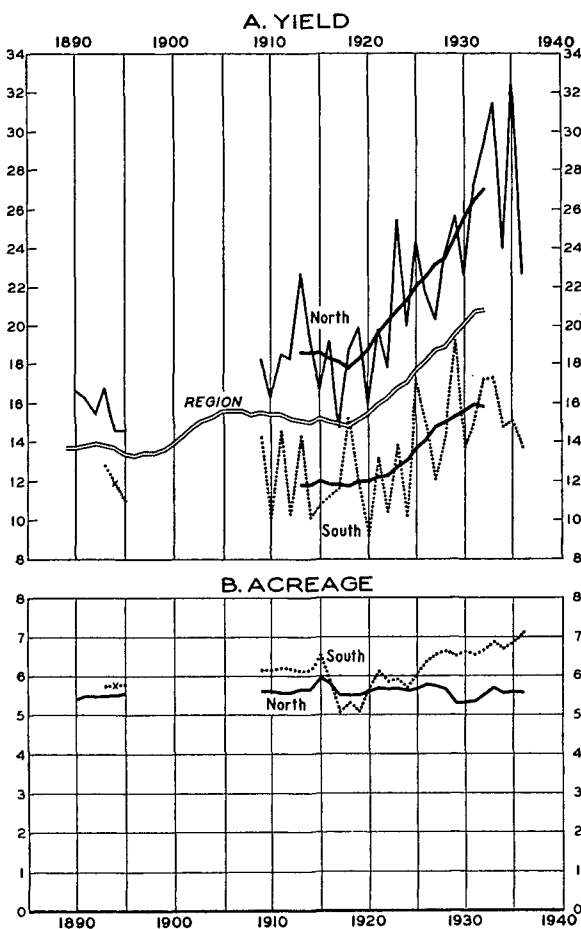
¹ For a favorable view of enhancement of Italian agricultural output before the war, see "Note sur la situation de l'Italie au point de vue des engrais, en général, et des engrais chimiques, en particulier," in Commission Scientifique Interalliée du Revêtement, *Rapport général sur les ressources et les besoins alimentaires des pays alliés. Deuxième rapport* (Rome, Décembre 1918), p. 51; for a moderately unfavorable view, see G. Valenti, "Italian Agriculture in the Last Fifty Years," International Institute of Agriculture, *Bulletin of the Bureau of Economic and Social Intelligence*, August 1912, XXII, especially p. 210. The "Note" gives estimates of Italian consumption of superphosphates (phosphatic fertilizers much outweighing all other types) as 1.5 million quintals in 1895, 5.0 million in 1905, and 10.0 million in 1913.

² J. Bossi (*Verso l'indipendenza granaria . . .*, Edito dalla Commissione Tecnica dell'Agricoltura, Intra, 1925, p. 19) gives data suggesting per-hectare use of the principal commercial fertilizers in Italy in 1913 only about half as large as in France, a third as large as in Germany. Comparative estimates of this sort in different sources, however, are difficult to reconcile one with another and give only a general impression. The livestock population per hectare of arable land was also relatively low in Italy, suggesting smaller use of barnyard manure. Bossi (p. 20) gives data indicating much larger per-hectare use of commercial fertilizer in northern than in southern Italy.

After about 1910, the trend of Italian wheat yield indicated in Chart 8 presumably represents the facts reasonably well. There was a moderate decline to 1917, occasioned partly by the war but perhaps partly also by exceptionally bad years in 1917 and 1920. The

CHART 8.—TRENDS OF WHEAT YIELD PER ACRE IN SUBDIVISIONS OF ITALY, AND YIELD AND ACREAGE ANNUALLY, SO FAR AS AVAILABLE FROM 1885*

(Bushels per acre; million acres)



* Subdivisions defined in accompanying text. The hollow line represents trend of yield in Italy as a whole, as in Chart 3.

small magnitude of this war-time depression of yield in Italy as compared with France and Germany reflects the generally smaller use of fertilizers in Italy,² so low as not to be subject to as heavy reduction; war-time curtailment of wheat acreage in the characteristically low-yield region of Italy, the south, rather than in

the heavy-yielding north; and possibly better average weather in Italy.

The net increase of Italian yield from 1910 to 1930 was about 4.7 bushels per acre, or 30 per cent. No such advance over this period can be found in any other of the fourteen wheat-producing regions of the world (see Chart 2, p. 73). It occurred in both parts of the country, but in absolute terms was much the larger in the north (Chart 8), and in percentage terms moderately larger.

There seems little reason to suppose that the succession of seasons had substantial effect on this relatively large increase of yield. Moreover, the nature of the shift in acreage— increase of the fraction lying in the low-yield south¹ and decline of the fraction lying in the high-yield north—tended to mask some of the increase. Hence the rising trend of yield reflects mainly man-made changes in the wheat plant or in its environment. No very large change has occurred in systems of crop rotation since 1910. Wheat both alone and together with other cereals occupied a larger fraction of the arable area in 1933 than in 1911, with corresponding decline in non-cereal area; but the non-cereal area showed some

¹ The addition to acreage in the south and the islands was probably mainly at the expense of hillside pasture; see C. T. Schmidt, "The Italian 'Battle of Wheat,'" *Journal of Farm Economics*, November 1936, XVIII, 650.

Yields in the north no doubt exceed those in the south partly because of the wider use of fertilizers and better cultivation; but S. Jovino asserts that purely climatic influences would keep yields 20 per cent lower in Basilicata (southern Italy) than in northern Italy, and 40 per cent lower than in northern France. See "Wheat Production in Southern Europe," International Institute of Agriculture, *International Review of the Science and Practice of Agriculture*, July-September 1924, II (new series), p. 627.

² Consumption of commercial fertilizers in Italy is said to have risen from 12 to 17 million quintals between 1910-14 and 1926-31; see G. Acerbo, *La economia dei cereali nell'Italia e nel mondo* (Milan, 1934), p. 457. The breeding of early-maturing varieties made great progress under N. Strampelli, and such varieties held great potentialities for Italy because reduction of yield from hot winds in late spring or early summer ranked as a major source of loss. It is estimated that improved varieties were sown on 46 per cent of the wheat area in 1931, 62 per cent in 1934 (with 76-93 per cent in northern Italy and 24-44 per cent in the south); see C. Longobardi, *Land-Reclamation in Italy* (London, 1936), pp. 43-44.

³ Schmidt, *op. cit.*, p. 656.

growth in the fraction devoted to hoed root crops, legumes, and cultivated grasses, and decline only in the fraction fallowed. The main specific factors that have led to increase of wheat yield seem to have been enlarged use of commercial fertilizers, introduction of improved varieties, more thorough soil preparation, and land reclamation and extension of irrigation. This may be the order of importance, though little can be said with assurance.²

Without doubt these influences were given exceptional scope by government measures exercised under the general heading "Battle of Wheat," which began in 1925. Wheat prices were artificially and differentially supported, costs of fertilizer and machinery held down, seed breeding and distribution subsidized, educational propaganda widely circulated, and land reclaimed, irrigated, and colonized. In short, wheat growing was made both remunerative and more scientific. To some extent the success of the "Battle" rested upon the relatively low initial level of yield; and it was not achieved without damage to the livestock industry and to specialized crops, or without threat to future agricultural productivity and the national standard of living.³

EASTERN NORTH AMERICA

The region designated Eastern North America (so named only for brevity) is far from homogeneous in climate. In California, wheat grows in a Mediterranean climate; in Nevada, Arizona, and Utah, in desert or semi-desert climates, largely under irrigation; in the eastern portion of North America, in a humid maritime climate ranging from cold in the north to warm in the south. The wheat acreage is not diffused throughout the region, but concentrates in four belts: southern Ontario (Canada) north of Lake Erie and western New York south of Lake Ontario; the Piedmont plateau on the eastern slopes of the Appalachian Mountains, running southwest from New Jersey to South Carolina; the western slopes of the Appalachians in central Kentucky and Tennessee; and the Great Valley of California. Very little wheat is grown in the six New England states, the southern states of South Carolina, Georgia, Alabama, Missis-

issippi, and Arkansas, and the western states of Utah, Arizona, and Nevada, although all of these are included in the region Eastern North America.

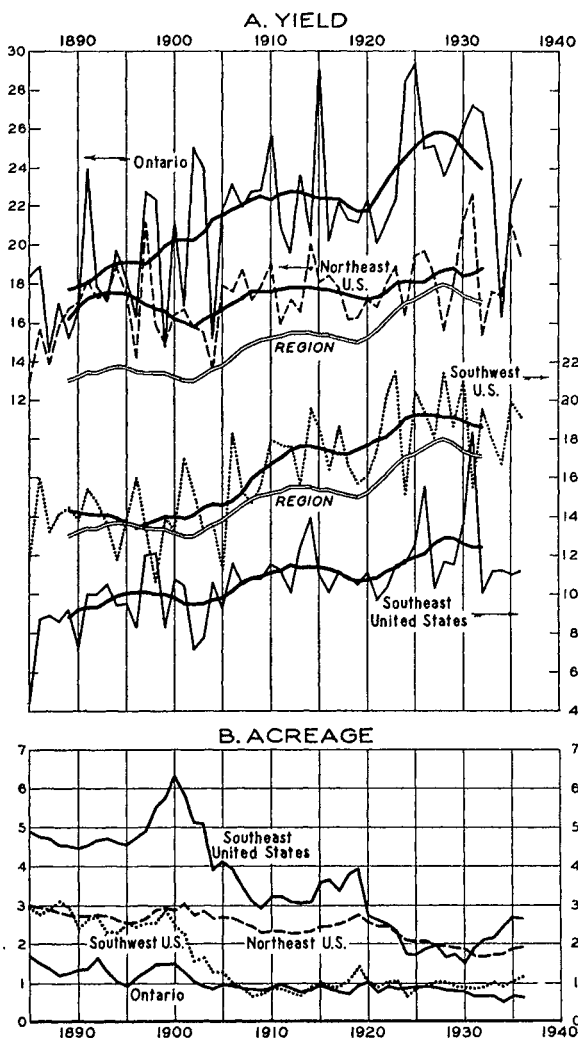
Even in the belts where the wheat acreage concentrates most heavily, wheat can hardly be said to be the major crop;¹ livestock and its products commonly are the principal sources of farm income. Fodder-producing crops occupy large areas. Winter wheat greatly predominates over spring, though there is some spring wheat, especially in Ontario. The winter wheat is mostly of the soft red type, with white wheat prominent in New York.² Crop rotations and the place of wheat in them are varied: in the north, often a root crop, corn, or perhaps beans or peas followed by winter wheat or spring-sown oats, followed by grasses for one year or several; farther south, corn or potatoes, then winter wheat or oats, then grasses; still farther south, cotton or corn or another cultivated crop, then winter wheat or oats, then grasses. Rotations in the southern belt often include legumes sown with the cultivated crop and clover sown with the wheat. There is a good deal of competition between wheat and a spring-sown grain, usually oats, for the place in the rotation following the cultivated crop, whether roots, corn, or cotton. Fallowing is rarely practiced. If much change in rotations has occurred in the past 50 years, it has probably involved wider use of legumes.

The wheat acreage in Eastern North America as a whole declined heavily — by more than half — between 1890 and 1930 (Chart 3, p. 74); no other region has shown so large a proportional reduction. As Chart 9 shows, reduction occurred in all parts³ of the region, but was greatest both absolutely and proportionally in the southeastern and southwestern

parts. In the region as a whole, wheat acreage has expanded at times in response to exceptionally favorable price influences. There was temporary expansion during the late 'nineties

CHART 9.—TRENDS OF WHEAT YIELD PER ACRE IN SUBDIVISIONS OF EASTERN NORTH AMERICA, AND YIELD AND ACREAGE ANNUALLY, FROM 1885*

(Bushels per acre; million acres)



* Subdivisions defined in accompanying text. The hollow lines represent trend of yield in Eastern North America as a whole, as in Chart 3.

¹ It was, however, a major crop in California prior to 1900.

² Wheat in California is largely of spring habit of growth and white-berried.

³ These parts are as follows: (1) Ontario alone; (2) Northeast United States, including Maine, Vermont, New York, New Jersey, Pennsylvania, Delaware, and Maryland; (3) Southeast United States, including Virginia, West Virginia, Kentucky, Tennessee, the Carolinas, Georgia, Alabama, Mississippi, and Arkansas; and (4) Southwest United States, including Utah, Arizona, Nevada, and California.

and in war-time; and another expansion, presumably temporary, has occurred since 1930 during the period of governmental intervention under the Federal Farm Board and the Agricultural Adjustment Administration.

Yield per acre in the region as a whole in-

creased by about 4.2 bushels between 1890 and 1930 (weighted averages). In absolute amount, the increase was smaller than those in Italy, Northern Europe, and France; but in percentage terms it was smaller only than in Italy, with approximate allowance for overstatement in the Italian statistics. The increase in Eastern North America, however, may also somewhat overstate the facts (see p. 77).

Within the four parts of Eastern North America, increase of yield occurred in each, but was smallest in the northeast, dominated by New York, Pennsylvania, and Maryland. As compared with the southeast and the southwest, this northeastern region had initially a higher level of yield from which further advance was perhaps more difficult; and in this area the wheat acreage was not so drastically reduced, suggesting a lesser tendency for wheat to retreat to naturally superior locations. As compared with Ontario, this northeastern area had initially a lower yield and its acreage declined in much the same proportion, which would suggest scope for greater increase of yield; but in Ontario, and not in the American northeast, there has been a strong tendency for the wheat acreage to consist more and more of higher-yielding winter wheat, less and less of lower-yielding spring wheat.¹ But it seems hardly feasible to trace the relative effects of different yield influences in each of the four parts of Eastern North America.

In the region as a whole, there seems little reason to suppose that the distribution of favorable and unfavorable seasons appreciably affected the increase in average yield between the particular periods centering in 1890 and 1930. Depressions of yield centering in 1902 and 1919, however, may reflect an unusually heavy sprinkling of bad years for wheat around those dates;² and the bulge centering in 1928 may reflect an unusually heavy sprinkling of exceptionally good years. No single year can be singled out as one exceptionally good or bad in all four parts of the region, as would be expected because of the wide geographical spread of Eastern North America.

Internal geographical shifts of acreage have

tended to strengthen the rising trend of regional yield. In 1930, the proportion of the regional acreage lying in the lowest-yielding part (southeastern United States) was smaller than it had been in 1890, while the proportion lying in the higher-yielding parts was larger. At the proportional distribution of regional acreage in 1890, the regional average yield in 1930 might have been about half a bushel less than it was in fact. Perhaps 10–15 per cent of the regional increase in yield from 1890 to 1930 rests on change in internal distribution of acreage. In this respect, Eastern North America resembles France and differs from Northern Europe and Italy.

The remainder of this increase—so far as it does not represent some slight statistical overstatement—must be due to a wide range of influences. One of these was presumably a tendency for wheat to retreat to better land as agriculture underwent contraction.³ Another, special to Ontario, was shift from spring to winter wheat. Another, special to the southwest, was increase in the proportion of the

¹ In 1890, spring wheat in Ontario constituted about 45 per cent of the total wheat acreage, in 1930 only about 12 per cent; winter-wheat yields exceeded spring by about 5 bushels per acre around 1890, and by about 7 bushels around 1930.

² We are inclined to assign more weight to the influence of weather than to temporary bulges of wheat acreage that may have involved some disturbance of crop rotations or expansion of wheat to inferior locations, with unfavorable effect on yields.

³ In all of the principal wheat-producing states of the region, except California, there was less land in farms in 1930 than in 1890—about 20 per cent less in five northeastern states and 13 per cent less in five southeastern states. Presumably—although official data are not compiled in such a way as to permit verification—there was decline of arable land as well. We are unable to compute ratios of wheat acreage to arable acreage over the period, but infer a decline in the proportion of arable land devoted to wheat. Wheat probably fell entirely out of the rotation on many farms and in some areas, and lost importance in the rotation on some farms and in some areas where it remained. The general process seems likely to have involved retirement of wheat to superior locations. But in southeastern Pennsylvania, wheat acreage and the place of wheat in the rotation seem to have been maintained, while yields have increased more than yields for the state as a whole. See G. F. Johnson, *Agriculture in Pennsylvania, A Study of Trends, County and State, since 1840* (Pennsylvania Dept. Agr. Bull. 15, Nov. 1, 1929), pp. 13–16; and E. Rauchenstein and F. P. Weaver, *Types of Farming in Pennsylvania* (Pennsylvania Agr. Exp. Sta. Bull. 305, April 1934), pp. 17–19.

wheat acreage produced under irrigation at relatively high yields per acre;¹ here, rotation of crops tended to supplant extensive methods of production, and dry-farming methods improved. Another, prominent mainly in the southeast, may have been change in date of sowing that minimized damage from the Hessian fly. Knowledge of the appropriate date has become more secure in the course of half a century. Beyond question, adoption of new varieties must have been an important factor in enhancing yields; the pace at which changes have occurred is illustrated by the fact that three varieties unknown before 1905 (Leap, Forward, and Nittany) occupied by 1929 roughly a third of the total wheat acreage in the parts of Eastern North America here designated Northeast and Southeast.² The use of commercial fertilizer in the United States is mainly confined to the states of this region, especially the cotton-growing South, and has expanded greatly while arable acre-

¹ In 1890, when about 95 per cent of the wheat acreage in the four southwestern states lay in California, it seems fairly certain that over three-fourths of the regional acreage was not irrigated. In 1930, when barely 75 per cent of the acreage lay in California (and there a substantial fraction was irrigated), it is possible that as much as half of the southwestern acreage was irrigated.

² Acreage estimates of varieties from J. A. Clark and B. B. Bayles, *Classification of Wheat Varieties Grown in the United States* (U.S. Dept. Agr. Tech. Bull. 459, April 1935), pp. 57, 60.

³ In illustration of rising trend of commercial fertilizer use per acre, see H. B. Weiss, "Field Crop Yields in New Jersey from 1876 to 1919," *Scientific Monthly*, October 1921, XIII, especially p. 348. The large increase there shown, however, was in market-garden areas rather than wheat areas. The use of commercial fertilizer per hectare of *harvested land* in Pennsylvania and Maryland, where the wheat acreage is relatively denser than in most parts of Eastern North America, was in 1929 about 144 kg., in contrast with 188 kg. per hectare of *arable land* in France; for the American data see R. O. E. Davis, "The Geographical Consumption of Fertilizers," *American Fertilizer*, Dec. 20, 1930, p. 2. The increase of per-acre use of fertilizer between 1913 and 1929 in the states named is here estimated as about 40 per cent.

⁴ W. B. Kemp and J. E. Metzger, *Environmental Factors Influencing Wheat Production in Maryland* (Maryland Agr. Exp. Sta. Bull. 297, July 1928), p. 173. This ingenious study suggests that, prior to about 1908, wet and cloudy weather in late spring was favorable to wheat yields per acre; but with spread of *Septoria*, which attacks wheat in such weather, dry and sunny weather in late spring became a favorable influence on yields.

age declined. The favorable effects of this factor upon trend of yield seem important, though probably less so since 1920 than before.³ There is a presumption that more barnyard manure has been used per acre with the passage of time; and that crop rotations have been improved especially through larger use of legumes, especially clover and alfalfa. Improvement of minor mechanical methods may have contributed to increase of yield; but this factor probably was less important than in Europe because American farmers have had to be more economical in use of labor.

From this complexity of favorable influences upon yield it seems impossible to find a secure basis for selecting the most important. Our impression is that (aside from possible statistical bias) stress ought to fall upon internal shift of acreage, retreat of wheat to superior land, improvement of varieties, improvement of rotations, and enlarged per-acre use of commercial and barnyard fertilizer. The net increase of yield in the northeastern part of Eastern North America since 1890 has perhaps been achieved in spite of the advent and spread of a rather serious plant disease (*Septoria nodorum*, Berk., or black scab). This disease "appeared in the neighborhood of Washington, D.C., about a half century ago; has slowly spread along the Atlantic seaboard; and has finally crossed the Allegheny Mountains into the Mississippi valley."⁴

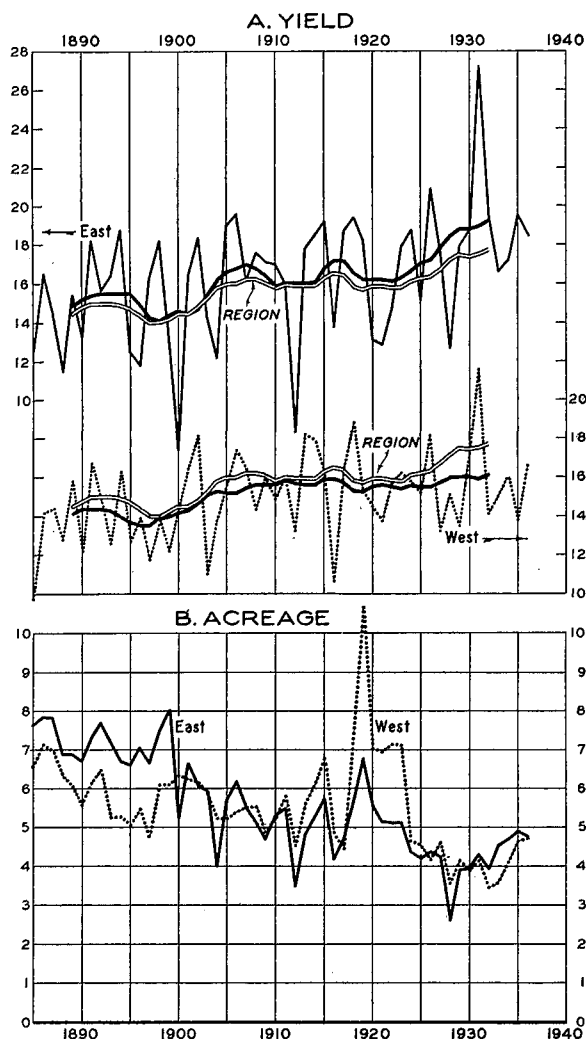
UNITED STATES SOFT WINTER

Wheat is on the average a more important crop in the United States Soft Winter region, especially in its southern reaches, than in Eastern North America. This region includes the states of Ohio, Indiana, and Michigan (designated the East in Chart 10, p. 98), and Wisconsin, Illinois, Iowa, and Missouri (the West). The region is moderately homogeneous as to climate—intermediate between the maritime and continental types; mainly humid and cool, ranging to subhumid and cool in the northwest and to humid and warm in the southwest; the annual rainfall ranges from 25 to 45 inches, diminishing from east to west and from south to north. There is no occasion for irrigation, little for fallow, some for drainage. The land is mostly gently roll-

ing or flat, originally forest-covered except for natural prairie, Illinois, Iowa, and northern Missouri. For half a century a very large proportion of the land has been in farms except in the wooded northern stretches of Wisconsin and Michigan.

CHART 10.—TRENDS OF WHEAT YIELD PER ACRE IN SUBDIVISIONS OF THE UNITED STATES SOFT WINTER REGION, AND YIELD AND ACREAGE ANNUALLY, FROM 1885*

(Bushels per acre; million acres)



* Subdivisions defined in accompanying text. The hollow lines represent trend of yield in the United States Soft Winter region as a whole, as in Chart 3.

There was moderate or substantial increase of land in farms between 1890 and 1910 in each of the seven states; but a persistent de-

cline began in Ohio, Indiana, Illinois, and Iowa between 1900 and 1910, and there was decline in Michigan, Wisconsin, and Missouri as well between 1920 and 1930. Total land in farms in 1930 was about the same as in 1890 in the three eastern states, but about 7 per cent larger in the four western states. Thus agriculture in the region as a whole has not shown the degree of general contraction characteristic of states to the east and south.

The great bulk of the wheat acreage has always been devoted to soft red winter wheat, though soft white winter is grown in Michigan and some hard red winter and hard spring is scattered especially through the four western states. Winterkilling is a serious hazard for wheat throughout the region; this accounts largely for the relatively wide and erratic fluctuations of harvested acreage (Chart 3, p. 74, and Chart 10). At least in the eastern part, the best years for wheat seem to be characterized by abnormally low rainfall, with the deficiency trifling in August–November, as large as 25–30 per cent in December–March, and about 15 per cent in April–July.¹ Other factors than rainfall, however, may be important. Sown acreage is likely to respond to relatively favorable wheat prices, because winter wheat can easily be substituted for spring-sown oats or corn in the customary rotations. There was a great increase of sown wheat acreage in this region, particularly the western part, in 1917 to 1919, reaching an extraordinary peak in 1919.

Practically everywhere throughout the region corn is grown wherever wheat is grown, and in some parts in the absence of wheat.

¹ Yields per acre in the states of Ohio, Michigan, and Indiana were best (highest in relation to general trend) in 1894, 1906, 1926, and 1931—averaging 21.6 bushels as compared with average trend ordinates of 17.1 bushels, an excess of about 25 per cent. The following tabulation shows normal rainfall and average rainfall for the four years of best crops in Ohio in inches:

Period	Normal	Best years	Deficiency
Aug.–Nov.	11.81	11.54	–0.27
Dec.–Mar.	11.99	8.53	–3.46
Apr.–July	14.79	12.74	–2.05
Aug.–July	38.59	32.81	–5.78

Rainfall data from C. A. Patton, *Some Observations on Forty-six Years of Ohio Weather* (Ohio Agr. Exp. Sta. Bull. 544, December 1934), pp. 15–16.

Common rotations are corn, corn, oats, hay (often leguminous types); corn, corn, winter wheat, hay; corn, oats, winter wheat, hay; or corn, oats or winter wheat, hay one or two years. In places, beans or soybeans, potatoes, or sugar beets may occupy the place of corn, while barley may occupy the place of oats or winter wheat. Such rotations, involving heavy production of fodder crops, imply a highly developed livestock industry, including dairying. Wheat is in general vulnerable to encroachment from corn, oats, and hay. Long-term tendencies seem to have involved approximate maintenance of land in farms, and increase in the fraction in permanent pasture with decline in the arable fraction. On arable land, there has apparently been expansion of the fraction devoted to corn, aided by development of early-maturing varieties; expansion of the fraction in hay, particularly of the leguminous types; maintenance or expansion of the fraction in oats; and contraction of the fraction devoted to wheat. The extent to which oats has held position while wheat has declined seems remarkable because of the great decline of the horse population which feeds largely on oats. Apparently spring-sown oats is a better alternative than fall-sown wheat in areas where corn predominates; the use of oats gives the farmer time to clear his field of corn (even by "hogging down") and to prepare a good seed bed in the spring for the oats, whereas the wheat must be sown hurriedly in the fall in the narrow space of time between corn harvest and onset of frosts. Perhaps the risk of winterkilling has also been disadvantageous to wheat.¹

The long-term tendencies imply enlargement of the livestock population per acre of arable land during the past half a century, and therefore of the supply and use of barnyard manure. Commercial fertilizers are of no significance in the western part of the region, but are used in moderate quantity in the eastern part.²

The average yield per acre of wheat in the Soft Winter region as a whole rose by about 2.6 bushels (18 per cent) between 1890 and 1930—less than in any of the four wheat-producing regions thus far considered.

Part of this may represent distribution of

favorable and unfavorable seasons. The weighted nine-year average of yield centering in 1890, so far as we can judge, does not reflect an unusual distribution of seasons; but that for 1930 may have been raised by the occurrence of an extraordinarily favorable season (1931) in the midst of a nine-year period (1926–34) otherwise to be described as containing about the usual scatter of good and bad years.³ The corresponding average centering in 1930, actually 17.4 bushels, would have been only 16.5 bushels if one substitutes for the altogether extraordinary yield of 1931 (24.5 bushels) a yield of 18 bushels, which itself would be one of the seven highest recorded in 52 years. Possibly a fifth to a third of the increase in yield between 1890 and 1930 represents accident of weather. The occurrence of this extraordinary year, which was more strikingly favorable in the eastern than in the western part of the region, helps also to explain why the trend increase of yield was greater in the east than in the west (Chart

¹ Publications tending to support the substance of this paragraph are E. B. Hill, E. T. Riddell, and F. F. Elliott, *Types of Farming in Michigan* (Michigan Agr. Exp. Sta. Spec. Bull. 206, December 1930); E. B. Hurd, *Cropping Systems in Iowa, Past and Present* (Iowa Agr. Exp. Sta. Bull. 268, April 1930); H. C. M. Case and K. H. Myers, *Types of Farming in Illinois* (Illinois Agr. Exp. Sta. Bull. 403, June 1934); E. C. Young and F. F. Elliott, *Types of Farming in Indiana* (Indiana Agr. Exp. Sta. Bull. 342, June 1930); and C. A. Helm and L. J. Stadler, *Productive Methods for Wheat in Missouri* (Missouri Agr. Exp. Sta. Bull. 188, July 1921).

² Average use of commercial fertilizer per acre of crop land has been estimated as only 5 pounds in the western part of the region; but in the eastern part as 47 pounds in 1913 and 82 pounds in 1928. By contrast, consumption in Italy (not a large consumer) per acre of arable land in 1928 was roughly 40 per cent larger. See R. O. E. Davis, "The Geographical Consumption of Fertilizers," *American Fertilizer*, Dec. 20, 1930, pp. 1–6, and "Plant-Food Consumption by Countries, 1928," *Fertilizer Review*, August 1930, V, 5. In R. M. Salter, "Fertilizer Usage in Ohio from 1920 to 1934" (Ohio Agr. Exp. Sta., *Bimonthly Bulletin*, March–April 1935, XX, 75), it is stated that commercial fertilizer first began to be used in Ohio (now the heaviest per-acre consumer of the seven states of the soft winter wheat region) about 50 years ago; and that the fertilizer sold in the fall—about half of the yearly total—is used on wheat.

³ Unprecedented drought in the eastern part of the region in 1930 may have benefited rather than injured wheat, though it was adverse to "composite" yields of crops generally. See J. C. Hoyt, *Droughts of 1930–34* (U.S. Dept. of the Interior, Geological Survey, Water Supply Paper 680, 1936), p. 33.

10). Depressions of yield centering about in 1897-98, 1912, and 1919-23 probably reflect weather conditions in the main, though bulges in acreage around the first and last dates may have exerted a minor adverse influence. A bulge of yield centering in 1916, and most prominent in the eastern part, seems to reflect an exceptional sprinkling of good years.¹

Internal geographical shifts of acreage were of two sorts. The proportion of the acreage lying in the humid and relatively high-yielding eastern part declined a little between 1890 and 1930, as is suggested by Chart 10; the ratio fell from 51 to 49 per cent. If the region is differently divided, it appears that the proportion of the acreage lying in the cooler states (Iowa, Wisconsin, Michigan, and Ohio), where also yields average higher than in the warmer states, declined from 54 to 37 per cent. These geographical shifts of acreage tend to mask increase of yield that might otherwise have occurred; but their effect seems not to be large, because levels of yield have remained so similar throughout the region as a whole. The effect of acreage shift on trend of yield was in the opposite direction here from what it was in Eastern North America and France, and in the same direction as in Northern Europe and Italy.

A substantial degree of adoption of new varieties during the past half-century is suggested by the fact that five varieties unknown before 1908 (Fulhio, Trumbull, Michikof, Iobred, and Red Rock) occupied in 1929 about 1.7 million acres, roughly a fifth of the regional total.

The rise in the trend of wheat yield in the United States Soft Winter region between 1890 and 1930 seems to represent in the main, and aside from statistical inaccuracies, (a) accident of weather in the late period; (b) larger per-acre use of farmyard manure; and (c) adoption of improved varieties. It is difficult to appraise the effects of change in crop rotations—the enlarged place of soil-improving legumes as against the enlarged place of

the soil-depleting crop, corn. We find difficulty in supposing that there was much benefit from retreat of wheat to superior locations, in spite of relative expansion of pasture land and contraction of arable; or that wheat yields can have benefited much from better mechanical methods of cultivation, including the greater cleanliness of fields that probably followed decline of winter wheat in the crop rotations; or from installation of drainage.

SUMMARY

The following tabulation summarizes the changes in yield per acre in the five regions discussed above, in terms of trend averages centering in 1890 and 1930.

Region	1890	1930	Increase	
			Bush-els	Percent-age
Northern Europe ..	21.1	27.3	6.2	29
France	17.3	22.3	5.0	29
Italy	13.7	20.1	6.4	47
East. N. America ..	13.2	17.4	4.2	32
U.S. Soft Winter...	14.8	17.4	2.6	18

The supplementary tabulation below indicates which of the six groups of influences (see p. 76) that may affect trend of yield per acre appear actually to have underlain the changes of yield indicated above. In this tabulation, the zero indicates no probable effect on yield in either direction; the plus sign a probable favorable effect; the negative sign a probable unfavorable effect; and the question mark uncertainty of effect.

Region	Sta-tis-tics	Acre-age shift	Ini-tial level	Weath-er	Envi-ron-ment	Plant
Northern Europe.	0?	—	—	+	+	+
France	0?	+	?	+	+	+
Italy	+	—	+	0?	+	+
East. N. America .	+?	+	?	0	+	+
U.S. Soft Winter..	+?	—	?	+	+	+

Two general classes of influence exerted favorable effects upon trend of wheat yield in all five regions: change in the environment of the plant due to man, and change in the wheat plant due to man. The changes in environment were of diverse types, discussed further below; and the changes in the wheat plant itself were mainly changes in varieties grown, with change of type (shift from spring

¹ C. A. Lamb, *The Trend of Wheat Production in Ohio* (Ohio Agr. Exp. Sta. Bull. 507, August 1932), p. 19, characterizes the years 1913, 1914, 1917, 1918, and 1919 as "very favorable seasons" in Ohio.

² Clark and Bayles, *op. cit.*, pp. 61, 62, 67, 122.

to winter) more or less prominent only in one district of Eastern North America and possibly in some districts of Northern Europe.

The distribution of good and bad seasons seems not to have been such as to affect the trend of yield adversely in any of the five regions; it was presumably a favorable influence in three (an important one in the United States Soft Winter region and France) and a negligible influence in two. Initial level of yield may be regarded as a subsidiary or conditioning influence, affecting the amount of change that results from other influences, but not tending directly to induce change. The initial level, probably nowhere very important, seems significant chiefly in explaining why Italian yields rose so much more in percentage terms than yields in Northern Europe. Internal shifts of wheat acreage were adverse to wheat yields in three regions, favorable in two. Statistical inaccuracies seem nowhere to have *understated* trend increase of yield, but to have *overstated* it in Italy and perhaps in two North American regions also.

All told, the principal factor adverse to increase of yield per acre in these regions was proportional shift of wheat acreage from high-yielding to low-yielding districts; but in two regions—France and Eastern North America—the shifting was favorable to yield. Disregarding initial level of yield as subsidiary, one can say that all developments other than shift in acreage, whether accidental or within the control of farmers, were either neutral or favorable to advance of yield. Accidental factors—statistical inaccuracies and weather in combination—exerted substantial influence and must account for an appreciable part of the recorded increase of yield in each region. If it were possible to correct the data for these “accidental” influences, none of the five trends of yield would incline upward to the full extent indicated in Charts 2 and 3. The available statistics give an exaggerated impression of success in the perennial battle between depletion of soil fertility and progress in the arts of cultivation, but there is no ground for doubt that in these regions in which yields increased, progress in the arts of cultivation may be credited with most though not all of the increase in yield.

The following tabulation summarizes our impressions of the effects of diverse aspects of man-made changes in the environment of the wheat plant upon regional trends of yield.

Region	Dis- ease con- trol	Im- proved rota- tions	Ma- nure	Com- mercial ferti- lizers	Me- chanical meth- ods	Wa- ter con- trol
Northern Europe.	+?	+	+	+	+	+?
France	+?	+	+	+	+	+?
Italy	+?	0?	-	+	+	+
East. N. America .	-?	+	+	+	+	+
U.S. Soft Winter..	+?	0?	+	0?	+	+?

On the elusive subject of plant pests and diseases, there is presumption of gradual conquest of known adversities overweighing advent and spread of new adversities, except perhaps in Eastern North America. Crop rotations seem to have improved generally, or at least not to have deteriorated; the more doubtful cases are Italy and the United States Soft Winter region. Mechanical methods of soil preparation and control of water supply have probably improved more or less everywhere, with Italy perhaps the most conspicuous illustration.

It is in Italy that the most striking increase of yield occurred between 1910 and 1930, and in northern Italy if comparisons are extended from the large regions to subdivisions of regions. Yield in northern Italy increased from around 18.4 bushels (the figure is a little uncertain) in 1910 to about 25.1 bushels in 1930, an increase of just over 35 per cent in 20 years. No such increase can be found elsewhere in the world except in Japan, where the increase was from 19.7 to 26.7 bushels—again about 35 per cent.¹ These large increases seem not to rest either on statistical inaccuracies, weather, or internal shifts of acreage; and they were made from initial levels of yield already rather high. They therefore represent gains that have been achieved by intensification of agriculture; and this in the form not of improved crop rotations, but of progressively enlarged use of fertilizer and of labor in tilling the soil, by discovery and adoption of im-

¹ Over the period 1890 to 1930, Japanese average wheat yields increased more than in any other part of the world of which we have a statistical record—by around 80 per cent.

proved varieties, and by land amelioration through drainage and irrigation (probably a minor factor). In both places governmental policies of protectionism have played an im-

portant role, especially in the recent decade. Even these large gains are much smaller than those obtained under experimental conditions (p. 87).

(Part II of this study will appear in March 1938)