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PERIODICAL FLUCTUATIONS OF SOIL FERTILITY AND CROP YIELDS

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A remarkable experience of soil investigation consists in the variations observed after repeating the sampling of the same spot. The deviations are considerably larger, as may be expected from the known errors of sampling and analysis. Influences of season play a part in this respect. Bruin (1) found that fluctuations of pH may be caused by variations of salt content and alternate drying and moistening of the soil.

Besides yearly differences are apparent, if the results determined at harvest are compared over a long period. It is noticeable that these fluctuations show an undeniable rhythmic character.

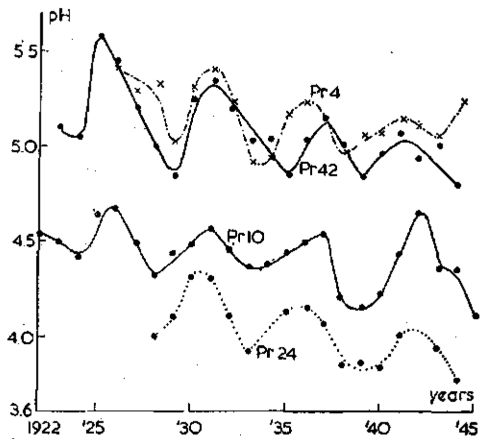

Fig. 1. Course of pH on 4 experimental fields.

The course of pH on a few experimental fields which are lying in a distance of some ten km from each other in the N.E. of the country is represented by fig. 1. Pronounced, though not altogether regular, rhythmic fluctuations are apparent. The results correspond on the different fields, though individual deviations occur. From these and a few other results the mean course of pH has been derived (fig. 2). The individual deviations of the different fields are plotted as dots.

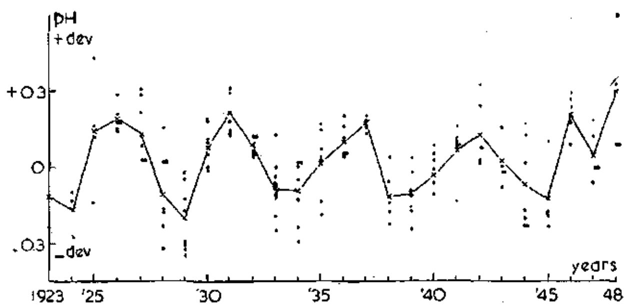

Fig. 2. Average course of pH.

Similar fluctuations have been noted for the determinations of K_2O in 0.1 normal HCl solution and P_2O_5 in water. The deviations are positively correlated to those of the pH (fig. 3). It may be observed, however, that also negative correlations between pH and K-number have been found in some cases.

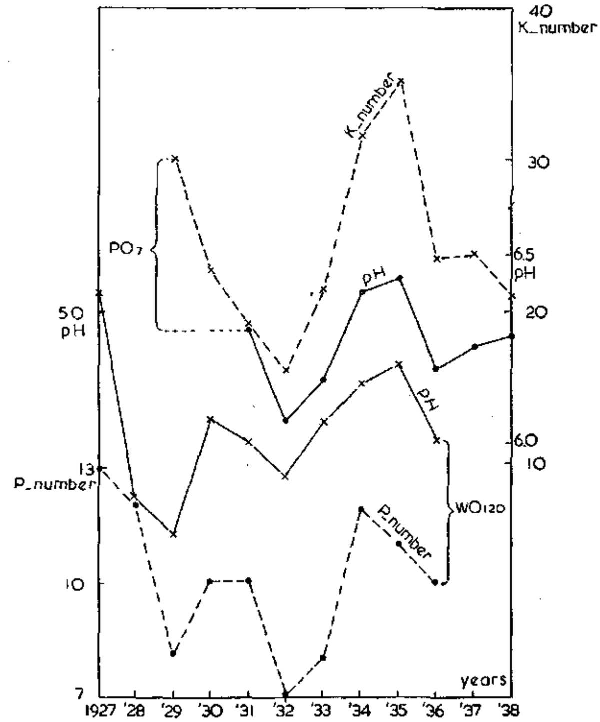

Fig. 3. Parallel course of pH and P-number and of pH and K-number on 2 exp. fields.

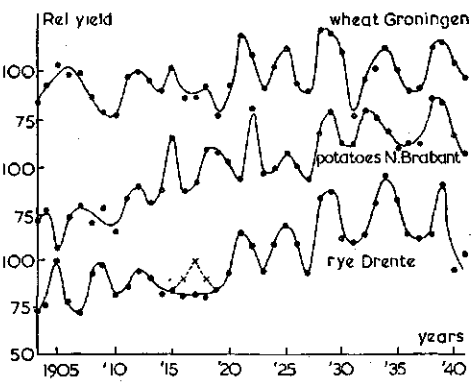

Fig. 4. Course of yields of rye, potatoes and wheat in different provinces. (Dotted line correction for deviating results during World War I).

Corresponding rhythmic fluctuations of crop yields have also occurred during the last half century. This is clearly demonstrated by the course of crop yields obtained in practice in different parts of the Netherlands (fig. 4). Especially after 1919 a regular periodicity is apparent. Before this year rye has also shown a similar rhythm, at least if a correction for the abnormal years of the first World War, which is based on experimental results, is accepted. After 1940 the yields are less reliable as a result of the war. It may be mentioned however, that the years 1943, 1948 and 1949 have yielded excellent crops, whereas the yields of 1945 and 1946 were bad (also on experimental fields). BEAN (2) has pointed out the existence of similar periodicities of the yields of wheat in the United States.

It is very interesting to note the agreement between the course of the yields of wheat grown on clay soil and of rye grown on sandy soil, especially after 1919. It is likely that the type of soil or the kind of crop have no dominating influence.

A comparison between the course of crop yields of wheat (*fig.* 4) and the course of pH (fig. 2) shows a marked negative correlation. The same was also repeatedly observed on the individual fields.

It is plausible to suggest that rhythmic variations of climate would be responsible for the periodicity observed. In fact, there are some indications, but little can be said with certainty at present.

Another question is put as to the mathematical significance [1]). It is not easy to tackle this question, as it is rather acceptable that a rigid periodicity, with periods of constant duration, is out of the question. It may be solved by means of a periodogram analysis to what extent may be spoken of a really constant periodicity. Starting-point of this method is the so-called BUYS BALLOT table.

According to this method a value P is determined, which indicates the probability that the period found as a result of the analysis would have completely arisen by chance in a progression which is not governed by periodicity.

The value P is determined for periods in which a periodical course seemed to be likely according to the graphical representation. The analysis has been tried for different duration of the period, in the case of pH e.g. of 4½, 5 and 5½ years respectively.

The following results were obtained:

period 4½ years $P = 0.015$
,, 5 ,, $P = 0.00014$
,, 5½ ,, $P = 0.0005$

According to these determinations the periodicity of the pH is quite significant. The best result is obtained for a period of 5 years. The short series (only 25 years) does not allow a greater accuracy.

The yields of crops (estimates) show a much higher value of P, though significant periodicity could be found in some cases. A really significant periodicity was also observed in the number of hot days (max. $t > 25°$) in the period 21 May—20 June.

crop	province	time	period in years	P
wheat	Groningen	1906—1941	4½	0.028
sugar beets	,,	1903—1938	4	0.021
,, ,,	,,	1892—1941	4	0.067
potatoes	Zeeland	1907—1941	3½	0.088
rye	Drente	1901—1940	4½	0.310
number of hot days	Groningen	1912—1943	4	0.009
number of hot days	,,	1904—1943	4	0.024

[1]) The mathematical calculations have been made under the direction of Mr TH. J. D. ERLEE and Dr E. F. DRION of the Statistics Department T.N.O.

A drawback of the method is that a shift of the periodicity or a shift in phase may be responsible for a high value of P. From fig. 4 it is obvious that a clear rhythmical course of yields is apparent in the case of rye. However, the result of the calculation is highly insufficient, which is caused by the varying length of 4 and 5 years respectively of the period.

Another objection to be raised is the arbitrary choice of the period of observation, in which a periodical fluctuation was presumed. Thus this period has not been taken at chance. This objection does not, however, hold good for the calculation with the pH-values. In this case all available observations have been used. As has been remarked the duration of this series is however still rather short.

The difficulty arising from a shift in phase is overcome by the calculation of serial correlation coefficients. According to this method the correlation is determined between pairs of numbers from the same progression, which differ n years (e.g. the correlation between the terms of the series 1919—1945 with the terms of the series 1921—1947, if $n = 2$).

It is necessary to eliminate the influence of a possible trend, which has been determined beforehand by means of a free-hand curve. The results of a calculation made with thoroughly estimated mean regional crop yields of sugar beets (1901—1940) and rye (1901—1939, fig. 4), the weighed yields of *oats grown on a large farm (600 ha) (1919—1947)*, and of pH on experimental fields (1923—1948, fig. 2) are given below:

serial correlation coefficient	beets	rye	oats	pH
r_1	— 0.13	+ 0.11	+ 0.14	+ 0.19
r_2	— 0.49	— 0.56	— 0.37	— 0.42
r_3	— 0.03	— 0.18	— 0.03	— 0.68
r_4	+ 0.43	+ 0.18	+ 0.34	+ 0.02
r_5	— 0.18	+ 0.18	+ 0.05	+ 0.66
r_6	— 0.19	— 0.06	— 0.12	+ 0.45
r_7	+ 0.15	+ 0.02	+ 0.19	— 0.34

There is a clear periodicity in the successive coëfficients and, moreover, the periods for the 3 crops are about the same (4 years); the period for the pH is perhaps a little longer (5 years). The agreement in the shape of the different periodograms makes it acceptable that the underlying series of yields are no random series. Moreover a number of these coëfficients are significantly different from zero at the 5 %-point (r about 0.38) and even at the 1 %-point (r about 0.44).

It can be proved mathematically that certain periodic series with random shifts in phase give correlograms with the same periodicity. The reasons given above therefore point to a periodicity in crop yields and soil fertility factors with a period of about 4—5 years.

LITERATURE

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