7 Variability in Wheat Yields in England: Analysis and Future Prospects

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This chapter presents data on variation in wheat yields in England and offers an assessment of the variation likely to be encountered in the future, given continued high levels of inputs. How yield stability might be modified by breeding and how the records from the U.K. may be helpful when considering likely changes in yields and their variability are discussed by Arnold and Austin (ch. 10).

The Partitioning of Variation

If the yields of wheat from a large number of individual fields are recorded over a period of years, variation can be partitioned into a number of different categories. In practice, complete sets of data that can be used to calculate the components of the total variation in yield are rarely available, and the best that can be done is to estimate the components from separate sets. A difficulty in making comparisons of variability is that mean yields can vary among different data sets, and the standard deviations are not independent of the means. Expressed as proportions of yield, that is, as coefficients of variation (cvs), they seem to be more constant for a given source of variation than the standard deviations themselves and so can conveniently be used for comparisons. Associations between means and their standard deviations are common in biology but the relationships are variable. Examples for animal populations are given by Taylor (1961).

Historical Trends in Wheat Yields and Their Variability

Records of wheat yields between 1200 and 1970 have been assembled by Stanhill (1976). Using these and more recent data, typical yields for the period from 1200 to 1980, together with the associated changes in agricultural practice, are summarized in table 7.1. Over the centuries, yield has

TABLE 7.1 Historical trends in English wheat yields

Period	Yield (t/ha)	New Features in Agriculture
1200	0.3-0.5	Open field system
1650	0.6	Enclosure, fallowing
1750	1.0	Seed drills
1850	1.8	Four course rotation
1920	2.1	Fertilizers, new varieties
1950	2.5	More fertilizers, herbicides
1980	6.5	More N fertilizer, short-straw varieties, fungicides

TABLE 7.2 Interannual variation in English wheat yields

Period	Average Yield (t/ha)	Standard Deviation of Yield (t/ha)	Coefficient of Variation
1832-59[a]	2.08	0.276	0.133
1880-1917[b]	2.12	0.179	0.084
1918-45[c]	2.25	0.167	0.074
1948-84[c]	4.18	0.492	0.118
1961-83	4.59	0.330[e]	0.072[e]

[a]Healy and Jones (1962).
[b]*Century of Agricultural Statistics* (1968).
[c]Ministry of Agriculture, Fisheries, and Food (1964-84).
[d]Time trends, where significant, removed by linear regression.
[e]For 1961-83, quadratic trend with time removed.

increased by 10-20-fold. Average yields of grain crops in semi-arid areas of the world today are similar to those obtained in England during the period from 1200 to 1850. Does the available evidence from England suggest that the variability of yield has changed over the centuries? Table 7.2 shows some results for national yields over a period when yields increased from an average of about two tons per hectare to over four tons per hectare. The results for 1832-59 are not strictly comparable with the remaining data because they include too great a proportion of fields outside the main cereal-growing area in England. Furthermore, yields were estimated from small samples. For the last ten years of the period 1948-1985, yields increased more rapidly than during the earlier period, and the trend in yield from 1948 was better fitted by a second degree polynomial in time. This reduced the cv of national yield from 0.118 (linear trend) to 0.101 (second degree polynomial), or to 0.088 when the data for the abnormally dry year of 1976 were excluded. Taking account of these features, no striking change in the interannual cv of yield is evident, though as the mean yield has increased substantially, the interannual variation in absolute terms has increased.

A more detailed examination of the interannual variation during the period 1948-85 was made by plotting the absolute values of the deviations of actual from fitted yields, expressed as a proportion of the fitted yields, against years.

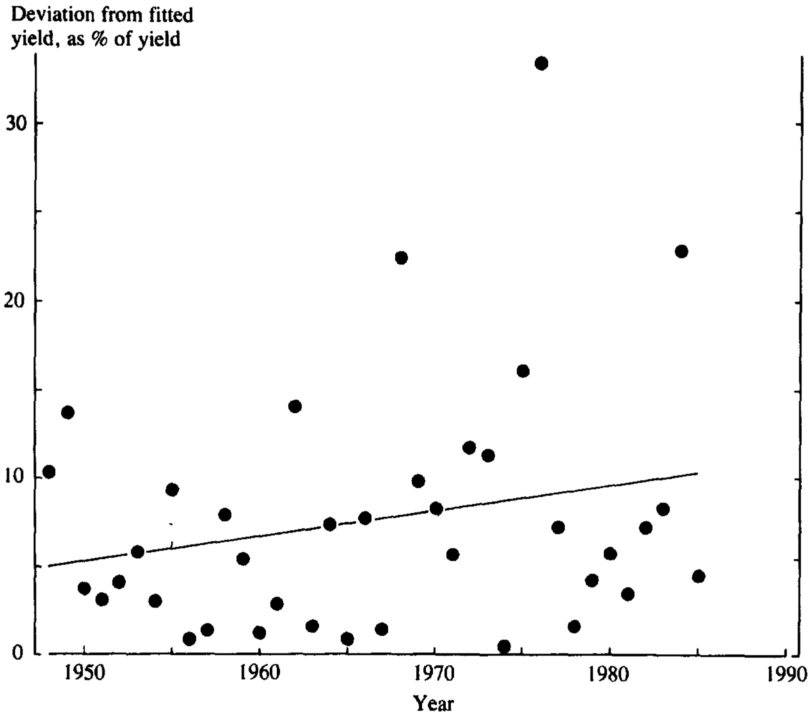
The ordinate in figure 7.1 is a detrended coefficient of variation of yield (linear trend removed). Linear regression analysis of the 38 years' data showed that the cv had not increased significantly over the period. When the data for the abnormally dry year of 1976 were omitted, the regression was likewise not significant. Even if the analysis had indicated a significant trend, it would be impossible with these data alone to attribute the trend to any cause, for example, to a change in the variability of weather elements affecting yield, to differences in the varieties grown, or to altered management practices. As noted above, conclusions about trends in variability can be quite sensitive to an abnormally low yield and to the degree of polynomial used to eliminate the time trend. Furthermore, when calculations were done for the years 1961-83 (the period usually considered by Hazell and his colleagues, e.g., ch. 2), the large sampling errors of the variances were further emphasized. Thus, after fitting a second degree polynomial in time to the data for 1961-83, the interannual cv of yield was 0.072 (compared with 0.101 for the entire period). Taking all the available data from 1930-85, it would seem unwise to conclude that the cv of yield has shown any real trend with years.

Considering the period 1961-83, the best estimate of the cv of English wheat yields (0.072) is similar to the averaged values for the two periods 1961-71 and 1972-83 studied by Hazell (1985b) for several other countries (India 0.082, France 0.082, Mexico 0.089, and the Federal Republic of Germany 0.074). In other countries where wheat is grown in more variable environments and usually without irrigation, the cvs derived from Hazell's data in the same way are markedly greater (e.g., U.S.S.R. 0.149, Canada 0.137, Argentina 0.136 and Australia 0.187) (ch. 2).

Interannual Variation in Yield at Particular Sites

Because national yields are averages of those of a large number of individual fields, it may be expected that they will be much less variable from year to year than those from individual fields, which are subject to the effects of variable management, rotations, and weather. Table 7.3 shows that interannual variation in yield at particular sites is indeed greater than

FIGURE 7.1 U.K. wheat yields, 1948–1984



NOTES: Deviations from fitted yields, expressed as percentages of fitted yields, plotted against years. Fitted yields computed by linear regression of yield on years.

that in national yield. In general, as yields increase the standard deviation of yield also increases, but as a percentage of yield, it generally decreases. While the reasons for these trends in variability cannot be analyzed rigorously, some factors likely to be important are: winter rainfall, weeds, diseases, summer drought, and the weather at harvest time.

For the earliest records, all these factors are likely to have affected yield, and it is not surprising that the greatest variability was observed during these periods. For the Rothamsted data for 1852 to 1918, yields were somewhat less variable, especially on the plots that received mineral fertilizers or farmyard manure. However, winter rainfall caused considerable, but variable, leaching of soil nitrogen, originating from both farmyard manure and autumn-applied fertilizer. Also, weed infestations caused yield losses that varied with seasons. After 1950, the use of herbicides greatly reduced weed infestations thus reducing the variation in yield that they

TABLE 7.3 Interannual variation in wheat yields at individual sites in the United Kingdom

Site	Period	Average Yield (t/ha)	Standard[f] Deviation (t/ha)	Coefficient of Variation
Downton[a]	1225-1349	0.412	0.126	0.306
West Wycombe[a]	1211-1349	0.504	0.167	0.331
Broadbalk experiment, Rothamsted[b,c]				
1. Farmyard manure only (Plot 20)	1852-1918	2.43	0.406	0.167
2. Inorganic fertilizers (Plot 8)	1852-1918	2.51	0.513	0.204
3. No farmyard manure or fertilizer (Plots 3 & 4)	1852-1918	0.86	0.215	0.249
1. Farmyard manure only	1970-78	5.87	1.061	0.180
2. Complete inorganic fertilizer (N at 144 kg/ha)	1970-78	5.09	0.507	0.098
3. No farmyard manure or fertilizer	1970-78	1.70	0.286	0.168
Rothamsted[d] ley-arable experiment	1952-71	6.20	0.682	0.110
National Institute of Agricultural Botany[e]	1967-78	5.60	1.008	0.180

[a]Titow (1972).
[b]Fisher (1921).
[c]Dyke et al. (1983).
[d]McEwan (private communication).
[e]Talbot (1984).
[f]Linear trend removed, if significant.

caused. In well-fertilized plots, particularly where most of the nitrogen was applied in the spring, winter leaching of nitrogen as a source of yield variation was greatly reduced. The remaining uncontrolled factors causing variation in yield were the direct effects of weather on crop growth (e.g., severe winters, summer drought), the indirect effects (e.g., delayed sowing, poor weather during harvesting), and the effects of diseases. In recent years, cultivation systems have been developed which facilitate early sowing, and diseases are controlled by a combination of improved genetic resistance and the use of fungicides. It may be expected, therefore, that the interannual variation of yields on individual sites will decrease in the future, and may level out to about 0.1 times the mean yield. It seems very unlikely that it would ever be lower than the interannual cv of national average yields.

TABLE 7.4 Variation in wheat yields from field to field in the United Kingdom

Source of Data	Mean Yield Deviation (t/ha)	Standard Deviation (t/ha)	Coefficient of Variation
Liverpool surveys[a] (16 years between 1830 and 1859)	1.93	0.336	0.17
91 farms[b] (1934-38 in U.K.)	3.40	0.490	0.14
Huntingdonshire[c] (271 fields, 1971-78)	5.44	0.761	0.14
National Institute of Agricultural Botany[d] (1967-78)	5.70	0.912	0.16
ICI[e] survey (1980)	7.37	1.38	0.19

Note: Interannual variation eliminated.
[a]Healy and Jones (1962).
[b]Cochran (1939).
[c]Church and Austin (1983).
[d]Talbot (1984).
[e]Tinker and Widdowson (1983).

Variation in Yields from Field to Field

Results from some surveys are given in table 7.4. Field-to-field variation within a year is apparently fairly constant at 0.14-0.19 times mean yield. In biological terms, this variation results from the combined effects of variation in soil type, the variety grown, variations in cultural treatments (sowing rates, fertilizer rates, agrochemical use, etc.), as well as the effects of variations in weather, particularly rainfall. In commercial farming, it is impossible to ensure that cultural operations are carried out optimally, in part because of the scale of operations and in part because the optimal timing is dependent on future weather and can be determined only in retrospect from experimental results.

The component of field-to-field variation due to variations in cultural operations under modern farming conditions can be estimated approximately from the results of multifactorial experiments carried out between 1981 and 1984 at Rothamsted Experimental Station (Lester 1981, 1982, 1983; Rothamsted 1984). Results from these experiments, not presented in detail here, show that the average improvements in yield due to the best levels of individual factors were, as proportions of the mean yield: sowing date, 0.064; timing of the main application of nitrogen fertilizer, 0.066; amount of nitrogen fertilizer applied, 0.069; individual crop protection measures separately, 0.033. In these experiments the major factor affecting yield was the previous crop through its effect on the severity of take-all disease (*Gaumannomyces graminis*), which was much more severe when wheat followed barley than when it followed oats. The average variation above and below the annual mean yield due to this effect was 0.31 times the mean yield. These results are discussed elsewhere in this volume by Arnold and Austin (ch. 10).

Plant Breeding and Yield Variation

In the U.K., winter wheat breeding during the past 50 years has been based on selection under farming conditions that have been broadly representative of the total production area (Silvey 1978, 1981). Moreover, new varieties, whether bred in the U.K. or not, are recommended to farmers only after evaluation for three seasons over a wide range of localities. Stability is an important requirement for recommendation, in addition to potential for yield. A very close watch is kept to detect the development of new or more aggressive pathogens, and the variability in the yield that these could cause is counteracted by the breeding of resistant varieties and the use of new control agents. Analyses of genotype-environment interactions have tended to show that the new semidwarf varieties are more responsive in absolute terms to high levels of inputs than the taller old ones, indicating a reduction in stability (Patterson 1980). As table 7.2 and figure 7.1 show, variability of yield has increased in absolute terms, although the coefficient of variation of yield has shown no marked trend with years. It is the view of experienced agronomists and breeders in England that the cv of yield may decrease in the future as farmers become more familiar with the requirements of the new varieties and the management of the higher input systems introduced in the past 20 years.