CYCLICAL VARIATIONS OF CROP YIELDS INDUCED BY WEATHER THROUGH THE INTERMEDIARY OF THE SOIL

by

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Crops yields are largely dependent on meteorological factors. In many cases these effects are transmitted through the intermediary of the soil. Rainfall in summer, for instance, controls the availability of soil potash (5); rainfall in winter determines the amount of nitrogen available in spring (6). However, in this paper still unknown cumulative weather effects will be discussed.

The marine climate of Western Europe is variable. It is therefore, remarkable that regular cyclical variations of crop yields with a period of about 4—5 years occur (3, 4).

These cyclical variations have been observed on experimental fields and in practical farming. The yields of various crops show similar variations. The same variations are found on different soil groups. This is demonstrated by the agreement between the sequence of yields of rye grown on sandy

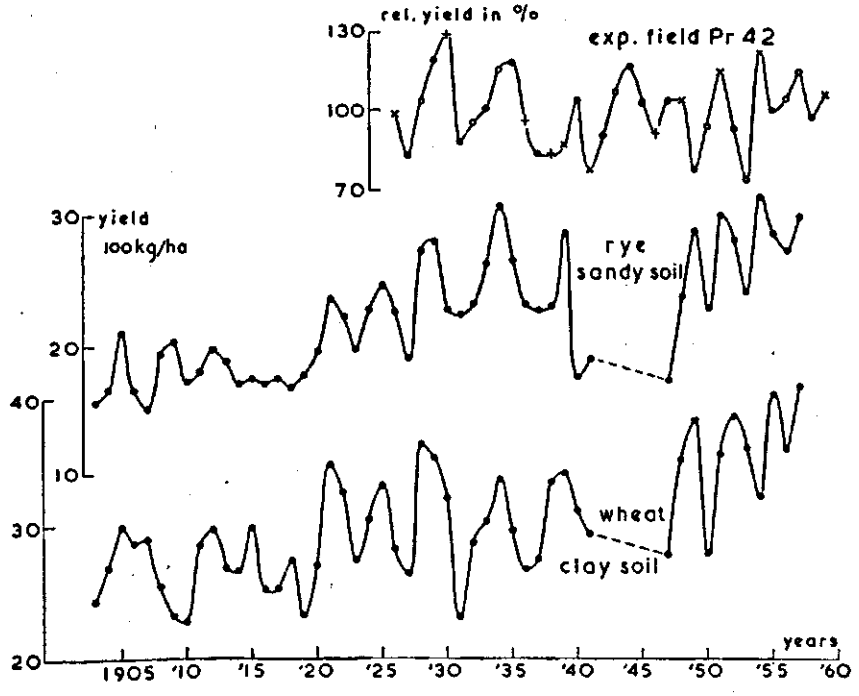

Fig. 1. *Cyclical variation of crop yields.* Course of yields of rye on sandy soils and wheat on clayey soils in practical farming in the northeastern Netherlands and course of yields (different crops in rotation) on the experimental field Pr 42 in the same region.

soils, and of wheat grown on clayey soils in practical farming (fig. 1), This agreement has been apparent especially since 1919.

So far the phenomenon of rhythmically varying crop yields has not drawn much attention in the literature (1, 2, 3, 4).

The similar conduct of different crops makes it possible to observe this phenomenon also on long-term experimental fields planted with crops in the rotation. For this purpose yields are expressed in percentages of the average yields obtained with the particular crop in the course of time. The sequence of these relative yields of different crops shows periodical variations similar to those obtained in practical farming with one single crop (also fig. 1).

It follows from this general agreement between results obtained in various cases that the phenomenon is probably controlled by meteorological conditions. On the other hand, the phenomenon of wave-like variations of weather conditions, is unknown. Moreover, such variations would have to be very regular and to bear on factors of considerable influence on the yields. It seems contradictory that crops grown in different parts of the year and with different ecological needs should behave similarly. It is also surprising that there is an agreement between soils generally supposed to show different responses to weather conditions (clay, sand). This calls for an explanation.

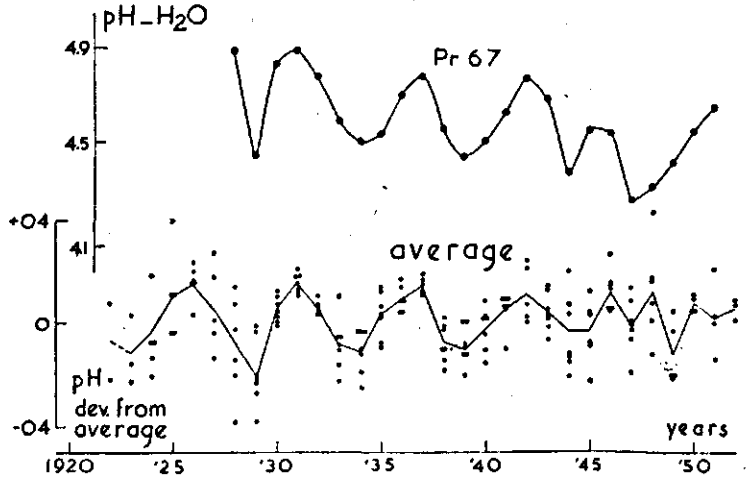

Fig. 2. *Cyclical variations of a soil fertility factor.* Course of pH determined once a year at harvest in water suspension on the exp. field Pr 67 and the average course of pH on 8 exp. fields.

Another aspect is that cyclical variations also occur in the soil, as has been found by means of annual determinations of soil factors, such as pH, water-soluble phosphorus and exchangeable potassium. Especially the first-mentioned factor, determined at harvest on the experimental fields once a year varies with an astonishing regularity (fig. 2). Average results of 8 long-term experiments are also shown in this figure. In some years all deviations tended in the same direction, in other years there were some differences between the individual fields. It is evident, however, that the average course of variations was regular in a period of considerable length.

A further study of weather reveals the occurrence of sharply alternating periods of higher and lower average rainfall, especially marked between 1917 and 1950. The duration of these phases has often been about 2 years or even more.

This is clearly demonstrated by a summation curve of the deviations from average rainfall of each month (fig. 3). Rising parts of this curve indicate periods with a rainfall above the average. The same figure shows the average course of pH and the yields of wheat in practical farming. For better comparison the latter have been plotted reversely. It is evident that there is a fair agreement between these curves.

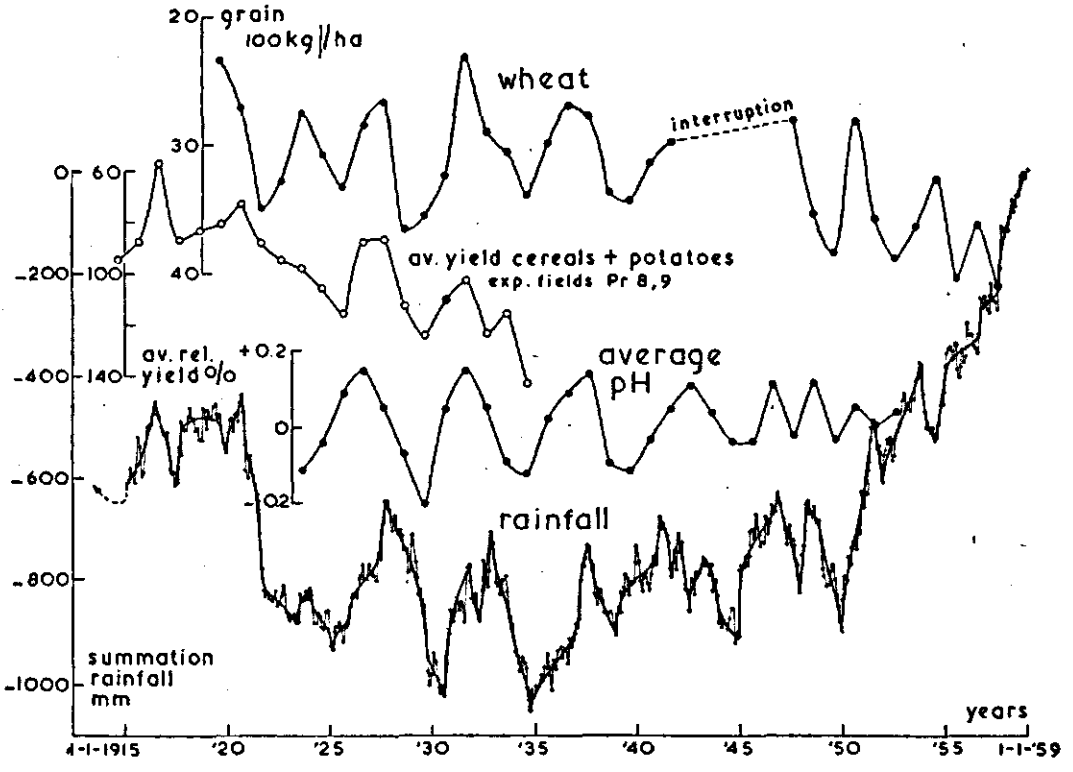

Fig. 3. *Agreement between rainfall, variations of soil fertility and yields.* Part of summation curve of the deviations from the averages of monthly rainfall, representing 1915—1958, computed for the period of 1-1-1880 till 31-12-1958, course of average pH, course of yields of wheat in practical farming, and course of average yields of potatoes and cereals grown on an old exp. field (Pr 8 + 9).

The fact that the course of pH is really controlled by rainfall is clearly confirmed, if a larger number of pH-values is determined during the year (fig. 4). pH rises continuously in wet periods and falls in dryer ones. In other words, the course of pH is controlled by the cumulative effects of rainfall. The actual pH-value depends on the sum of effects during some preceding years. As similar results have been obtained for available phosphorus and potassium (and it is probable that also other factors are involved) it is obvious that considerable fluctuations of soil fertility occur.

The close agreement between yield curve and pH curve suggests that the cyclical course of crop yields is due to the same cause. The periodicity found originated as soon as weather phases of about equal length and lasting for not too short a time alternate. This actually happened between 1917 and

1950. In later years the phases were shorter and the resulting periodicity of crop yields was less pronounced.

This does not mean, however, that pH is the controlling factor of crop yields. On the contrary, the fact that pH, soluble phosphorus as well as exchangeable potassium show a similar pattern, suggests the conclusion that a complex of soil factors undergoes the same changes.

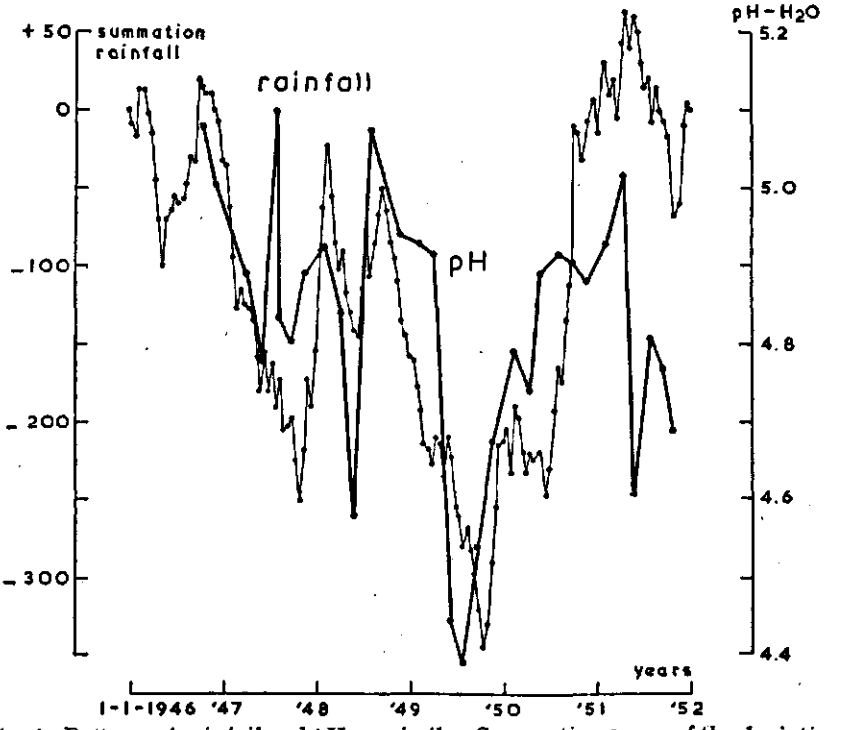

Fig. 4. *Patterns of rainfall and pH are similar.* Summation curve of the deviations from the averages of $\frac{1}{4}$ monthly rainfall for a period of 6 years compared with the course of pH on exp. field Pr 837 determined every two months.

The view that soil fertility is an intermediary factor explains why crops with different ecological needs and different growth periods generally behave similarly. Apparently, both sandy and clayey soils undergo the same harmful effects of long wet periods. It is evident that crop yields are largely controlled by these fluctuations of soil fertility originating from continual weather effects.

However, it seems rather unexpected that the regularity of the variations of crop yields and soil fertility factors is so great in spite of a possible influence of experimental errors and the rather restricted regularity of the inducing agent. Possibly, this might point to an already existing susceptibility of soil fertility to a variability of a cyclical nature. Should this be true, then more or less regular changes of weather might be looked upon as coordinating rather than causing factors.

Part of the average results obtained on the oldest fertilizer experimental field in the Netherlands, dating from 1881, are also shown in fig. 3. The yield pattern resembles the pattern of cumulative rainfall. The same was apparent before 1915.

As long ago as 1916 Kamerling (2) pointed to the cyclical variation of wheat yields on the well-known Broadbalk field of Rothamsted Experimental Station at Harpenden, England where this crop has been grown since 1843. These fluctuations are similar to those observed on Dutch experimental fields in recent years. It could be shown that the cyclical variations observed on this field can also be explained to a large extent by cumulative effects of rainfall. In this earlier period similar alternating wet and dry periods occurred.

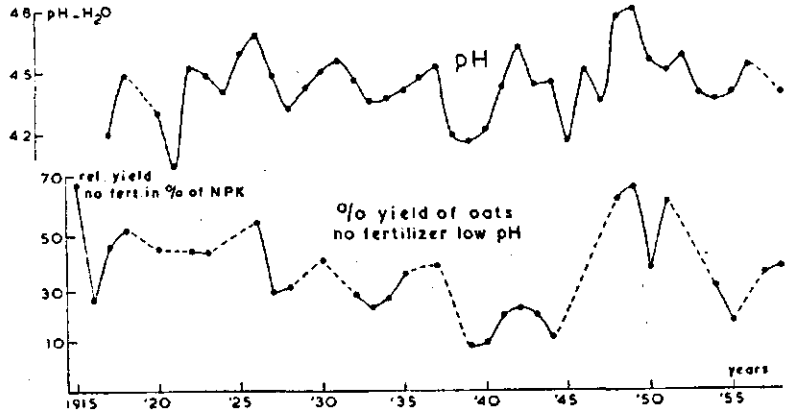

Fig. 5. *Periodical lime response.* Course of pH determined at harvest and course of yields of oats in % grown without fertilizers and at low pH (in % of yields with complete dressing and with high pH).

The cyclical variation of the separate soil factors may of course also give rise to a cyclical response to certain fertilizing treatments. The course of relative yields of oats (% of maximum yields) from a plot receiving no N. P, K and lime and the course of pH, show a high correlation (fig. 5). It seems likely, therefore, that this rhythmical lime response is due to the variations of lime status, which was induced by alternating weather phases.

A cyclical variation of phosphate response has been found on the above-

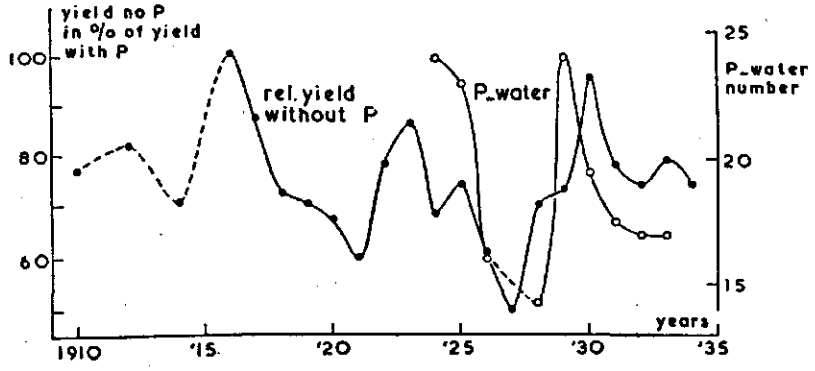

Fig. 6. *Periodical phosphorus response.* Course of yields of potatoes in % obtained without phosphorus dressing on an old fertilizer exp. field Pr 8 + 9 (in % of complete dressing) and course of content of water soluble soil phosphorus.

mentioned long-term experimental field. Since 1881 the phosphorus response has generally increased. However, no response was found in 1916 (fig. 6). After this year the yield depression without phosphorus gradually increased which again alternated with a regular decrease. The same phenomenon has been found three times. Since 1924 the water soluble phosphorus of the soil has been determined (fig. 6). The striking agreement between the courses of phosphorus content and phosphorus response might also indicate a causal relationship. It is a fact that phosphorus responses are largely dependent on the content of water-soluble phosphorus in the soil of this experimental field.

In a recent nitrogen experiment steadily decreasing yields were observed in the long wet period starting in 1950. Moreover periodical variations of the fields of potatoes obtained without nitrogen dressing, possibly due to the variations of rainfall in this period, were also observed.

These examples clearly demonstrate that cyclical variations of soil factors may largely affect the yields. The total effect is such that crop yields are about 1½ times higher after a succession of some dry years than after a succession of some wet years.

Literature

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Summary

Soil fertility varies under the cumulative influences of the weather. Large differences of crop yields originate from these fluctuations. The occurrence of alternating periods of different average rainfall of about equal length has caused a cyclical course of soil fertility factors and of crop yields in certain periods. Cyclical response to nutritional factors (lime, phosphorus, nitrogen) may be attributed to the same cause.

It will be the task of soil science and agriculture to recognize the mechanism of the improvement and deterioration of soil fertility under climatological influences, so that a rational approach to the problem will be made possible.

Résumé

La fertilité du sol varie sous les influences cumulatives du climat. Des grandes différences dans les rendements des cultures sont dues à ces fluctuations. L'existence de périodes alternantes de pluviosité moyenne différente et de longueur à peu près égale, a pu causer à certaines périodes une variation cyclique des facteurs de la fertilité du sol, et du rendement des cultures. Les réactions cycliques à des facteurs de nutrition (chaux, phosphore, azote) peuvent être attribuées à la même cause.

Ce sera la tâche de la pédologie et de l'agriculture d'apprendre à connaître le mécanisme de l'amélioration et de la détérioration de la fertilité du sol sous l'influence du climat, afin que le problème puisse être abordé d'une manière rationelle.

Zusammenfassung

Die Bodenfruchtbarkeit variiert unter den kumulativen Einfluss des Wetters. Grosse Unterschiede der Ernteerträge finden in den Witterungsschwankungen ihren Ursprung. Das Vorkommen abwechselnder Perioden verschiedenen mittleren Niederschlags von ungefähr gleicher Länge hat einen cyclischen Umlauf der Bodenfruchtbarkeitsfaktoren und der Ernteerträge in gewissen Perioden zur Folge.

Cyclische Korrelationen mit dem Nahrungsfaktoren (Kalk, Phosphor, Stickstoff) dürften derselben Ursache zugeschrieben werden.

Es wird die Aufgabe der Bodenkunde und Landwirtschaft sein, den Mechanismus der Verbesserung und Zerstörung der Bodenfruchtbarkeit durch klimatologische Einflüsse auszuarbeiten, damit eine rationelle Annäherung des Problems ermöglicht wird.

Discussion

L. de Leenheer: I suppose the experimental fields were located in an area with a shallow ground water table. The seasonal changes in depth of the ground water table may be, in dry years, an important factor of productivity. Two soil types, very similar in the upper 40 cm., but with different internal drainage of the subsoil, showed a difference in the elevation of the water table of 20 cm. during April and March (Belgian Polder Soils) and a difference in productivity of 25 %.

F. van der Paauw: Crop yields were observed to vary in cycles in all parts of the Netherlands on all kinds of soils. The changes of water table have not been determined. However, deviation of the general pattern is often observed. These deviations are due to individual variations of factors but generally the pattern of different fields is similar.

E. von Boguslawski: Have you found a correlation to the factor temperature, too? I ask because in western Europe there is a correlation between rainfall and temperature.

F. van der Paauw: No. Rainfall has been taken as a measure of weather conditions. Of course, rainfall and other climatological factors are interrelated. A separation will not be easy. It may be an object of further research.