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Luxembourg, Centre Européen, Boîte postale 1907 — Tél. 43011. Télex: Comeur Lu 3423
1049 Bruxelles, Bâtiment Berlaymont, Rue de la Loi 200 (Bureau de Liaison) — Tél. 7358040

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Forcasting of crop yields from meteorological data in the EC countries

Etudes de statistique agricole: No 21

~~Prof Dr~~ H. Hanus

Christian-Albrechts-Universität Kiel
Lehrstuhl Allgemeiner Pflanzenbau

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Report on a study of investigations into the forecasting of crop yields from meteorological data in the countries of the European Community

H. Hanus

1. Introduction and aims of the study

Scientific research led to the development of a method which could be used to forecast the wheat yields of a 100 m^2 experimental plot from meteorological data with surprising accuracy (Hanus 1969). After appropriate modification, this method of estimation was also used to calculate average yields in the Federal Republic of Germany (Hanus 1970). The results attained a similar degree of accuracy to that achieved in the experiment, and consequently, after a period of revision (1968-1970), the method has been used in the FR of Germany since 1971 for official forecasts.

As the estimated results to date had been satisfactory, the question arose whether the principles of the method could also be applied to other countries with somewhat different climatic conditions. An attempt was therefore to be made, in cooperation with the Statistical Office of the EC, to estimate the yields in each of the EC countries, again on the basis of meteorological data. The investigations concentrated on the fundamental suitability of the method and the accuracy of estimate which could be achieved. They were also concerned, however, with the question whether the accuracy and reliability of the estimates could be further improved by modifying the methodology or extending the data base. The last-mentioned investigations ran parallel to some extent with similar research on the data for the Federal Republic of Germany. The two sets of investigations therefore complemented each other effectively. The conclusions from these methodological investigations are to be discussed before the actual results for the yield forecast, since they are essential for a critical assessment of the efficiency of the method of estimation developed.

2. Theoretical principles of the method of estimation developed

In order to be able to calculate and quantify the influence of the weather on yield development, a sample with observations of the yields and weather conditions over a fairly long period of time is required. Within this sample, which should cover as many years as possible, it must be ensured, however, that the yield fluctuations from year to year are caused solely by differing weather conditions. In a fairly long time series this is only rarely true, however, since the yields are also affected by other factors which can bring about a systematic change during the reference period. Thus, for example, in almost all the countries there has been a varying but steady upward trend in yields since the last war, due to improved methods of cultivation, increased use of fertilizer, more productive varieties, etc.

In addition to the weather, account must also be taken therefore of this trend for the purpose of calculating the relationship between weather and yield. Assuming that the trend includes all the factors which influence yields apart from the weather, the yields in each year of the reference period can be defined as a function of the trend and of the weather.

$$y = f\ (T,\ x)\quad [1]$$

y = average yield in a particular country
T = time variable for recording of the trend (year of the reference period)
x = weather

The weather in a particular year is not, however, a singular variable but a plurality of disparate factors. In the first place, account must be taken of the individual weather factors which can be used to characterize the weather and which can exercise a widely differing influence on yields (temperature, precipitation, duration of sunshine, etc.).
Equation [1] must therefore be expanded to

$$y = f\ (T,\ x_1,\ x_2\ \ldots\ldots\ x_k)\quad [2]$$

where the indices 1 ..... k represent various weather factors.

The yields of agricultural field crops are the result of growth and development processes extending over a long period of time. Within the growing season the type of weather required may be subject to considerable changes. The whole of the growing season must therefore be divided into smaller periods which are closely linked to the yield development processes. Although from the point of view of yield physiology a division of the growing season into phenological periods of this type would be the most suitable, it is scarcely feasible in practice. If the aim is to estimate the average yields of a fairly large area, it is impossible to establish any uniform phenological periods because, for example, the phenological period florescence - harvest can begin at widely differing times and also be of different duration, depending on the topography of individual areas of land. A division of the growing season into phenological periods is therefore possible only where the whole of the area under cultivation exhibits uniform climatic conditions. As this happens only rarely, it is generally necessary to use calendar units instead. Regardless of the division of the growing season, it is nevertheless necessary to take several periods into consideration, since the influence of a weather factor on the yield is uniform and constant throughout the growing season in exceptional cases only. Equation [2] must therefore be expanded to

$$y = f\ (T,\ x_{11},\ x_{21}\ \ldots.\ x_{12},\ x_{22}\ \ldots.\ x_{kl})\ [3]\ ,$$

where the indices 1 .... k represent different weather factors and the indices 1 .... l different periods of the growing season.

Equation [3] represents the yield function at a certain place or in a narrowly defined area with completely uniform weather conditions. If, however, the aim of the investigations is to determine the average yields of larger areas, the regional differences in the weather cycle must also be taken into account, using meteorological data from different weather stations.

The final yield function therefore reads:

$$y = f\ (T,\ x_{111},\ x_{211}\ \cdots\ x_{121},\ x_{221}\ \cdots\ x_{112},\ x_{212}\ \cdots\ x_{klm}) \quad 4$$

y = average yield in a particular country

T = time variable for recording of the trend (year of the reference period)

x = weather factors

1 ... k = weather elements

1 ... l = periods of the growing season

1 ... m = weather stations.

On the basis of this theoretical yield function it should be possible to calculate the yields from meteorological data, if the following conditions are met:

1. The weather factors recorded must include the weather elements essential for the development of the yield.
2. The division of the growing season must accord with the physiological processes during the development of the yield.
3. The choice of weather stations must cover regional differences in the weather cycle sufficiently accurately.
4. There must be a sufficiently large sample which covers the possible variations in the weather cycle to a great extent and enables the complete estimation model to be used.
5. The calculation method used must describe the quantitative relationships between weather and yield sufficiently accurately.

As a rule, these conditons cannot be satisfied. Precise yield forecasts from meteorological data are therefore ruled out from the outset in many cases. The crucial question is, therefore, what degree of accuracy of estimation can be achieved under given conditions and whether this is acceptable. The degree of accuracy achieved primarily provides, therefore, information only as to whether the given conditions are adequate or not.

If the result is unsatisfactory, the reason may lie in the data base or in the calculation method, and it is then a question of whether there are any possible ways of improving the results.

In the development of estimation models for yield forecasts it is therefore recommended that a pragmatic approach should always be adopted and data which are readily available be used initially. In the light of the results obtained, a decision can be taken at a later date as to whether additional expenditure (widening of the data base or improvement of the calculation basis) can be expected to lead to an improvement of the estimated results or not, or whether the additional expenditure is worthwhile.

In view of the structure of the theoretical model, a possible method of solving the equation is by multiple regression.

3. Methodological aspects of yield forecasting from meteorological data

Before the results of the investigations into the forecasting of crop yields in various EC countries are discussed, it seems necessary to consider a number of methodological questions which were the subject of extensive research. Only a summary of the main conclusions can be given here; for further information, reference should be made to the original paper (Hanus and Aimiller 1978).

3.1. Determination of the trend of the yields

The relationships between weather and yield cannot be precisely quantified unless all other influences are eliminated. This means that the trend of the yields must also be determined precisely, since each error in this respect distorts the quantitative relationships between weather and yield. As detailed investigations showed, the trend values determined may show considerable fluctuations, depending on the size and composition of the sample. On account of these uncertainties in the determination of the trend, it seemed advisable not to correct first the yield series on the basis of a predetermined trend and then correlate it with the weather, but to include a time variable in each individual estimate and to calculate a partial trend. Since the numerical values for the partial trend show fluctuations depending on the combination of characteristics in the regression equation, the occurrence of a systematic error, which could happen if only a single more or less erroneous trend value was used to correct the yield, is avoided.

3.2. Importance of the size and composition of the sample for the accuracy of estimation

The validity of a regression equation is limited by the variance of the base data. Reliable yield forecasts are therefore possible only if the sample also includes extreme weather cycles. This requires long series of observations, which are not always to hand. In meteorology, samples of around 30 years are required for the determination of long-term averages, if reliable (representative) values are to be obtained. In the present investigations, the samples were in some cases considerably shorter. The shorter a sample is, the more unreliable the yield forecasts become, particularly in extreme years, since the probability decreases that years with a similar weather cycle are already represented in the sample.

The composition of the sample, too, is important. The more one-sided it is (frequent occurrence of favourable or unfavourable years), the more unreliable the estimate becomes in years with an opposite weather cycle. In addition, many facts indicate that in unfavourable years different weather factors are important for yield development than in years with high yields.

3.3. Suitability of the weather stations

For forecasting the average yields of fairly large areas meteorological data from different weather stations must always be used. The question therefore arises as to which stations should be chosen. The choice should be based on the following criteria:

- situation in relation to the main growing areas
- representativeness of the readings for the wider area around the station
- completeness and scope of the observations
- homogeneity of the series of observations
- availability of the observation data in the current year for yield forecasts.

Despite careful selection, the fundamental suitability of a weather station's data for yield forecasts cannot be calculated in advance. This can be determined only by test calculations, which quite often are contradictory to subjective expectations. For the recording of meteorological data the network of weather stations should therefore always be set up on a narrower basis, since in the course of data collection or test calculations stations frequently have to be eliminated because in some cases certain data are missing or the stations do not seem at all suitable. Particular attention must be paid to ensuring that the data used can be made available quickly and easily for proposed forecasts in the current season.

3.4. Division of the growing season

For reasons outlined above, the growing season must as a rule be divided by calendar units. The question is, however, which units are to be used. In many publications dealing with the relationships between weather and yield, periods of ten or even five days are preferred to monthly values, because even short periods of time can have a considerable influence on the yield. As investigations into this question showed, the practical division of the growing season must be considered in conjunction with the size of the sample. Since statistical procedures are used for yield forecasting (regression), the representativeness of the sample plays an important part. A sample is fully representative only if its parameters (e.g. average or its variance) remain constant even if the size of the sample is increased. In order to ensure that the monthly averages attain a certain degree of stability and reliability, samples of at least 30 years are required. The shorter the time interval becomes (ten- or five-day averages), the longer the sample must become in order to attain the same degree of reliability.

Since the samples available are as a rule considerably shorter than 30 years, it follows from the above that, with regard to the required representativeness, monthly values merit preference over ten- or five-day averages. The fact that long time intervals are required results in a reduction of the number of potential variables and consequently a reduction in the cost of calculation. Provided correspondingly long series of observations are available, ten-day values can, of course, be used as well. Consideration must, however, be given to the question whether the additional expenditure leads to a corresponding improvement in the accuracy of estimation.

3.5. Possible procedures of calculation

The forecasting of crop yields from meteorological data presents three main problems:

1. The number of potential variables is generally considerably greater than the scope of the sample, with the result that the full estimation model (see equation [4]) can be used only rarely.

2. Not only the main effects of the individual weather factors but also the interactions between these factors are important for the development of the yield.

3. The aim in forecasting crop yields from meteorological data is to determine a single point in a multidimensional system, whereas the statistical procedures used for estimating purposes were developed for determining average parameters from distributions.

As the theoretical model can rarely be fully used, even if the three dimensions of the weather factors (number of weather elements, number of periods of time, number of weather stations)are kept on a small scale, increased importance attaches to the procedure of calculation.

The scope of the regression model is determined by the size of the sample; where possible, the number of variables included in an estimating equation should not be greater than the number of degrees of freedom remaining. The full model must therefore be divided up into various smaller sub-sets. This may be done in the following ways:

1. From the total number of weather factors, equations with the desired number of variables are developed by "forward selection" in accordance with predetermined statistical parameters, the meteorological data included in the equation being eliminated from the remaining matrix until the whole matrix has been used or the specified test limits are no longer reached.

2. The whole matrix is divided up from the start into sub-sets of meteorological data as small as can be included together in an equation. In view of their three-dimensional structure, the meteorological data can be combined in three different directions, only one of the three dimensions being taken into considaration at any time. In this way it is possible at the same time to take account of the different interactions between the weather factors. The following model equations are possible:

   a) $y_{lm} = f(T, x_{1lm} \ldots x_{klm})$, $l = 1 \ldots l$, $m = 1 \ldots m$

   b) $y_{km} = f(T, x_{klm} \ldots x_{klm})$, $k = 1 \ldots k$, $m = 1 \ldots m$

   c) $y_{kl} = f(T, s_{kl1} \ldots x_{klm})$, $k = 1 \ldots k$, $l = 1 \ldots l$

   y = average yield in a particular country
   T = time variable for recording of the trend (year of the reference period)
   x = weather factors
   1 ... k = weather elements
   1 ... l = periods of time
   1 ... m = weather stations.

Detailed investigations showed that the formal development of estimating equations from the whole matrix of weather factors in accordance with statistical parameters does not lead to usable solutions if the matrix exceds the size of the sample.

Although the estimating equations can always be based on very high multiple correlations, since only significant weather factors are included, the forecasts fail because the estimating equations are fitted to too great an extent to the specific features of the sample.

If the matrix of weather factors is subdivided from the start into specific smaller sub-sets, equations of widely varying quality are also obtained. It is, however, possible at a later stage to select equations which can be expected to produce a high degree of accuracy even in forecasts. In the course of these investigations it was shown that the category of estimating equations listed under c) is generally less efficient than the others. This would indicate that regional differences in the weather cycle are not as important for the development of the yield as differences and interactions during the growing season. The principles governing the choice of estimating equations and the way in which the probable accuracy of yield forecasts can be estimated are discussed later.

First of all, it should be pointed out that the disproportion between the number of weather factors and the size of the sample can also be avoided in another way. In principle, it is possible to group several weather factors together to form intermediate variables and thus reduce the total number of weather factors. Possible ways of doing this include dovetailing regressions, as demonstrated previously (Hanus 1969), or aggregating several weather factors by means of discriminatory analysis to form statistical universes. Both methods are relatively costly and have certain shortcomings. Although no information is lost, the aggregation of meteorological data does not therefore as a rule lead to better results than subdivision of the matrix of weather factors followed by aggregation of the estimated results of those equations which can be expected, in view of their statistical parameters, to produce the most accurate results.

3.6. Estimation of the yields for sub-areas

Attempts are frequently made to solve the abovementioned methodological problems, which arise out of the disproportion between the size of the sample and the matrix of weather factors, by combining yield series and meteorological data from various sub-areas of a country to form a common sample. Although the size of the sample then increases by the factor of the number of sub-areas, the representativeness of the thus expanded sample for all potential weather cycles is barely increased, unless the regional differences in the weather cycle are very extreme. A possible advantage is thus to be expected only if the differences in the weather cycle between the individual regions are so great that they can offset the possible variance between different years. As the annual nature of the weather is determined by large-scale constellations, such an advantage can scarcely be anticipated given the surface area of the countries of western Europe.

If, on the other hand, attempts are made to estimate the yields for the various sub-areas separately, the same problems crop up as in the estimation of the average yields of the whole country, except that the necessary expenditure increases in proportion to the number of sub-areas.

3.7. Data processing

On the basis of theoretical considerations it must be assumed that the relationships between weather and yield follow an optimum curve. However, in many cases calculations are made with linear models. This happened in the subsequent investigations as well. In order to be able to describe an optimum relationship, the quadratic terms would have to be included in the equation in addition to the linear values.

As a result, the number of variables would double; in view of the discrepancy between sample size and the matrix of weather factors, this would make the methodological problems correspondingly more complex. In addition, the variance of the weather cycle under given climatic conditions extends over the whole range of the assumed optimum relationship in exceptional cases only. On either side of the optimum the trend of the curve can, however, also be described approximately by a straight line. Methodological considerations, too, point to the use of linear equations initially.

Generally speaking, the trend of a regression line can be defined and certain only within the sample. Outside the range delimited by the extreme values of the sample, the regression equation is not automatically valid. If a curvilinear equation is used, the regression line is fitted as accurately as possible to the existing point distribution of the sample. Particularly with a very pronounced curve trend it is not certain, however, whether this curve continues outside the sample as well. If extrapolation is necessary in years with extreme weather conditions, sizeable errors of estimation may arise in certain circumstances. This danger is particularly great if the sample is not fully representative.

3.8. Choice of the estimating equations

In choosing the estimating equations the following principles should be observed:

1. The final estimate should always be based on several individual values. As a rule it can be assumed that, depending on the estimating equation used, there are for the same year under- and overestimates of the yield which offset one another. Even if the deviations have the same sign in all the equations, extreme errors of estimation can be avoided by aggregation of several individual values.

2. The equations should be chosen in order of variance around the regression. As the average error of estimation initially diminishes if several individual results are aggregated and subsequently increases again if an increasing number of inaccurate results is taken into consideration, the number of estimating equations should be limited. The increase of the variance around the regression to 150 % of that for the best estimating equation in each case may serve as a rough point of reference.

3. In order to bring out the interactions between the various weather factors, as many different model equations as possible should be used for the estimate (equations for different stations, months or weather factors).

4. As well as on the probable accuracy of estimation the choise of equations should also be based on the possible compensation effect resulting from over- and underestimates of the yields for the same year. This compensation effect can be deduced from the correlations between the residuals of the estimated and observed yields within the sample. If the correlation between the residuals is low or even negative a higher compensation effect can be expected, and vice-versa.

3.9. Deduction of the probable accuracy of estimation from parameters of the sample

The variance around the regression can be regarded as a yardstick for the probable accuracy of estimation. It is, however, only a relative standard of comparison, as it must always be based on comparable conditions. If, for example, regression equations are developed from an extensive matrix of weather factors, considerably lower variances around the regression are generally obtained than if the same number of variables is specified beforehand.

A higher degree of accuracy in the forecasts is not, however, achieved in such cases. If, on the other hand, equations are calculated for individual months and the same weather factors used in each month, for example, similar gradations from month to month in the accuracy of the forecasts are to be expected as in the variances around the regression, i.e. equations with a lower variance produce more accurate estimates than equations with a high variance.

The variance around the regression is a measure of the deviations within the sample between observed yields and yields calculated on the basis of the regression equation. These deviations are always smaller within the sample than in forecasts, since the parameters of the equation are determined in such a way that the squares of the deviations assume a minimum value. Comparative investigations showed not only that the deviations are generally higher in the case of forecasts but also that, with increasing variance around the regression, they increase more rapidly than is to be expected in relation to the gradations of the variances.

The regression equation for the differences between observed and calculated yields within the sample and in forecasts is as follows:

$$y = -0.45 + 1.93 \cdot x$$

y = differences between observed and calculated yields in forecasts
x = differences between observed and calculated yields within the sample.

According to this, the error increases roughly twice as rapidly in forecasts than within the samples. This fact, too, calls for strict criteria to be applied when choosing estimating equations.

For the optimum accuracy of estimation the variance around the regression obtained by the best equation is important. By aggregating the estimated results of several equations it is generally possible to aim at a lower mean error of estimate than using only estimates of the best individual equation, since over- and underestimates of the yield cancel one another out. On the basis of the results to date it can be assumed that the aggregation of several individual results gives a mean error of estimate approximately 20 % lower than the standard deviation for the best regression equation (the standard deviation is the root of the variance around the regression). The probable accuracy of yield forecasts can therefore be deduced from the results within the sample. This is an advantage inasmuch as it eliminates the need for costly simulation of forecasts and permits rapid assessment of whether or not satisfactory results can be expected for yield forecasts from meteorological data.

3.10. Weighting of the individual results

As each estimating equation gives projected results of varying accuracy depending on the variance around the regression, the question arises whether these anticipated differences in the accuracy of estimation could not be taken into account by varying the weighting of the individual results. This is possible in principle. A possible criterion for such weighting is the ratio of the variances around the regression to that of the best equation. Investigations on this subject showed that accuracy can be increased by about 10 % by such weighting of individual results aggregated to give an average value. Whether this opportunity to improve the accuracy of estimation is to be used in addition depends on the absolute accuracy of estimation achieved.

The investigations to date have shown that only modest increases in accuracy can be achieved by improving the survey methodology or the basic set of data. The greatest uncertainties generally arise out of inadequacies of the samples; an extenstion or improvement of the data base, can as a rule therefore be expected to be more effective.

4. Results of the investigations into the forecasting of crop yields in the countries of the EC

4.1. Material used

The source material for the investigations carried out varied greatly from country to country. This applied both to the yield series and to the meteorological data and weather stations available.

Table 1 shows which crops were covered by the investigations in each country. The yield data were supplied partly by the appropriate departments in each country and partly by the Statistical Office of the EC in Luxembourg directly or taken from the official Community statistics. A distinction within the types of crops by spring and winter varieties was possible only where separate statistics were recorded. Although on account of differences in productivity or growth rate the yields of winter and spring varieties are often widely divergent and subject to different weather requirements, the error arising when the two yields are aggregated must not be assumed to be particularly great, since the growing of one variety generally predominates.

Although a wide range of crops was studied, the estimates were concerned mainly with wheat. It was only for this crop that the accuracy of estimation derived from the parameters of the sample was checked by means of simulated forecasts as well. As Table 2 shows, widely varying samples, comprising between 17 and 26 years, were used for the yield forecasts in the various countries. The yields given for wheat show that with regard to the yield level and to the absolute and relative variance of the yields the initial data varied considerably. The number of weather stations used was based on the size of the country or on the meteorological statistics which could be supplied.

The smaller the number of stations, the more difficult the subsequent choice becomes, because it cannot be assumed at the outset that the stations used are equally well suited for yield forecasting or even that they are suited at all. Since in Belgium data on several weather factors were available for Uccle only, whereas other Belgian weather stations could supply data on precipitation only, stations in France and the Netherlands were also used for estimating the yields (see Table 3).

The meteorological data available, too, varied from country to country. There are scarcely two countries in which the available meteorological data were completely identical. Consequently, the efficiency of the method of estimation could be tested over a wide range of different basic conditions. Table 3 shows in detail from which stations data were available. Generally speaking, they were monthly averages or totals. The maximum and minimum temperatures were likewise monthly averages and not absolute values. The mean temperatures represented the monthly averages of the daily mean temperatures.

As the calculations were made simultaneously for all the crops and the main interest was in cereals or wheat, only the meteorological data from January to July were used (in Italy from December to June).

The diversity of the basic data illustrates the flexibility of the method developed, since it can be adapted to any situation. It is not until later that the test results show whether the existing data base is adequate or not.

4.2. Methodology

In the previous chapter various methodological aspects of yield forecasting were discussed. These questions were the subject of detailed investigations, the results of which were presented in a special paper (Hanus and Aimiller 1978).

With regard to yield forecasting from meteorological data it was concluded that the possible methodological approaches can be reduced to certain ones which promise the greatest effectiveness.

The results below are therefore based only on such basic sets of data; generally speaking, only the meteorological data from a single station were used each time and correlated with the national average yields. The following basic sets of data were used:

1) Aggregation of all the meteorological data for a month in a regression equation and separate calculations for all the months and weather stations (in Italy the values for two months were used simultaneously, since data on only three weather factors were available each month).

2) Aggregation of all the monthly values of a weather factor in a regression equation and separate calculations for all weather factors and weather stations.

A time variable (year of the reference period) was also included in each regression equation in order to take account of the trend of the yields. As a rule, only linear multiple regressions were calculated.

After the first set of calculations there was therefore a large number of regression equations for each crop, totalling (weather stations x months) + (weather stations x weather factors). From this total it was possible to select those equations which had the lowest variances around the regression. Using the meteorological data in these equations (approximately 10 per basic set of data), further multiple regressions were calculated, but one year after the other was constantly eliminated from the sample. Using the equations which were calcultated on the basis of the samples without the year in question, it was possible to calculate the yield for this year as though it were a forecast. As another year was constantly eliminated from the sample, simulated forecasts could be obtained in this way for all the years in the sample.

This simulation of forecasts was carried out to wheat only in order to check whether the accuracy of estimation deduced from the parameters of the sample is also achieved in practice. When these simulated forecasts were available for all the years of the sample from all the selected equations, the results were successively averaged, the results of the equations being continuously included in the average in the order of their variance around the regression. As a result of including several individual values the estimate initially becomes more accurate, but from a minimum point the error of estimation increases again, because it is necessary constantly to include results of equations which provide increasingly more inaccurate individual estimates. This minimum point represents the maximum accuracy of estimation that can be achieved. The results of the estimates in the individual years presented below are generally based on values in this range.

4.3. Results of the simulated yield forecasts for wheat in the various EC countries

Before individual results are discussed, the methodology is to be illustrated by examples. The results for wheat in Denmark were chosen. Tables 2 and 3 show the data and weather stations available.

If the relationships between the meteorological data and the country's average wheat yields are calculated for each station and each month or for each station and each weather factor, the coefficients of multiple correlation and the standard deviations around the regression set out in Table 4 are obtained. Depending on the basic set of data, the coefficients of multiple correlation ($r^2 . 100$) vary between 88 and 61 in the case of the months and between 94 and 76 in the case of the weather factors.

Since for each month only five different weather factors but for each weather factor seven different monthly values were aggregated, lower multiple correlations, which were, however, based on a correspondingly higher number of degrees of freedom, were inevitably obtained for each month. For assessing the quality of an estimating equation the coefficients of multiple correlation are therefore suitable only if they can be based on the same number of degrees of freedom. Accordingly, the variance (s^2) or the standard deviation (s) around the regression is a more suitable parameter for assessment of the estimating equations, since their calculation takes account of the differing number of degrees of freedom.

There are considerable differences in the standard deviations around the regression, too; they vary between 1.8 and 3.2 dt/ha depending on the month and between 1.4 and 2.8 dt/ha depending on the weather factor. Even from these results it can be concluded that good estimates are to be expected, since the standard deviations are relatively low, at least in the case of the best equations.

On the basis of the standard deviations it is now possible to select the basic sets of data which promise the most accurate estimated results. These are set out in Table 5 and renked in order of the standard deviation around the regression. The same table also shows the errors of estimation which were obtained in simulated forecasts using the meteorological data listed. With the data on precipitation for Jyndevad and Copenhagen, an annual average error of estimation of 1.7 dt/ha over the perival of years was obtained in each case. The average values of the errors of estimation never have a sign, since in the individual years only the absolute errors of estimation may be taken into consideration. If, however, averages for individual years are produced from several estimates, the sign of the errors of estimation must be taken into consid-aration, as over- and underestimates can cancel one another out. If, therefore, an average is derived from the estimates by means of the two abovementioned equations for each year, the average error of estimatión over the period of years decreases to 1.6 dt/ha, even though each individual equation on its own resulted in an error of 1.7. By including the results of further equations, the successive average value gradually falls to 1.3 dt/ha, subsequently rising again slightly to average 1.5 dt/ha for the ten basic sets of data used. In relation to the average yield of 44.5 dt/ha for the reference period, the average error of estimation obtained is only 3 % and is therefore to be classed as very statisfactory.

In all the countries the same principles were followed in order to determine the best regression equations for forecasting the yields. Table 6 shows which meteorological data were considered the most suitable in each country for forecasting the wheat yields. It can be deduced from the standard deviations of the regression equations selected that different errors of estimation must be expected in each country, since the best regression equation in each case results in widely differing standard deviations around the regression.

For the purpose of assessing the accuracy of estimation attainable, account must be taken not only of the absolute error of estimation but also of the respective yield level. Table 7 therefore shows, in addition to the range of fluctuation of the standard deviations around the regression, the average yields and the absolute and relative errors of estimation which were obtained with the basic sets of data listed in Table 6. The results again show clearly that, averaged over several individual results, the error in simulated forecasts falls below the level of the standard deviation around the regression for the best estimating equation. Only Denmark is an exception in this respect. The highest error of estimation occurred in Luxembourg with 2.0 dt/ha, the lowest in Italy with 0,8 dt/ha. If the respective national yield levels are also taken into account, the relative errors of estimation are very close to one another and, with the exception of Luxembourg, vary between only 3 and 5 %.

This accuracy of estimation can be regarded as satisfactory, whereas neither the absolute nor the relative value for Luxembourg seem acceptable for the present. In this case, the reasons for the unsatisfactory estimate should be investigated in order to discover whether there are any possible ways in which the accuracy of estimation can be improved.

Table 7 shows at the same time that the accuracy of estimation that can be achieved in simulations is closely related to the minimum standard deviation that can be obtained with the best regression equation. As already stated in the methodological section, the accuracy of estimation that can be achieve in forecasts can therefore be deduced from this minimum standard deviation of the best regression equation. It can be assumed that the average error of estimation for forecasts is at least the same as, and in most cases even below, the standard deviation of the best equation; a figure of 80 % of the lowest standard deviation may serve as a rough guide.

The average relative error is just one important yardstick for the accuracy of estimation. It is also important, however, to know whether the yearly variations in the yield can be plotted by the estimates and also whether the yields in extreme years can be forecast correctly. Figures 1-6 show, therefore, the average estimated results in the individual years for the basic sets of data listed in Table 6. Figure 1 presents a comparison of the results of several countries with widely differing yield levels, while the other figures show the results of one country in each case.

These diagrams show that the actual yield trend can be plotted extremely well by the estimates in all the countries. Only in Luxembourg (Fig. 6) and the United Kingdom (Fig. 2) is the parallelism between observed and estimated yields limited. In the other countries, however, the concordance is statisfactory, since extreme yields cannot be correctly estimated only in a few individual cases.

The estimates for Ireland must be regarded as unusually good (Fig. 5), since the yield trend throughout the reference period is reproduced very accurately by the simulated forecasts, despite enormous fluctuations in the yield.

From the examples given in Fig. 1 it can be concluded that, using the method developed, equally good yield forecasts can be obtained irrespective of the size of the country, the yield level, the data available and the climate, since, although these conditions varied greatly in the countries concerned, the yield forecasts attained a similar degree of accuracy. For comparison and to give a better illustration of the efficiency of the method, Fig. 1 also shows results which were worked out for Turkey on behalf of the FAO.

Overall, it can be concluded from the results that the method of forecasting crop yields is in principle suitable for use in other countries as well, since a comparison with the corresponding diagram for the Federal Republic of Germany (Fig. 7) reveals no fundamental difference from other countries. This figure also shows that the errors in simulated and true forecasts are approximately the same, since the figures from 1968 onwards are the results of forecasts which were carried out on behalf of official bodies, whereas previously only simulated yield forecasts were available.

4.4. Results of the investigations into yield forecasting in each of the countries for various crops

The suitability of the estimation method developed for the forecasting of crop yields in the countries of the EC was initially examined for wheat only. In the case of this crop, the accuracy of estimation deduced from the parameters of the sample (minimum standard deviation around the regression for the best equation) was tested by means of simulated yield forecasts. As was shown in Table 7, the deduced accuracy of estimation tallied well with that actually achieved, the actual errors of estimation being around 80 % of the minimum standard deviation around the regression. If similar relationships are assumed for the other crops, the probable accuracy of yield forecasts can be roughly estimated for them as well.

This method is also endorsed and justified by the fact that in the Federal Republic of Germany the genuine yield forecasts carried out on behalf of official bodies achieved, not only for wheat but also for the other crops, levels of accuracy of estimation which tallied well with the derived values.

The accuracy of estimation derived from the minimum standard deviation around the regression obtained with the best equation is shown in Tables 8 and 9 for the various countries and crops.

Although in some cases considerable differences in the absolute errors of estimation (Table 8) can be seen if the crops of a country are compared with one another or if the countries are compared in respect of one crop, not too much weight should be given to these differences, since they must always be considered in conjunction with the respective yield level. Moreover, there is hardly any systematic bias which might, for example, make the errors of estimation for one crop or in one country particularly high or low. Only in the case of Luxembourg are there, for nearly all the crops, errors of estimation which are always relatively large in comparison with the other countries.

If the absolute errors of estimation are related to the respective average values of the yields, the differences between crops and countries are generally levelled out to an even greater extent (see Table 9). In individual cases, however, greater errors of estimation are brought out more clearly for the first time (Italy: spring wheat; Luxembourg: nearly all crops). These peculiarities are to be dealt with in greater detail at a later stage. First of all, it must be stated that the errors of estimation in all the other cases are at a level that seems acceptable for yield forecasts, since with only a few exceptions the errors of estimation range between 2 and 5 % of the average yield.

Although the errors of estimation for the other crops were merely derived from the standard deviation of the best regression equation in each case, the comparative values in all the countries for wheat and in the Federal Republic of Germany for other types of cereals as well show that these derived levels of accuracy of estimation in forecasts can be achieved in practice.

Overall, it can be concluded from these results that, using the method described, it is possible to forecast yields in other countries of the EC with similar accuracy to that achieved in Germany. It must also be borne in mind at all times that the levels of accuracy of estimation given in Table 9 are the result of a first analysis. It would still be necessary to check in all cases whether these values are to be regarded as the upper limit of the accuracy of estimation or whether there are still possibilities for improvement (extension of the data base, improvement of the methodology, weighting of the individual results, etc.).

In view of the degree of accuracy achieved in most cases, it would be possible to make only gradual improvements, however, which make it seem doubtful whether the necessary additional expenditure is in reasonable proportion to the desired effect. In certain cases (e.g. Luxembourg) a check of this type would have to be carried out, since there is a suspicion here that, in view of the extremely broken nature of the surface of the area investigated, the data base (only three stations) was not adequate, notwithstanding the limited size of the area. The errors of estimation for maize and root crops, which tended to be higher, could probably also be reduced still further, since the present investigations covered only the growing season up to the end of July. In the case of the abovementioned crops there is, however, considerable growth even later in the year.

Another individual result (spring wheat, Italy) shows the limitations of a yield forecast from meteorological data if the yield fluctuations from year to year are not only a consequence of different weather conditions but also attributable to factors whose influence cannot be readily quantified and thus at least mathematically eliminated.

Although the error of estimation for spring wheat in Italy is still, in absolute terms, within the limits of the errors of estimation for other crops, it cannot, in view of the level of the yield, be accepted. More detailed investigations showed that this extreme average error of estimation was caused by glaring misestimates in two years, namely 1961 and 1967, in which extremely high yields were obtained. Since for the other types of cereals these two years could in no way be classed as record years, the question was to what the particularly favourable situation for spring wheat was attributable. The solution became apparent when the crop areas in each of the years were compared, for it was precisely these two years that the crop area was two to three times as high as in most of the other years (see Table 10). Since at the same time there was a corresponding decrease in the crop area for winter wheat, it may be assumed that in these two years an increased quantity of spring wheat was grown on land which is normally reserved for winter wheat. In Italy this land is also, however, in the more favourable locations. Consequently, the higher spring wheat yields in the two years mentioned are the result not of particularly favourable weather conditions but of the better quality of the land owing to the extended crop area. It is obvious that in such a case a yield forecast based solely on meteorological data must be wrong, since these abrupt variations in the yields in two individual years cannot be mathematically determined on the basis of the trend.

This initially negative individual result can, however, be interpreted positively as well, in that it can be assumed in all the other cases that the vast majority of the annual yield fluctuations are attributable only to different weather cycles. At least, the influence of other factors is determined to a great extent by taking account of the trend as well, since there remains only a small error of estimation which cannot be explained by weather and trend.

Bearing in mind how complicated and diverse the yield development processes of agricultural crops are and what interactions and possible compensating effects there can be between the different weather factors in the long period between sowing and harvest, the accuracy of estimation achieved must be classed as unexpectedly good, especially as in theory there are still various possibilities for improvement.

4.5. Results of true yield forecasts for wheat in the years outside the respective reference periods in the various countries of the EC

The previous results on the accuracy of estimation that can be achieved in yield forecasts from meteorological data were either based on simulated yield forecasts or deduced from parameters of the samples. Depending on when the investigations for the various countries were carried out or on what data were available up to this time, the reference periods ended as early as 1970 in some cases (France, United Kingdom, Federal Repulic of Germany) and later in others (not until 1975 in the case of Denmark and Luxembourg, for example).

As part of the 1977 investigations, the wheat yields of the individual countries were therefore calculated retrospectively for the years which had not been included in the sample originally. At he same time the wheat yields for 1977 were estimated in advance.

During the retrospective recording of the meteorological data and the transmission of the up-to-date figures for 1977 it transpired, however, that not all the data originally used were available, with the result that it was not possible in all cases to use those equations which, in terms of the accuracy of estimation, promised the best results. This is particularly true of the yield estimates for 1977, for which in France meteorological data only up to and including May, in the United Kindom up to June and in Italy only up to and including March could be used.

Table 11 shows both the results of these calculations and the numerical values of the simulated forecasts for the years in the respective reference periods. The results of the simulated forecasts for years within the samples differ from the estimates in subsequent years in that different estimating equations were used for each individual result, since new equations had constantly to be calculated, eliminating the data for the year in question. The estimates in the later years, which in Table 11 are separated from the simulated forecasts by lines across the columns, were on the other hand always calculated with the same equations, the samples given at the head of the table serving as the calculation basis in each case.

Somewhat closer consideration of these results and of the current forecasts for 1977 reveals similar errors of estimation to those obtained in the simulated forecasts. Only in 1976 were the results very inaccurate in some cases. The reason for this is clearly to be found in the extremely dry weather in that year, since the estimates were wrong to a greater extent primarily in those countries which lay in the centre of the drought area (Luxembourg, Belgium, Federal Republic of Germany). Since the relationships between precipitation and wheat yields are as a rule negative and, moreover, the calculations were based on a linear regression equation only, the high overestimate of the yields in this extremely dry year is understandable. In an extreme situation of this type, more accurate estimates could certainly be expected from a curvilinear regression equation which could describe an optimum relationship. Reference has already been made, however, to the special problems of an equation of this type in the section on methodology. Since in Germany, too, there was in 1976 a sizeable error of estimation which was well outside anything previously known, a curvilinear estimation model also was developed for the forecast of the yields in 1977. As was to be expected, in view of the largely normal weather cycle in 1977 there was practically no difference in the estimated figures (47.4 with the linear and 47.9 dt/ha with the curvilinear model equation). As the actual yield was 45.3 dt/ha, the linear equation not entirely unexpectedly gave, in fact, the more accurate result.

That the only possible reason for the greater errors of estimation is the extreme drought is also corroborated by the fact that the yields in the countries which did not suffer so much from the effects of the drought (Denmark, the Netherlands, Ireland) were also overestimated, although only slightly. Mention must also be made of another extreme result which was apparently caused by an adverse weather situation, namely the high overestimate of the yield in the Netherlands in 1972. Whereas the yield in the drought year 1976 was estimated very precisely in that country (deviation 0.2 dt/ha), the error in 1972 was 10 dt/ha. The extremely low wheat yield was caused by a high level of rainfall, which led to lodging and the growth of fungi which, particularly in countries with a high yield level, constitute a considerable danger to the development of the yield.

This reveals a fundamental weakness of the method of estimation, since it does not yet take account of qualitative differences in the effects of high levels of rainfall. The effects of 100 mm of rain in a month can, however, vary greatly depending on whether or not they cause lodging. Whereas in larger countries such effects are moderated or offset by regional differences in the weather cycle, they are particularly striking in countries with a small crop area and uniform site conditions, especially if such situations did not occur during the reference period.

Considering that the past few years were characterized by an accumulation of extreme weather cycles (record yields in 1971 and 1974, adverse effects of the drought in 1976, above-average yields in 1973, 1975 and 1977), the accuracy of the yield forecast in these years can be regarded as satisfactory, apart from the few exceptions mentioned. The 1977 forecasts in particular, which could be regarded as a genuine test, gave acceptable results in all the countries.

Tables 12 a and b show the individual estimates given by the equations used for each of the countries. Widely differing individual values were determined, depending on the meteorological data used. For the calculated averages the respective standard deviations are therefore given as well. However, they give only an idea of the range of fluctuation of the individual values and cannot be interpreted as errors of estimation. For this purpose it is better to use the data from Table 8.

On the basis of the estimated wheat yields and the area under cultivation in the various countries, total production for the whole of the EC was calculated at 39 million t see Table 13). Compared with the actual figure of 37 million t (No 11 - 1977 Crop production), there is a deviation of approximately -5 %. The comparison is, however, not entirely correct, in that in some countries (Italy, Luxembourg) only comparative values for total wheat are available, whereas the estimates apply only to winter wheat and are therefore higher from the start. In addition, final yield determinations are not yet available for all the countries.

5. Summary

A theoretical model describing the relationships between weather and yield is being developed. Using this model it is possible to calculate the yields from meteorological data, subject to the following conditions:

1. The meteorological data available must include the weather elements essential for the development of the yield.

2. The growing season must be divided into periods which are of particular importance for the development of the yield.

3. In order to take account of regional differences in the weather cycle, data from several weather stations, whose readings should be representative of fairly large growing areas, must be used.
4. In order to quantify the influence of the weather on the yields, a correspondingly long sample (time series), permitting use of the full yield model, must be available.
5. The calculation method used must determine and describe the quantitative relationships between weather and yield sufficiently accurately.

As a rule, these conditons cannot be met. The methodological part of the study therefore describes possible ways of reducing or modifying the model equation and points out relevant practical and methodological considerations.

On the basis of the investigations carried out so far, the following conclusions can be drawn and overall assessment made with regard to yield forecasting from meteorological data:

1. Multiple regression in the form of a linear equation seems to be the most suitable calculation method. Curvilinear equations are suitable only if the trend of the curve can be determined with certainty and is valid for any necessary extrapolations.
2. The easily available observed values can initially be used as the basis for characterization of the weather conditions.
3. In the investigations to date it was sufficient to divide the growing season into monthly periods. Advantages can be expected of smaller time units only if long samples (over 30 years) are available.
4. Account must be taken of factors which influence yields apart from the weather (increased use of fertilizer, better varieties, etc.) by including a trend function.
5. A regression equation should comprise only as many variables (weather factors + time variable) as there are degrees of freedom remaining.

6. In view of possible interactions and compensating effects, different basic sets of data should be used in order to be able to take account of various interactions between weather factors.

   In the present investigations the following sets were used:
   a) aggregation of all weather factors for a particular month in a regression equation;
   b) aggregation of all monthly values for a particular weather factor in a regression equation.

   These calculations were carried out separately for all weather stations and months or weather factors.

7. From the large number of regression equations calculated only those which promise accurate estimated results should be used for the yield forecast. The variance (s^2) or the standard deviation (s) around the regression can be used as a measure of the probable accuracy of estimation.

8. The final estimated result should always be calculated as the average of several individual results (at least 10). By aggregating several individual results it is generally possible to obtain errors of estimation which are approximately 20 % lower than the standard deviation of the best regression equation. The probable accuracy of the yield forecasts can therefore be estimated from the standard deviations obtained with the best equations.

9. In the present investigations the majority (approximately 70 %) of the errors of estimation ranged between 2 and 5 % of the respective average yield. The reason for the higher errors of estimation observed in certain cases (up to 10 % of the individual yield) was either an inadequate data base (Luxembourg) or the fact that the full growing season was not taken into consideration (only January-July in the case of root crops and maize).

10. With the help of simulated forecasts it was possible to show not only that the average errors of estimation over several years were of a satisfactory magnitude but also that the yield variations from year to year could be plotted very accurately, since larger deviations occurred only in very isolated cases.

11. On the basis of the results available it can be concluded that the method of estimation developed for Germany is also suitable for the forecasting of crop yields from meteorological data in other countries with different climatic conditions and can be expected to give similarly low errors of estimation to those obtained in Germany.

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Fig. 1 : Trend of the measured and estimated wheat yields in a number of EC countries and in Turkey.

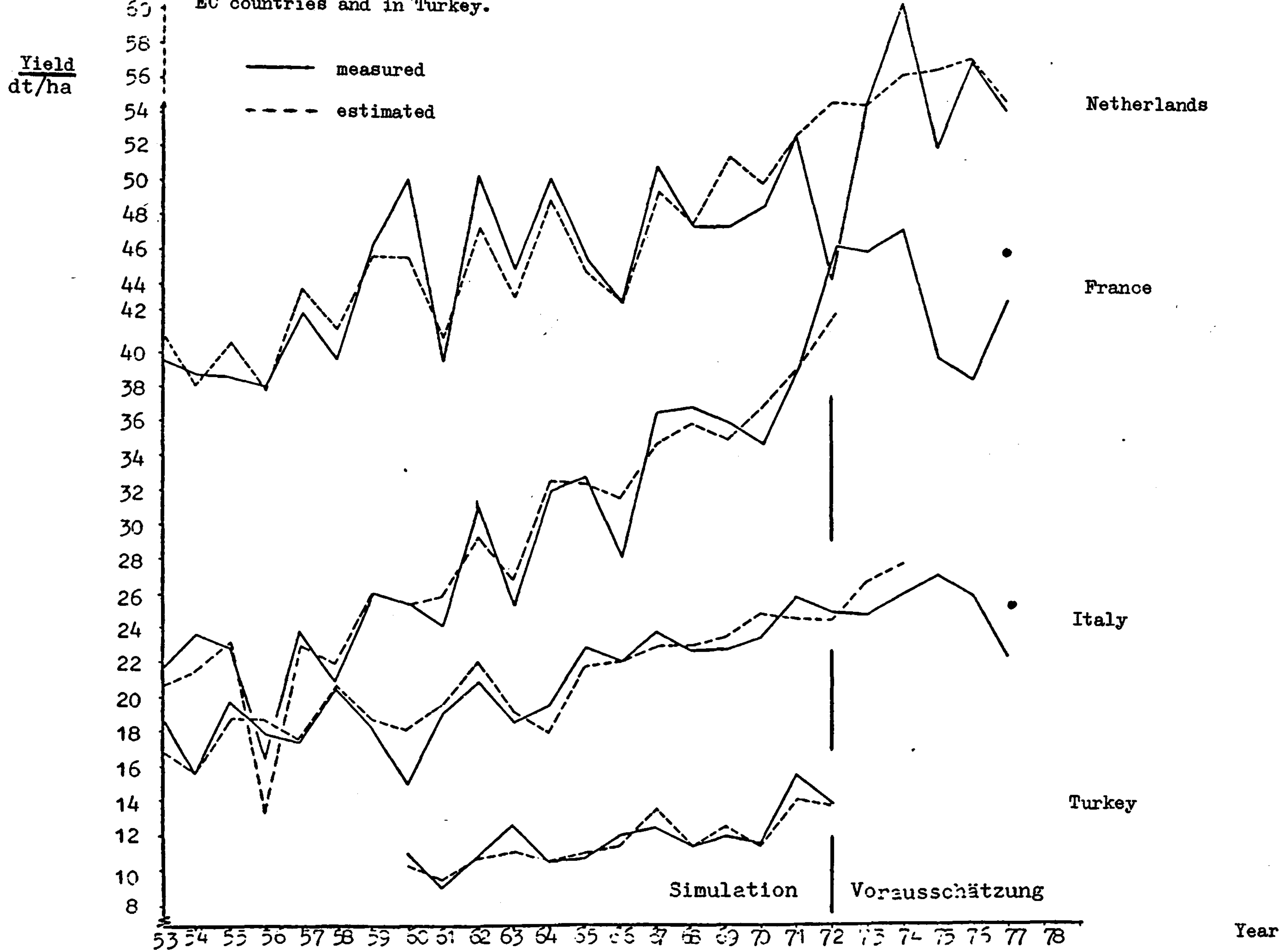

Fig. 2 : Trend of the measured and estimated wheat yields in the United Kingdom

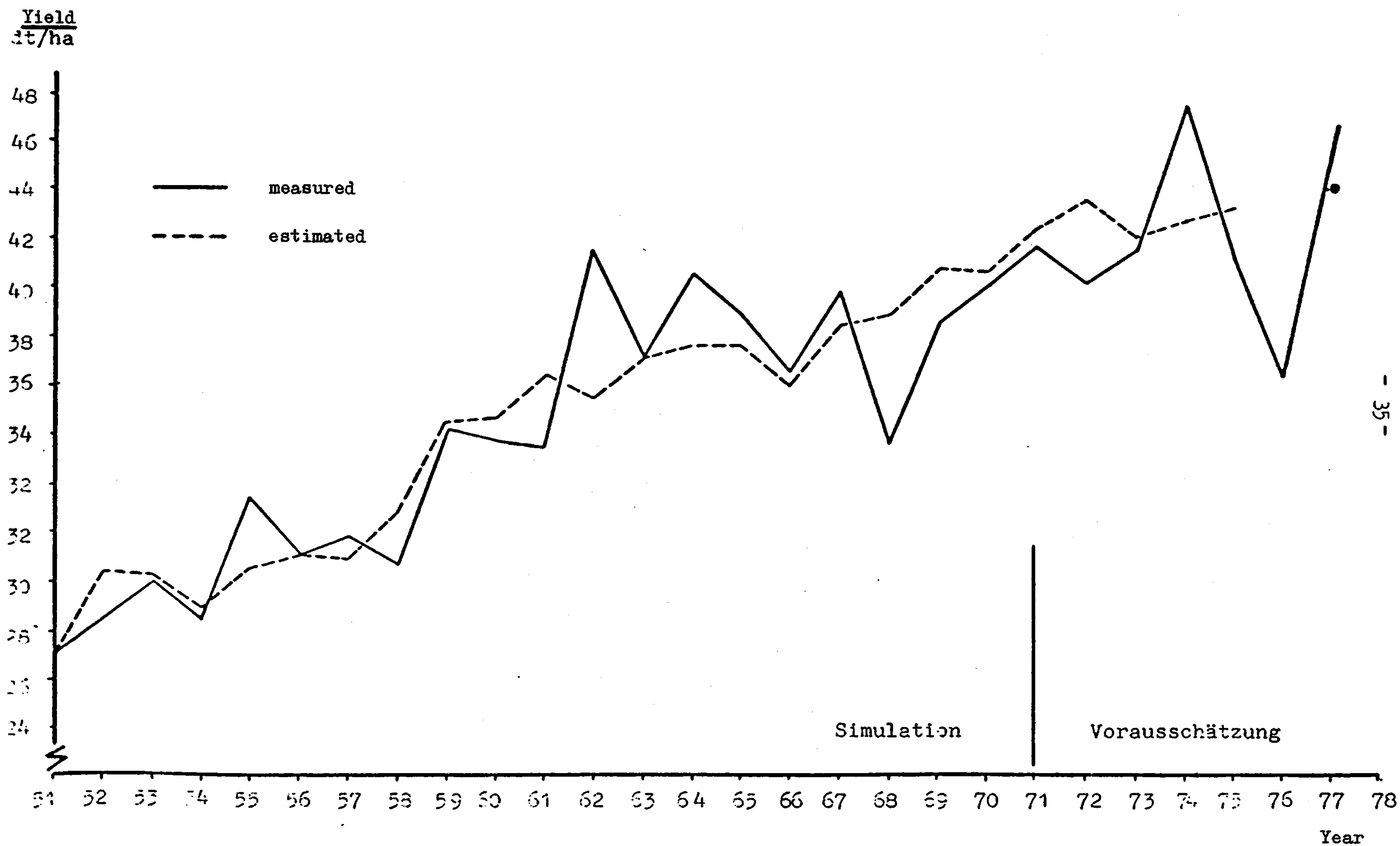

Fig. 3 : Trend of the measured and estimated wheat yields in Belgium

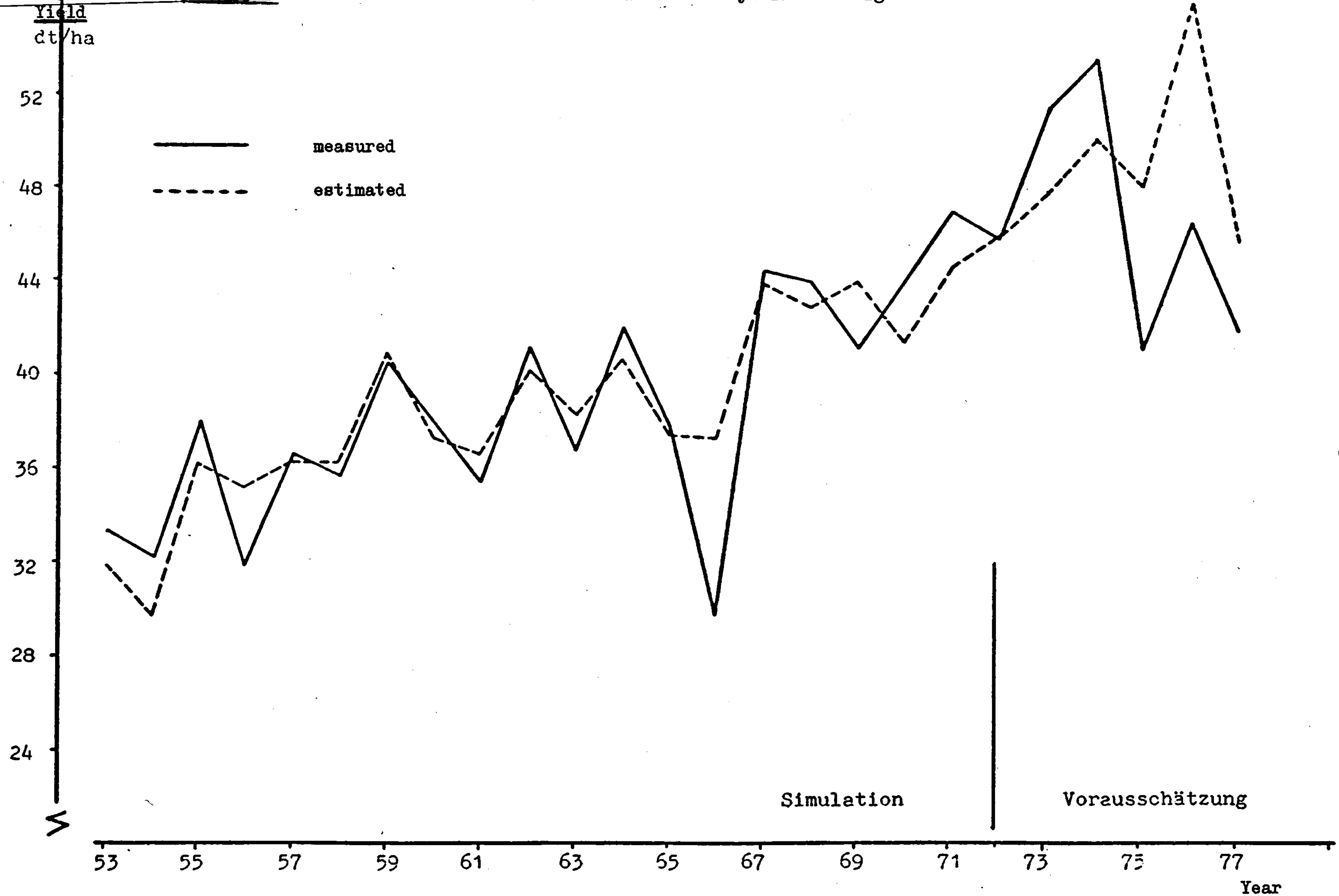

Fig. 4 : Trend of the measured and estimated wheat yields in Denmark

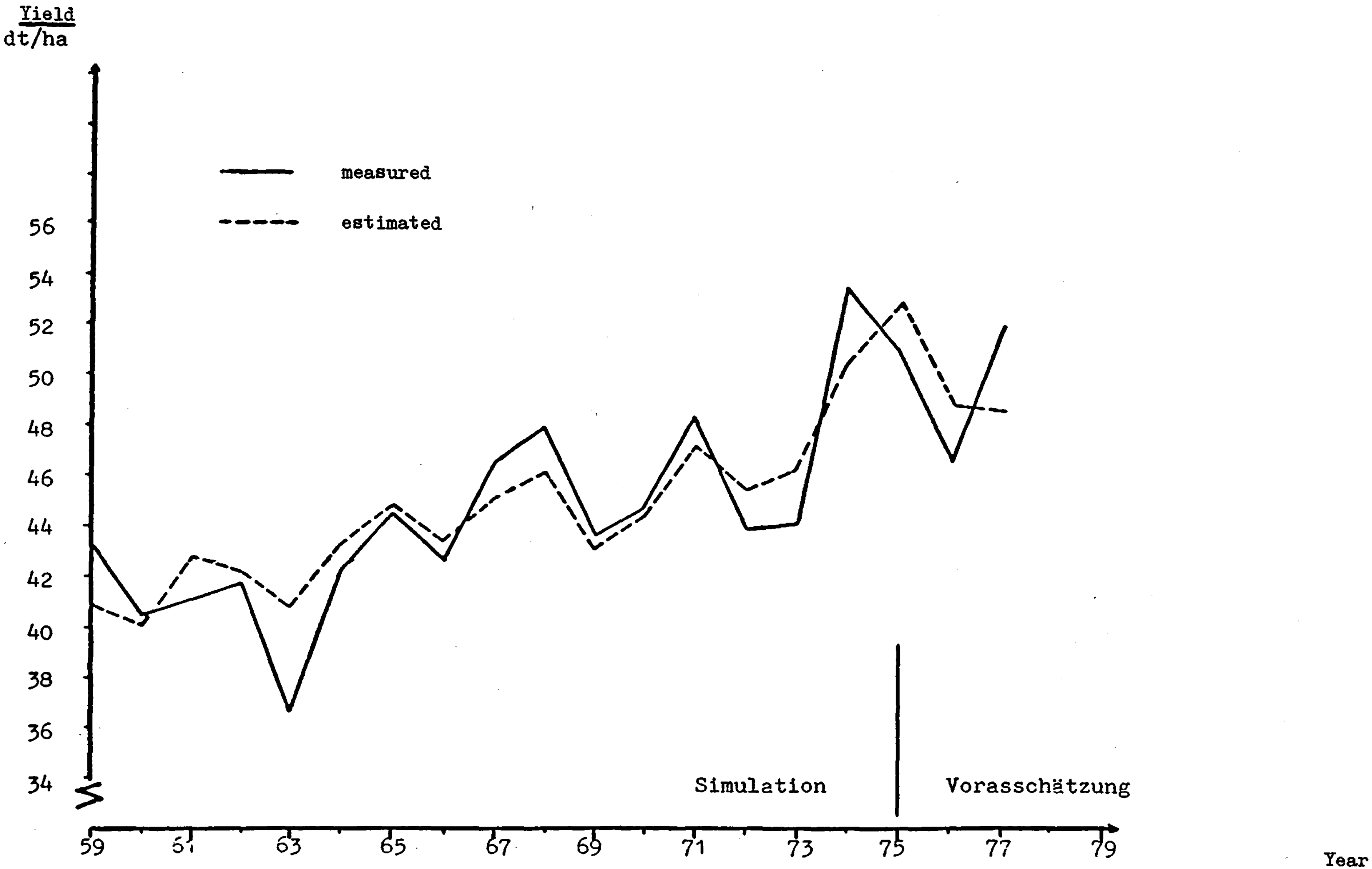

Fig. 5 : Trend of the measured and estimated wheat yields in Ireland

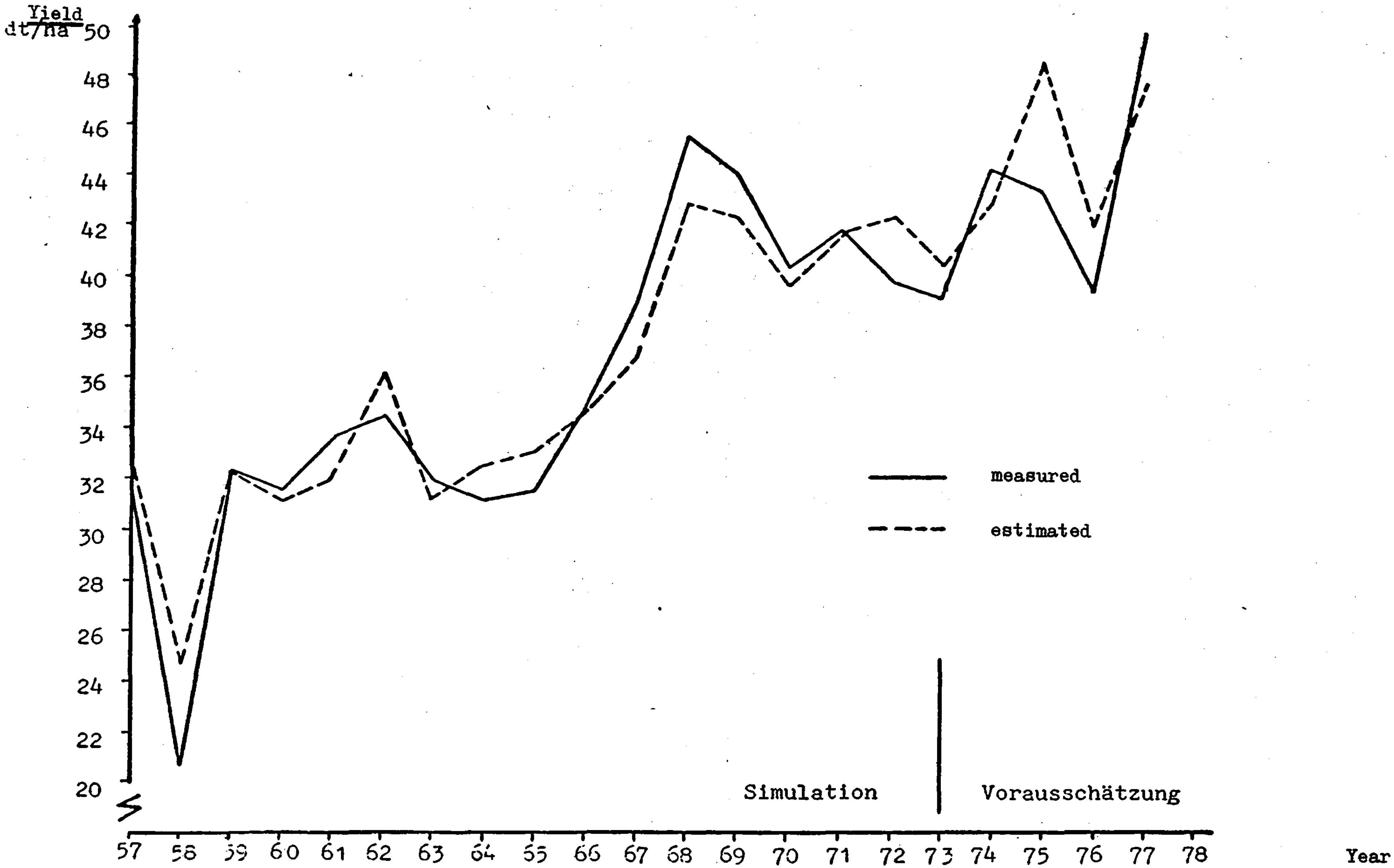

Fig. 6 : Trend of the measured and estimated wheat yields in Luxembourg

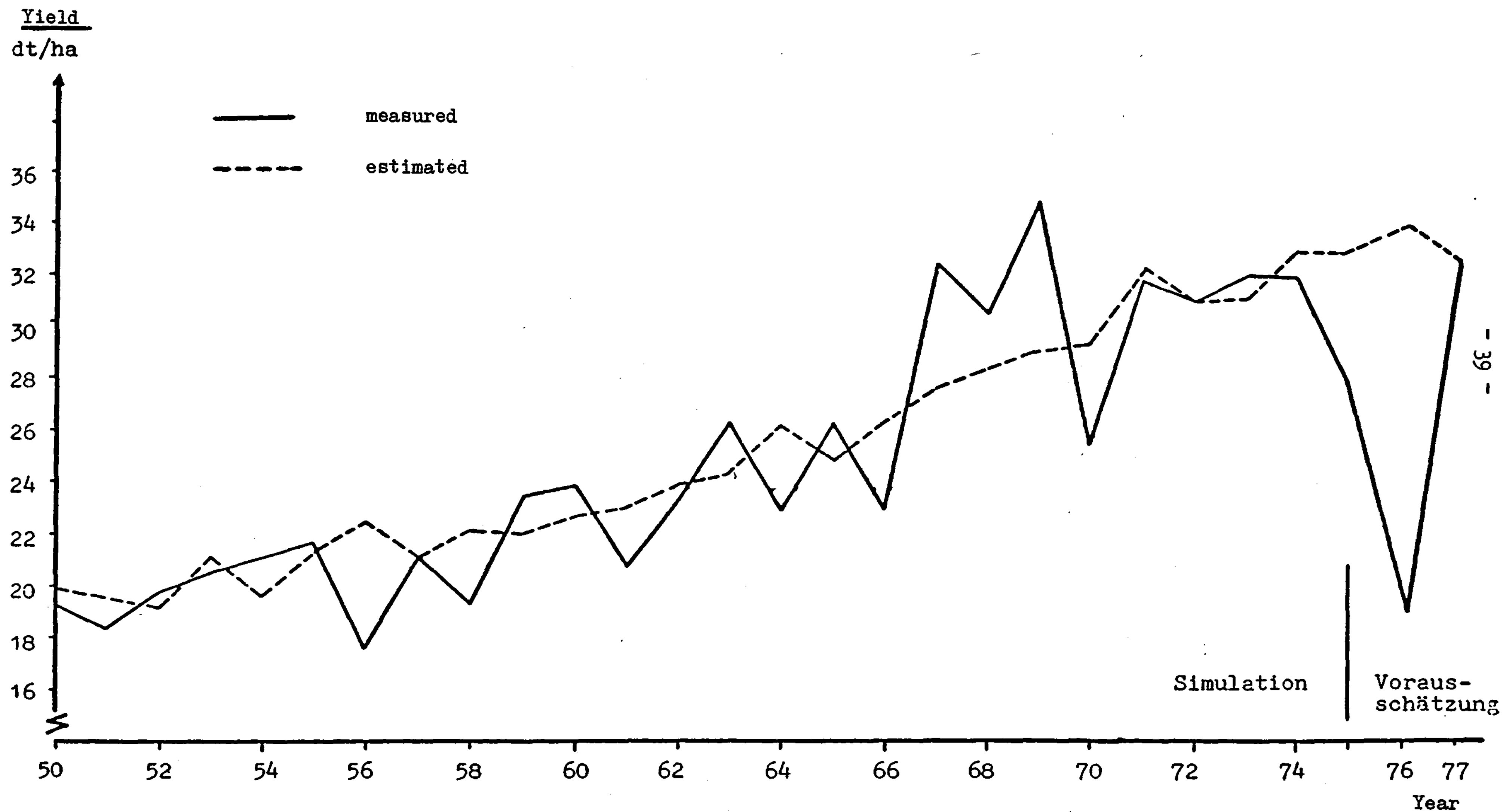

Fig. 7 : Trend of the measured and estimated wheat yields in the Federal Republic of Germany

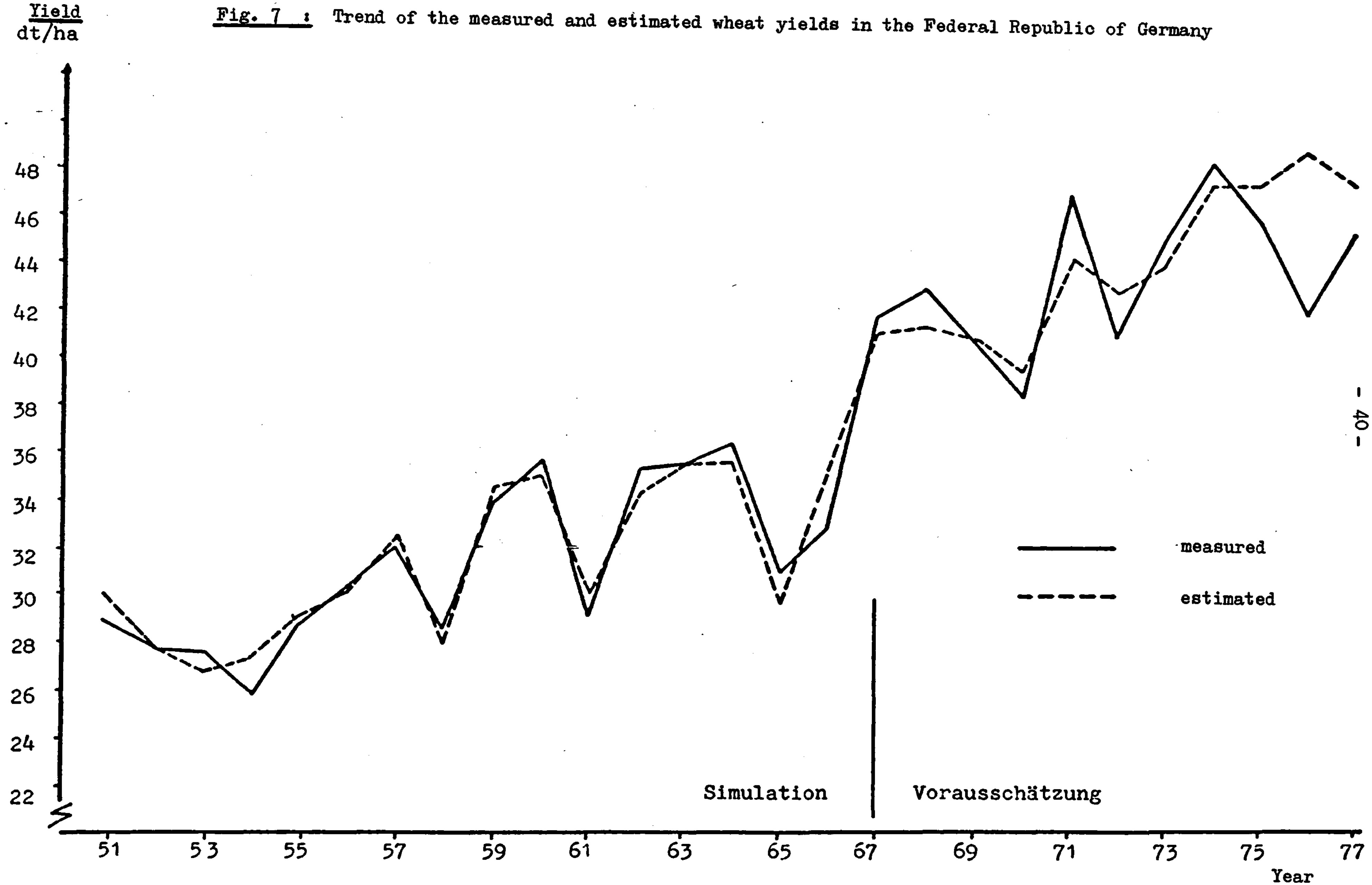

Table 1 : Crops covered in each of the EC countries

	D	F	UK	I	NL	B	L	DK	IRL
Winter wheat	x	x		x	x	x	x		
Spring wheat				x					
Wheat, total			x					x	x
Winter rye	x				x				
Rye, total		x	x	x		x	x	x	
Winter barley	x	x			x	x	x		
Spring barley	x	x			x	x	x	x	x
Barley, total			x	x					
Oats	x	x	x	x	x	x	x	x	x
Cereals, total		x			x		x		
Maize		x		x		x			
Rice				x					
Main crop potatoes	x								
Potatoes, total		x	x	x	x	x	x	x	x
Sugar beet	x	x	x	x	x	x		x	x

D = Germany
F = France
UK = United Kingdom
I = Italy
NL = Netherlands
B = Belgium
L = Luxembourg
DK = Denmark
IRL = Ireland

Table 2 : Data used for the forecast of crop yields in various countries (monthly averages or totals)

Country	Sample	Yield data for wheat $\bar{x}$	s	$s_{\bar{x}}$ %	Number of Stations	Meteorological data: Temperatures Max.	Min.	Mean	Duration of sunshine	Precipitation	Wind speed	Relative humidity	Wet days
Germany	53-71	34.6	5.7	16.5	13	x	x	x	x	x	-	x	-
France	51-72	28,2	7.9	27.9	18	x	x	x	x	x	x	x	-
United Kingdom	51-70	35.6	5.2	14.7	16	x	x	x	x	x	-	-	x
Italy	53-69	19.8	2.6	13.1	13	x	x	-	-	x	-	-	-
Netherlands	53-70	44.5	4.6	10.4	5	-	x	x	x	x	x	x	-
Belgium	53-72	38.9	4.9	12.6	5	x	x	x	x	x	x	x	(x)
Luxembourg	50-75	24.9	5.2	20.7	3	x	x	x	x	x	-	x	-
Denmark	59-75	44.5	4.0	9.1	4	x	x	x	-	x	-	x	-
Ireland	57-73	35.5	6.1	17.1	12	x	x	-	x	x	-	x	-

( ) available only at Uccle

Table 3 : Weather stations which supplied data for the forecast of yields in the various countries

France	United Kingdom	Italy	Netherlands
Alencon	Abington	Bari	Beek
Auxerre	Acklington	Bologna	De Bilt
Brest	Auchincruive	Brescia	Den Helder
Dijon	Boscombe Down	Catania	Eelde
Le Bourget	Cambridge	Florenz	Vlissingen (Flushing)
Le Puy	Craibstone	Naples	
Lille	Cranwell	Ornano	
Lyon	Dumfries	Parma	
Montpellier	Durham	Prescara	
Nantes	East Malling	Rome	
Nice	Raunds	Turin	
Perpignan	Shrewsbury	Udine	
Poitiers	Stonyhurst		
Rennes	Turnhouse		
Strasbourg	Woburn		
Toulon	Writtle		
Toulouse			
Tours			

Belgium	Luxembourg	Denmark	Ireland
Beek	Clervaux	Hald Ege	Belmullet
Le Bourget	Echternach	Jyndevad	Birr
Lille	Luxembourg	Copenhagen	Claremorris
Vlissingen		Naesgard	Clones
Uccle			Dublin
			Kilkenny
			Malin Head
			Mullingar
			Roches Point
			Rosslare
			Shannon
			Valentia

Table 4 : Coefficients of multiple correlation (B) and standard deviations around the regression (s) for Denmark (wheat), as a function of the basic sets of data used in the regression equation.

	multiple B ($r^2 \cdot 100$)					s around the regression				
	Hald Ege	Jyndevad	Copenhagen	Naesgard	Ø	Hald Ege	Jyndevad	Copenhagen	Naesgard	Ø
January	84	83	86	82	84	2,1	2.1	1.9	2.2	2,1
February	88	87	74	86	84	1,8	1.8	2.6	1,9	2,0
March	70	61	66	61	64	2,8	3.2	3.0	3.1	3,0
April	71	74	71	86	76	2.8	2.6	2,7	1.9	2,5
May	87	84	72	79	80	1.8	2,0	2.7	2.4	2.2
June	71	79	74	62	70	2.7	2,5	2.6	3,1	2.7
July	78	79	65	73	74	2.4	2.3	3.0	2.7	2.6
Ø	78	78	73	76	76	2.3	2.4	2.6	2.5	2.4
Ø Temp.	78	83	77	85	81	2.6	2.3	2.7	2.2	2,4
Max. "	82	85	82	81	82	2.4	2.2	2.4	2,5	2.4
Min. "	84	83	89	76	83	2.3	2,4	1.9	2,8	2.4
Rel. hum.	82	86	81	86	84	2.4	2,1	2.5	2.1	2.3
Precip.	89	94	93	82	90	1,9	1.4	1.5	2.5	1.8
Ø	83	86	84	82	84	2 3	2 1	2 2	2 4	2 3

Table 5 : Differences between measured and estimated yields for each basic set of data, with cumulation of several individual results (Denmark, wheat)

	Jyndevad Precip.	Copenhagen Precip.		Hald Ege February		Jyndevad February		Hald Ege May		Copenhagen January		Naesgard February		Naesgard April		Hald Ege Precip.		Copenhagen Min. temp.		Ø
mult.B	94	93		88		87		87		86		86		86		89		89		
s	1.4	1.5		1.8		1.8		1.8		1.9		1.9		1.9		1.9		1.9		
59	1.7	2.4	4.1	1.1	5.2	3.2	8.4	0.9	9.3	2.9	12.2	1.6	13.8	4.9	18.7	1.4	20.1	5.3	25.4	2.5
60	-0.1	-0.2	-0.3	0.8	0.5	3.2	3.7	-0.3	3.4	- 2.1	1.3	1.4	2.7	1.9	4.6	-1.1	3.5	0.8	4.3	0.4
61	-1.6	-0.6	-2.2	-5.8	- 8.0	-2.4	-10.4	2.4	-8.0	- 2.2	-10.2	-0.9	-11.1	-2.5	-13.6	-0.5	-14.1	-2.3	-16.4	-1.6
62	-1.8	-0.9	-2.7	0.8	- 1.9	-0.5	- 2.4	1.8	-0.6	- 2.3	- 2.9	-0.8	- 3.7	0.9	- 2.8	1.4	- 1.4	-2.3	- 3.7	-0.4
63	-5.3	-3.6	-8.9	-2.6	-11.5	-2.1	-13.6	-2.6	-16.2	-12.4	-28.6	-3.9	-32.5	-1.7	-34.2	-3.0	-37.2	-2.6	-39.8	-4.0
64	2.5	1.9	4.4	-0.9	3.5	-1.1	2.4	-0.8	1.6	1.6	3.2	-2.0	1.2	-6.1	- 4.9	-1.3	- 6.2	-4.5	-10.7	-1.1
65	0.1	0.2	0.3	-1.3	- 1.0	-2.4	- 3.4	-3.5	- 6.9	2.2	- 4.7	0.9	- 3.8	-0.9	- 4.7	2.0	- 2.7	-0.4	- 3.1	-0.3
66	0.1	-1.6	-1.5	1.3	- 0.2	-1.5	- 1.7	-1.8	- 3.5	- 2.1	- 5.6	-0.6	- 6.2	-1.9	- 4.3	-4.2	- 8.5	1.4	- 7.1	-0.7
67	2.7	1.5	4.2	1.5	5.7	1.1	6.8	3.6	10.4	2.0	12.4	-0.9	11.5	0.7	12.2	2.0	14.2	0.8	15.0	1.5
68	3.0	0.0	3.0	0.2	3.2	0.0	3.2	-0.7	2.5	0.8	3.3	4.0	7.3	3.8	11.1	3.0	14.1	4.0	18.1	1.8
69	2.3	0.6	2.9	0.6	3.5	-0.5	3.0	0.0	3.0	- 1.2	1.8	4.2	6.0	-0.7	5.3	-0.9	4.4	2.0	6.4	0.6
70	0.1	3.5	3.6	-1.5	2.1	3.4	5.5	-1.3	4.2	- 0.7	3.5	0.5	4.0	-0.6	3.4	0.0	3.4	-0.3	3.1	0.3
71	-1.6	2.2	0.6	2.0	2.6	3.6	6.2	2.4	8.6	1.1	9.7	-0.1	9.6	0.8	10.4	-5.3	5.1	6.4	11.5	1.2
72	-1.2	-2.1	-3.3	-0.5	- 3.8	-2.1	- 5.9	-4.1	-10.0	1.0	- 9.0	-3.0	-12.0	-1.2	-13.2	1.1	-12.1	-3.4	-15.5	-1.6
73	0.2	0.3	0.5	-4.9	- 4.4	-3.3	- 7.7	3.4	- 4.3	- 4.3	- 8.6	-4.1	-12.7	-4.8	-17.5	-1.7	-19.2	-2.3	-21.5	-2.2
74	2.0	2.2	4.2	4.4	8.6	0.5	9.1	3.0	12.1	4.2	16.3	3.4	19.7	2.8	22.5	7.4	29.9	-1.5	28.4	2.8
75	-3.3	-4.4	-7.7	-2.1	- 9.8	4.0	- 5.8	-0.1	- 5.9	- 6.4	-12.3	-1.5	-13.8	1.2	-12.6	-6.7	-19.3	0.7	-18.6	-1.9
Ø	1.7	1.7		1.9		2.1		1.9		2.9		1.9		2.2		2.5		2.4		
Cumul.	Ø		1.6		1.5		1.5		1.3		1.4		1.4		1.4		1.4		1.5	1.5

Table 6 : Basic sets of data which promised the most favourable estimated results for wheat in each of the countries, and standard deviations around the regression

France	s	United Kingdom	s	Italy	s	Denmark	s
Brest April	1.6	Cambridge June	1.8	Catania April/May	1.0	Jyndevad Precip.	1.4
Tours Wind speed	2.1	Cambridge Min. temp.	1.8	Crnano Feb./March	1.2	Kopenhagen Precip.	1.5
Le Bourget Wind speed	2.3	Acklington April	1.9	Brescia Feb./March	1.2	Hald Ege February	1.8
Brest Wind speed	2.3	Stoneyhurst Precip.	1.9	Crnano March/April	1.2	Jyndevad February	1.8
Lyon June	2.3	Auchincruive February	1.9	Brescia March /April	1.3	Hald Ege May	1.8
Montpellier Precip.	2.3	Raunds Min. temp.	2.0	Brescia Dec./Jan.	1.3	Copenhagen January	1.9
Nantes June	2.4	Writtle February	2.0	Pescara Max. temp.	1.3	Naesgard February	1.9
Le Bourget March	2.4	Writtle Min. temp.	2.0	Bari Max. temp.	1.3	Naesgard April	1.9
Nice Precip.	2.4	Turnhouse February	2.0	Bologna June /July	1.4	Hald Ege Precip.	1.9
Lille April	2.4	Rounds Precip.	2.1	Naples March/April	1.4	openhagen Min. temp.	1.9

Netherlands	s	Belgium	s	Luxembourg	s	Ireland	s
Beek Sunshine	1.6	Lille April	2.1	Luxembourg April	2.4	Birr Sunshine	1.8
Eelde April	1.7	Uccle Precip.	2.1	Echternach February	2.5	Shannon Humidity	1.8
Vlissingen April	1.8	Lille Humidity	2.1	Clervaux July	2.5	Malin Head Humidity	2.0
Beek Precip.	1.9	Uccle January	2.2	Echternach January	2.6	Valentia Sunshine	2.1
Beek June	2.3	Beek Precip.	2.2	Clervaux February	2.6	Belmullet Humidity	2.1
Den Helder April	2.3	Vlissingen Sunshine	2.3	Clervaux May	2.6	Clones Humidity	2.2
Vlissingen Precip.	2.4	Lille Sunshine	2.4	Echternach July	2.6	Shannon Sunshine	2.2
Eelde Wind	2.5	Lille July	2.5	Echternach Sunshine	2.6	Belmullet May	2.2
Beek February	2.5	Vlissingen April	2.5	Luxembourg Max. temp.	2.6	Claremorris Humidity	2.3
Vlissingen May	2.6	Vlissingen Precip.	2.5	Luxembourg Humidity	2.6	Mullingar Sunshine	2.3

Table 7 : Accuracy that can be achieved in the forecasting of wheat yields in the EC countries

	Yield	s around regr.*		Ø deviation in simulated forecasts	
	$\bar{\bar{x}}$	min	max	abs.	as % of $\bar{\bar{x}}$
Germany	34.6	-	-	1.4	4
France	28.2	1.6	2.4	1.4	5
United Kingdom	35.6	1.8	2.1	1.7	5
Italy	19.8	1.0	1.4	0.8	4
Netherlands	44.5	1.6	2.6	1.4	3
Belgium	38.9	2.1	2.5	1.6	4
Luxembourg	24.9	2.4	2.6	2.0	8
Denmark	44.5	1.4	1.9	1.5	3
Ireland	35.5	1.8	2.3	1.4	4

* range for the ten best equations used for the yield estimate

Table 8 : Derived errors of estimation* for various countries and crops (in absolute terms in dt/ha or t/ha)

	D	F	UK	I	NL	B	L	DK	IRL
Winter wheat	1.6	1.4		0.8	1.4	1.7	1.9		
Spring wheat				2.3					
Wheat, total			1.5					1.1	1.4
Winter rye	0.9				1.1				
Rye, total		0.6	0.8	0.4		0.7	1.5	0.5	
Winter barley	1.5	1.4			1.0	1.8	1.8		
Spring barley	1.8	1.2			2.5	2.2	2.1	0.7	1.0
Barley, total			1.4	0.4					
Oats	1.8	0.9	0.7	0.6	1.4	1.4	2.1	0.7	0.5
Cereals, total		0.8			1.0		2.0		
Maize		2.4		1.0		2.6			
Rice				1.8					
Main crop potatoes (t/ha)	0.9								
Potatoes, total (t/ha)		0.8	0.8	0.2	1.0	1.8	2.3	0.9	1.7
Sugar beet (t/ha)	2.4	2.0	1.8	0.8	2.1	2.8		2.1	2.1

* 80 % of the minimum standard deviation around the regression achieved with the best equation.

Table 9 : Derived accuracy of estimation for various countries and crops (relative errors of estimation given in Table 8 as % of average yields)

	D	F	UK	I	NL	B	L	DK	IRL
Winter wheat	4(4)	5(5)	4(5)	4(4)	3(3)	4(4)	8(8)	2(3)	4(4)
Spring wheat				19					
Wheat, total									
Winter rye	4(3)				4				
Rye, total		4	3	2		2	6	2	
Winter barley	3(3)	6			3	5	7		
Spring barley	4(5)	4			7	6	8	2	3
Barley, total			4	3					
Oats	2(5)	4	3	4	4	4	9	2	2
Cereals, total		3			3		8		
Maize		7		3		6			
Rice				4					
Main crop potatoes	3								
Potatoes, total		4	4	2	3	7	10	4	7
Sugar beet	5	6	6	2	5	7		5	6

( ) accuracy of estimation actually achieved in genuine forecasts (D) or simulated forecasts

Table 10 : Crop areas and yields of spring wheat in Italy

	Crop areas in 1 000 ha	Yield (dt/ha)
1955	67	9.6
56	66	8.2
57	61	10.0
58	77	9.8
59	97	10.1
60	89	8.6
61	214	20.0
62	75	10.2
63	74	11.6
64	68	10.5
65	63	12.6
66	54	12.7
67	154	25.9
68	56	14.1
69	59	14.6
1970	56	14.0

Table 11 : Results of the yield forecasts for wheat in each of the EC countries in the years outside the reference period.

Country / Crop / Sample	Germany Wint. wheat 51-67		France Wint. wheat 51-72		Italy Wint. wheat 53-69		Netherlands Wint. wheat 53-70		Belgium Wint. wheat 53-72		Luxembourg Wint. wheat 50-75		Un. Kingdom Wheat, tot. 51-70		Ireland Wheat, tot. 57-73		Denmark Wheat, tot. 59-75	
Year	meas.	estim.	meas.	estim.	meas.	estim.	meas.	estim.	meas.	estim.	meas.	estim.	meas.	estim.	meas.	estim.	meas.	estim.
1950	25.8	-	17.9	-	16.6	-	33.2	-	31.9	-	19.2	19.8	26.3	-	22.5	-	35.0	-
51	28.6	29.4	16.7	16.7	14.8	-	37.4	-	32.6	-	18.4	19.5	27.2	27.2	22.0	-	33.8	-
52	27.6	27.4	19.6	18.1	17.0	-	40.6	-	34.3	-	19.7	19.0	28.5	30.4	25.8	-	40.6	-
53	27.5	26.2	21.3	20.9	19.1	17.7	39.6	41.4	33.4	31.9	20.6	21.0	30.1	30.2	29.1	-	39.8	-
54	26.1	27.5	23.6	21.1	15.4	15.6	38.7	38.1	32.3	29.7	21.1	19.6	28.5	28.8	25.2	-	34.2	-
55	28.9	29.2	22.8	22.4	19.7	18.8	38.6	40.6	38.0	36.3	21.6	21.2	33.5	30.5	28.0	-	39.0	-
56	30.4	30.2	16.4	19.9	17.9	18.7	38.0	37.9	31.9	35.3	17.6	22.4	31.1	31.2	31.5	-	41.9	-
57	32.0	32.5	23.8	22.9	17.4	17.6	42.4	43.7	36.7	36.3	21.1	21.0	31.9	30.9	31.8	32.5	44.1	-
58	28.5	27.9	20.8	22.6	20.5	20.6	39.6	41.3	35.8	36.2	19.4	22.2	30.8	32.9	20.7	24.6	36.2	-
59	34.0	34.4	26.1	26.0	18.3	18.7	46.2	45.6	40.6	40.8	23.5	22.0	36.2	36.6	32.3	32.2	43.4	40.9
60	35.8	35.0	25.4	25.2	15.0	18.1	50.1	45.5	38.0	37.4	23.9	22.7	35.7	36.6	31.6	31.2	40.5	40.1
61	29.1	29.9	24.1	25.8	19.1	19.5	39.5	40.7	35.5	36.7	20.8	23.0	35.4	38.4	33.7	32.1	41.2	42.8
62	35.3	34.6	31.1	29.4	21.0	22.0	50.3	47.4	41.2	40.2	23.4	23.9	43.5	37.4	34.5	36.3	41.8	42.2
63	35.6	35.8	25.3	26.9	18.6	19.2	44.8	43.2	36.9	38.2	26.5	24.4	39.0	39.0	31.9	31.2	36.8	40.8
64	36.4	35.6	31.8	31.8	19.6	18.0	50.1	48.9	42.1	40.7	23.0	26.2	42.4	39.5	31.3	32.6	42.2	43.3
65	30.9	29.5	32.7	32.3	22.9	21.8	45.5	44.8	37.9	37.6	26.5	24.8	40.6	39.5	31.6	33.2	44.6	44.9
66	32.9	35.1	28.2	31.3	22.1	22.1	42.9	42.9	30.0	37.4	23.0	26.3	38.4	37.9	34.9	34.7	42.7	43.4
67	41.7	40.8	36.3	35.1	23.8	23.0	50.9	49.5	44.5	44.0	32.5	27.7	41.8	40.3	39.0	36.9	46.6	45.1
68	42.8	40.0	36.9	35.6	22.7	23.0	47.4	47.5	44.0	43.0	30.5	28.4	35.4	40.8	45.6	42.8	48.0	46.2
69	40.6	39.8	36.0	35.3	22.8	23.5	47.4	50.5	41.2	44.1	35.0	29.1	40.4	42.7	44.0	42.3	43.7	43.1
70	38.3	39.3	34.7	36.3	23.5	24.8	48.6	49.8	44.2	41.5	25.5	29.4	41.9	42.5	40.3	39.7	44.8	44.5
71	46.8	44.0	39.3	39.4	25.7	24.6	52.3	52.4	47.0	44.8	32.0	32.2	43.9	44.5	41.8	41.7	48.5	47.3
72	40.8	42.8	46.4	42.9	24.9	24.4	44.2	54.2	45.9	46.0	31.0	31.0	42.4	45.8	39.8	42.3	43.9	45.5
73	44.8	44.5	45.6	-	24.7	26.6	54.2	54.0	51.6	48.0	32.0	31.1	43.7	44.2	39.1	40.7	44.1	46.3
74	48.3	47.0	46.8	-	25.9	27.6	59.9	55.8	53.7	50.3	32.0	33.0	49.7	44.9	44.5	43.2	53.5	50.7
75	45.5	47.1	39.5	-	26.9	-	51.5	56.1	41.3	48.3	28.0	32.9	43.4	46.5	43.7	48.9	51.0	52.9
76	41.9	48.7	38.3	-	25.8	-	56.5	56.8	46.7	57.1	19.1	34.2	38.5	-	39.7	42.2	46.8	49.1
77	45.3	47.4	42.7*	45.6	22.3*	25.1	53.8	54.4	42.1*	45.8	32.6*	32.7	48.8	46.2	50.0*	48.0	52.2	48.8

* provisional

Table 12 a : Basic sets of data used and results of the wheat yield forecast for 1977

France		Calculated yield	United Kingdom		Calculated yield
Lille	February	44.1	Cambridge	June	41.1
Lille	April	50.1	Writtle	February	36.7
Le Bourget	February	45.2	Auchincruive	February	45.0
Le Bourget	March	45.8	Craibstone	February	44.5
Rennes	March	49.8	Turnhouse	February	46.6
Brest	April	48.7	Boscombe Down	February	38.3
Strasbourg	February	41.5	East Malling	June	54.1
Strasbourg	May	46.8	Turnhouse	April	49.5
Lyon	April	45.5	Durham	May	53.2
Pau	January	43.3	Raunds	February	43.3
Pau	February	43.8			
Pau	March	46.6			
Toulouse	April	50.5			
Montpellier	January	41.7			
Toulon	January	39.9			
	ø	45.6		ø	46.2
	S ±	3.3		S ±	8.0

Italy			Danmark		
Parma	Feb./March	25.2	Hald Ege	February	45.7
Pescara	Feb./March	22.7	Hald Ege	May	54.0
Bari	Jan./Feb.	26.3	Jyndevad	May	49.7
Bari	Feb./March	23.5	Naesgard	February	44.4
Rome	Feb./March	25.9	Hald Ege	July	50.9
Turin	Jan./Feb.	30.5	Naesgard	April	50.0
Turin	Feb./March	21.8	Jyndevad	February	47.3
Brescia	Jan./Feb.	24.3	Jyndevad	June	47.5
Brescia	Fab./March	24.2	Jyndevad	July	50.6
			Jyndevad	April	47.5
	ø	25.1		ø	48.8
	S ±	2.7		S ±	2.8

Table 12 b : Basic sets of data used and results of the wheat yield forecast for 1977

Netherlands		Calculated yield	Belgium		Calculated yield
Vlissingen	April	56.1	Uccle	Wet days	38.1
Vlissingen	May	61.7	Uccle	Sunshine	45.3
Vlissingen	Precip.	54.9	Uccle	Precip.	42.6
Eelde	April	56.9	Vlissingen	April	50.7
Eelde	Wind	53.9	Vlissingen	Sunshine	45.0
Beek	February	53.3	Vlissingen	Precip.	50.5
Beek	June	65.3	Beek	June	43.9
Beek	Sunshine	54.9	Beek	Precip.	47.5
Beek	Presip.	49.7	Beek	Sunshine	46.7
Den Helder	April	48.8	Beek	April	48.0
	ø	54.4		ø	45.8
	S ±	6.2		S ±	3.8

Luxembourg			Ireland		
Luxembourg	April	33.5	Birr	Sunshine	50.1
Echternach	February	35.4	Shannon	Humidity	45.1
Clervaux	July	32.6	Malin Head	Humidity	43.7
Echternach	January	34.2	Valentia	Sunshine	52.6
Clervaux	February	32.0	Belmullet	Humidity	49.4
Clervaux	May	26.8	Clones	Humidity	47.2
Echternach	July	32.8	Shannon	Sunshine	43.5
Echternach	Sunshine	31.6	Mullingar	Sunshine	55.0
Luxembourg	Max.temp.	34.2	Mullingar	Humidity	41.3
Luxembourg	Humidity	34.1	Roches Point	Sunshine	44.8
			Claremorris	Humidity	52.5
			Belmullet	May	56.7
			Birr	April	45.6
			Valentia	April	44.5
	ø	32.7		ø	48.0
	S ±	2.4		S ±	4.8

Table 13 : Forecast yields and production of winter wheat in each of the countries and EC average.1)

Country	Crop area (1 000 ha)	Yield (dt/ha)		Production (1 000t)	
		meas.	est.	meas.	est.
FR of Germany	1406	45.3	47.4	6376	6664
France	3997	42.7	45.6	17052	18226
Italy **	2786	22.3	25.1	6218	6993
Netherlands	109	53.8	54.4	584	593
Belgium	164	42.1	45.8	690	751
Luxembourg **	8	32.6	32.7	27	26
United Kindom *	1073	48.8	46.2	5227	4957
Ireland	48	50.0	48.0	242	230
Denmark *	116	52.2	48.8	605	566
EUR-9	9707	38.14	40.18	37021	39006

1) Data on crop areas and measured yields and production taken from EUROSTAT publication "Crop production" No 11-1977.

* including spring wheat

** including spring wheat, although the yield of winter wheat only is estimated.

Veröffentlichungen

Publications

Publications

Agrarstatistische Studien — Agricultural Statistical Studies — Etudes de statistique agricole

1	Influence des différents caractères de la carcasse de bovins sur la détermination de son prix — B.L. DUMONT, J. ARNOUX	1968	FR
2	Statistische Methoden zur Feststellung der Produktionskapazität der Obstanlagen — G. NEURAY, S. MASSANTE, M. PETRY Méthodes statistiques en vue de déterminer le potentiel de production des vergers — G. NEURAY, S. MASSANTE, M. PETRY	1968	DE, FR
3	Die methodischen Probleme bei einer Erhebung der Struktur der Betriebe mit erwerbsmäßigem Anbau von Gartengewächsen — H. STORCK Méthodologie d'une enquête sur la structure des exploitations horticoles professionnelles — H. STORCK	1968	DE, FR
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[1] The French version is published in the series 'Statistical Information' under the number 4-1976.

[2] An English version is available on special order.

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