THE EXPANSION OF SOIL FERTILITY RESEARCH IN RELATION TO ITS IMPORTANCE FOR THE IMPROVEMENT OF FARMING PRACTICE

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by P. Bruin *)

Introduction

One must have confidence in the observations of a farmer, but one must not believe his interpretations. This saying of a pioneer in soil fertility research in the Netherlands appears strange but has a deeper meaning in the context of the working method of researchers in this field of science. It is the principal aim of these investigators to trace the cause of the differences in growth and other phenomena observed by persons well acquainted with the behaviour of plant and soil within a small area. This means that field observations and field trials must be the centre of those working in soil fertility research.

Rather than speaking of "the cause" of the appearance of growth patterns the term "Growth determining factors" is to be preferred. Growth differences are determined by many actions of, and interactions with environmental influences (soil and climate). These influences are already continuously disturbing the approach to steady states in the soil plant system. It is becoming more and more urgent to gain insight into the possible equilibrium states, and how they may be altered by the interference with the soil, even with the whole profile, and with the crops caused by man. The consequence of these ever continuing advances in our knowledge about soil fertility, plant nutrition and susceptibility to pests and diseases is that discussions on the concept of soil fertility are losing their significance and need to be replaced by symposia on the various influences of man's interference on the productivity and the highest possible productivity, both quantitive and qualitive, of the crops (1).

This paper considers the extent to which coherent expansion of soil fertility research in space and time is possible. Hereabout the researchers working in this field of applied science are very often criticized. A few quotations from the Presidential Address given by Dr. E.G. Hallsworth on the occasion of the opening of the 9th International Congress of Soil Science in Adelaide, Australia, will illustrate this.

In his "Perspectives in Soil Science" (2) Hallsworth seems to be pessimistic about the progress of the research of Commission IV (Soil Fertility and Plant Nutrition). He remarks "Since almost all the work in the papers listed in Soil Fertility and Plant Nutrition is chemical in nature, in looking for perspectives I have combined these with the soil chemistry papers." - and further on - "In soil chemistry many of the papers make dreary reading. So often they

- are -

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are merely the repetition on another soil, in another area, for another nutrient of an investigation done many times before. By and large they contribute little to our knowledge, for either the parameters are inadequate, or the bound of the investigation too restricted to allow valid generalisations to be made, even from one paddock to the next" - and finally - "An enormous effort has been put into attempts to find methods of measuring available nutrients. Most of these have been simple extractive procedures, and in most cases no attempt is made to obtain any fundamental measures. Rather the attempt is to find some method giving a good statistical correlation with crop yield and in areas of uniform soil and climate such methods are proving of value".

Not indeed a favourable judgment! Against this, we hope to testify to progress with cause for optimism, with the conviction that the certainty of success is not a necessary condition for optimism.

Firstly we may remark that it is incorrect to connect soil fertility research entirely with soil chemistry. In doing so, one does scant justice to the essence of this research of which the aim is to give a broad scientific description of the nutritional status of the soil under the various climatic conditions. Soil fertility is indicated by the growth of crops and the nutritional status of the soil is described in terms of physical, chemical and biological variables and parameters. Attempts may be made to interpret the differences in growth observed in different localities in different seasons. This mainly ecological approach, which gives description of the environment of the crop, must be supported by physical, chemical and biological studies of plant nutrition, which explore the whole soil/plant system. When soil fertility research is viewed in this way, it ceases to be a melting pot of the results of various studies, which may only be remotely connected with soil fertility, and is considered rather as a soil fertility science having its own specific methodology. As a matter of course, soil chemistry, soil physics, soil biology and plant nutrition are separate disciplines, but investigators of soil fertility ask their colleagues working within these disciplines "provide us with concepts we can use in soil fertility research based on your knowledge of soil processes and metabolism". The concept of the p_F-value introduced by soil physicists (3) may be cited as an example. This was shown to be of great importance to various problems in soil fertility research. Now we are frequently using air contents or moisture contents as various p_F-values of the soil as experimental parameters. In view of what has been said in this introduction, this paper perhaps might be titled just as well: "From a localized approach to soil fertility research toan universal approach and from a specialized view to a generalized view".

Soil fertility research on a basis of single values

The development of soil fertility research has taken different courses according to area, to country and especially to the soil conditions where farming is practised. We may cite as a first example the development in the Netherlands, characterized by the phrase "from a system of soil testing by means of single values towards a system of soil fertility analysis" (4).

This typifies the development of soil fertility research in the Netherlands where nearly half of the agriculture is supported by diluvial sandy soils, especially heather and peat/sand reclamations,

- that -

that are originally poor in plant nutrients (content of particles $< 16\mu$ less than 10% and humus content 2% to 14%). In these soils the introduction of fertilizers has been a benediction. Also, older clay soils which had been under cultivation for several centuries, and had been exposed to the leaching influence of a surplus of rain water (26% drainage water from an average annual rainfall of 765 millimetres) showed a favourable reponse to fertilization. Systematic fertilizing experiments have therefore been carried out already very early in the relevant areas, and soil testing has been introduced also. Large-scale experimental fields and carefully selected series of field trials have been employed, always attended by physical, chemical and biological investigations. The results obtained in the field determined the choice of the so called "single values".

Considering the chemistry of the system alone, this conventional method of working has indeed shortcomings , however it became clear to the investigators in this branch of applied science that such single values might be of great advantage in farming practice long before their significance in the context of soil science was discovered. Thus for example the application of the p_H-determination for advising the farmers cultivating diluvial sandy soils was profitable before all the difficulties of p_H-measurement were overcome and before the complex relationships between p_H and the phosphate status of these soils, and p_H and the status of trace elements in the soil, were fully understood.

A specific methodology has been developed for the analyses and interpretation of results of large scale experiments, and for selecting suitable plots in trial series and relating the results gained from these trials (7). Van der Paauw has explained these methods elsewhere (5). The methods predominantly involve an iterative graphic technique, the development and theoretical background of which have been explained by Visser (6) and Ferrari (7a). Some illustrative examples of this development are as follows.

Fig. 1 Figure 1 shows the results obtained by the iterative technique for an investigation of the interaction of some important fertilizing factors in one large experimental field. The three sub-figures show the interaction between potassium and nitrogen at three phosphate levels, and the influence of nitrogen and phosphate on the grain yield of spring wheat (8).

Mention may be made of some points which have advanced the change from separate large experimental fields in different areas to series of field trials:

a. the introduction of corrections to compensate for differences in fertility among various parts of an experimental field in a large-scale experiment; for these corrections the results of soil analyses of samples taken from all plots separately may be used also;

b. the appreciation of the significance of studying both fertility differences arising naturally and differences caused by farming practice, for the testing of single values (uncontrolled next to controlled experiments) (9);

c. the existence of a central soil testing laboratory using standard analysis methods;

d. a close co-operation between the institute of soil research, the soil testing laboratory and the advisory service which represents farming practice.

- Fig. 2 -

Fig. 2 Figure 2 gives an example of the co-operation mentioned in (d) above, that is a survey of all experiments and trials completed all over the Netherlands to test a phosphate single value which is relevant to grassland on various soil types. Figure 3 shows a graphical summary of the results (10). Fig. 3

It is clear that the introduction of uncontrolled experiments especially has promoted a transition from "soil testing" to "soil fertility analysis". This uncontrolled experimentation was necessary for determining the influence of physical single values on soil fertility.

Fig. 4 Figure 4 gives an example of the relationship between the clay content of the soil and the amount of organic matter associated with good physical qualities of the soil, at two lime levels (11).

Boekel obtained these results for clay and loam soils in Friesland and Groningen from controlled experiments (lime and organic matter trial fields, influence of the application of Krilium) and uncontrolled experiments (spot investigations). The three curves indicate the changes in the slaking process, soil structure (air and moisture contents) and resistance to the effects of heavy machinery. Later, the important effect of groundwater level was studied (12). In giving advice on farm practice, the soil texture, organic matter, lime status, and drainage conditions must be taken into account, sometimes supported with laboratory determinations. The measures to be taken also depend on the farming practice itself.

Ferrari, in his thesis entitled "An agronomic research on potatoes on the river ridge soils of the Bommelerwaard" (about 10.000 ha) (13), succeeded in accounting for 88% of the total variance (excluding the variance of the experimental error) with the aid of nine "single values".

Fig. 5 This successful soil fertility analysis is illustrated in figure 5. Application of this model was not, however, always successful. The amount of the total variance accounted for by single values may vary from 25% - 85%. Nevertheless, solutions to many lesser problems may be found in this way. As an example, Ferrari studied the interaction between the potassium status of the soil, the p_H and the applied

Fig. 6 potassium dressing (13). Figure 6 shows the effect of potassium dressing on the potato yield at two p_H values. As the potassium status of the soil increases, the effect of potassium dressing on the yield decreases, and no effect of added potassium is detected when the potassium content reaches 0.02% K_2O (measured by extraction with 0.1 n HCl). At this potassium level, the maximum yield has been obtained. It seems to be impossible to obtain the highest yield with a dressing applied in one year when the potassium status is less than optimal. Increasing the p_H aggravates this situation. Relationships between potassium dressing, K^+-uptake, yield and profit, give some insight into the economics of this potassium problem, which arises from a strong potassium fixation in river-clay soil (open illite). The result of this fixation is observed when comparison is made of the relation between potassium status of the soil and the potassium content of the potato leaves for soils with and without potassium fixation respectively.

Fig. 7 Figure 7 shows the contrasting degrees of potassium availability in two types of clay soil. The effect of the potassium supply of the potato on its quality, especially the blue colouring, is well-known. Results of the international permanent ecological experiments (discussed at greater length below) have shown that the phenomenon can be given a general interpretation. Schiller and Lengauer found that 85% of the total variance of the potassium content of tubers from sixteen experiments throughout the temperate zone of Europe was accounted for by the variances of the potassium content of the soils and the potassium fixation (14).

- Soil -

Summer-wheat

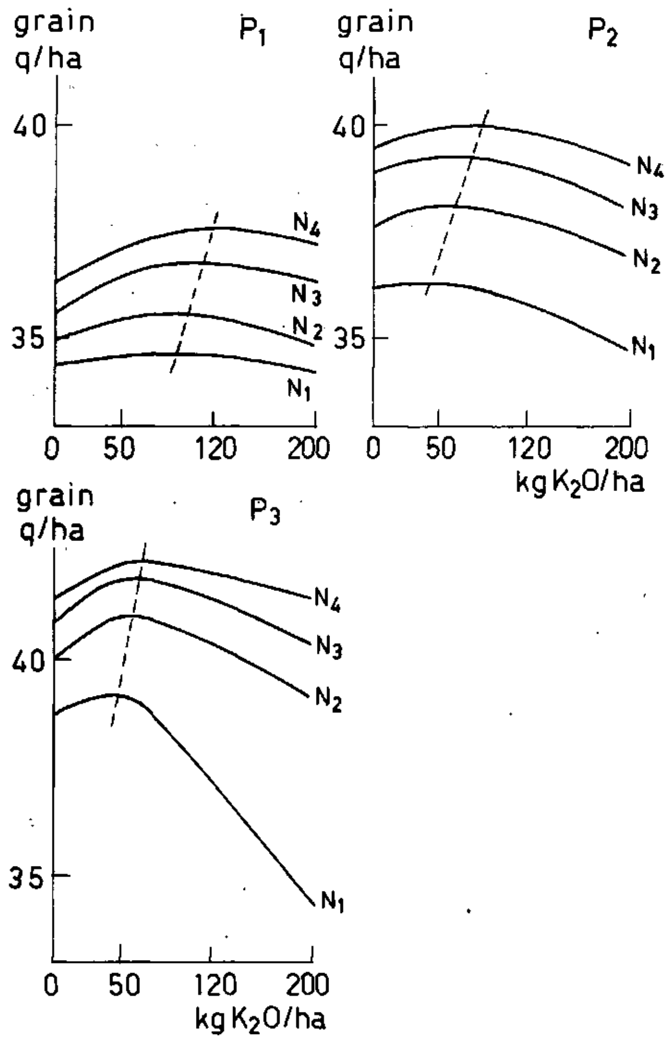
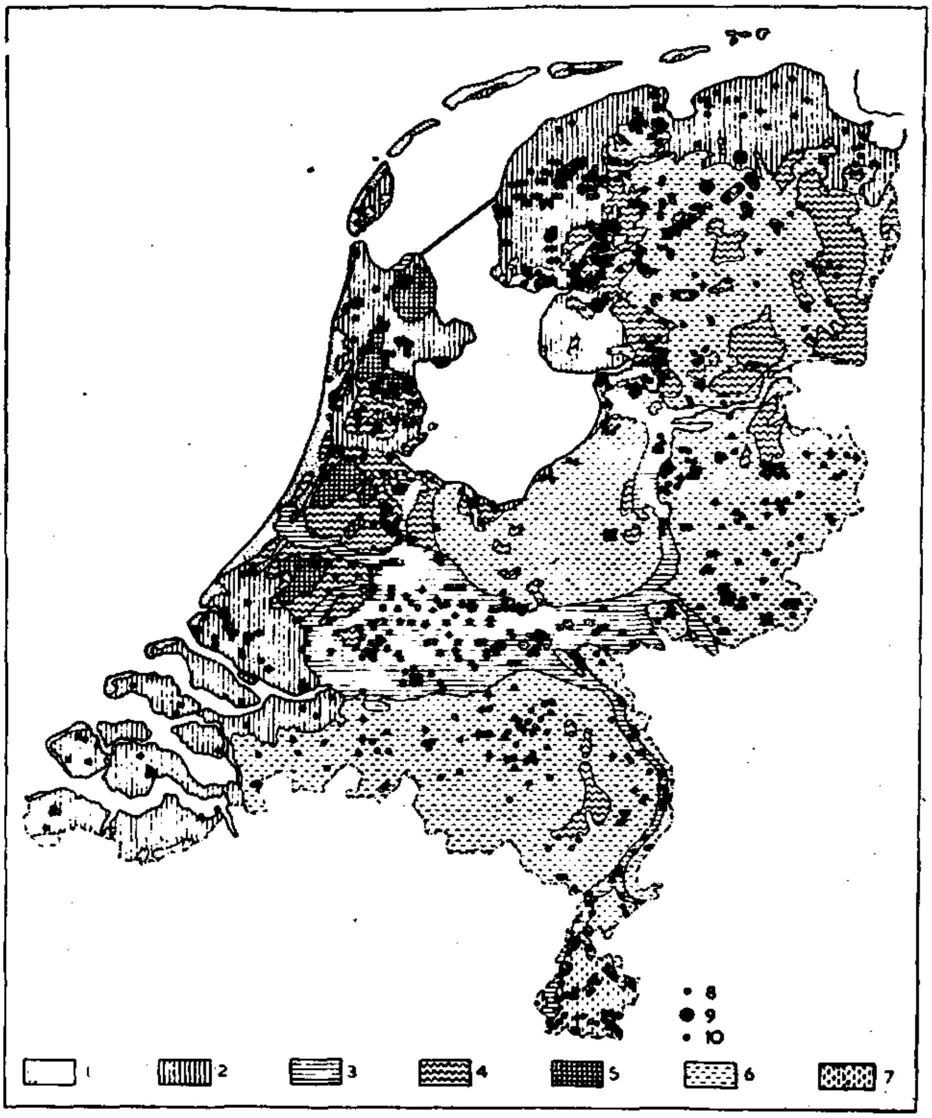


Fig.1 Relations between N-, P- and K-dressings on a light loamy clay soil poor in lime



Phosphate experiments on grassland for soil testing in the Netherlands. 1. marine sand, coastal dunes; 2. younger sea clay; 3. fluviatile clay; 4. peat; 5. older sea clays; 6. preglacial, glacial and postglacial sand; 7. loess; 8. experimental fields in 1947 or 1948; 9. series of 20—21 exp. fields on clay, peat and sand in 1939, 1940 and 1941 respectively; 10. "experimental spots" in 1943.

Fig.2

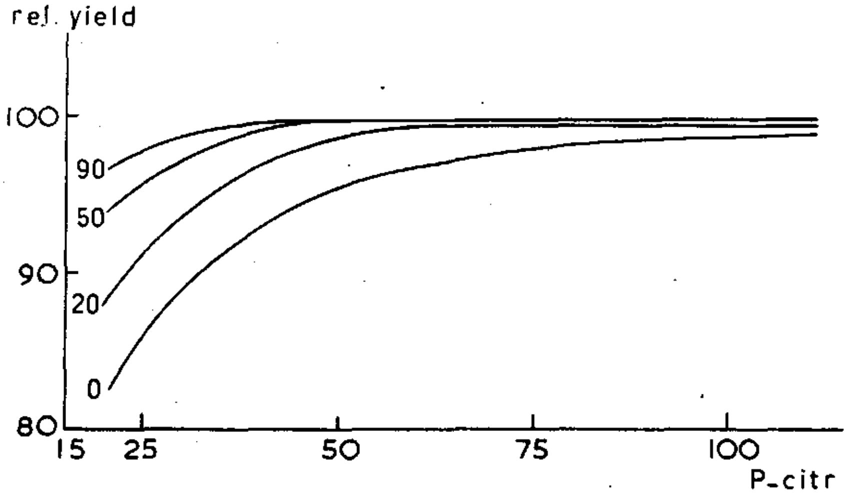


Fig. 3[a] Relations at different levels of phosphate application.

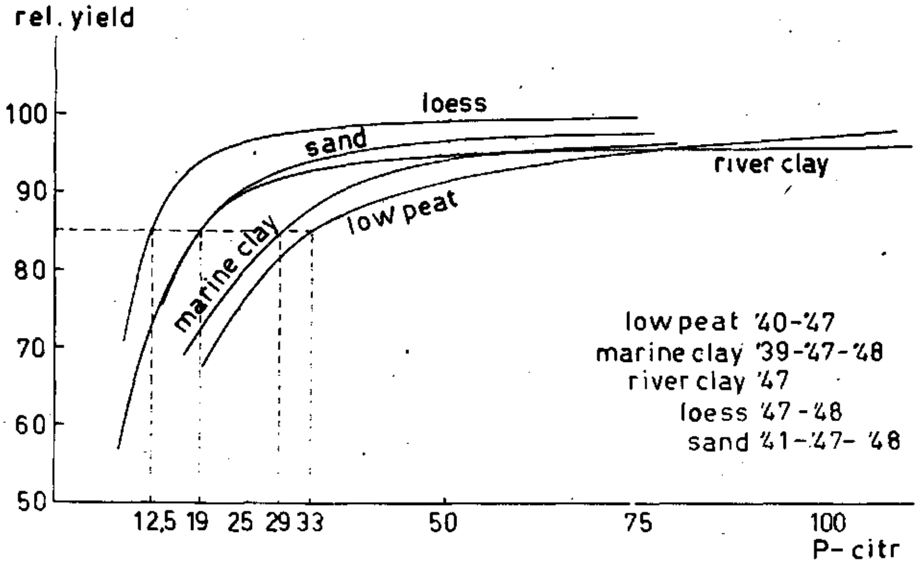


Fig. 3[b] Relations between the averaged values for varying numbers of years

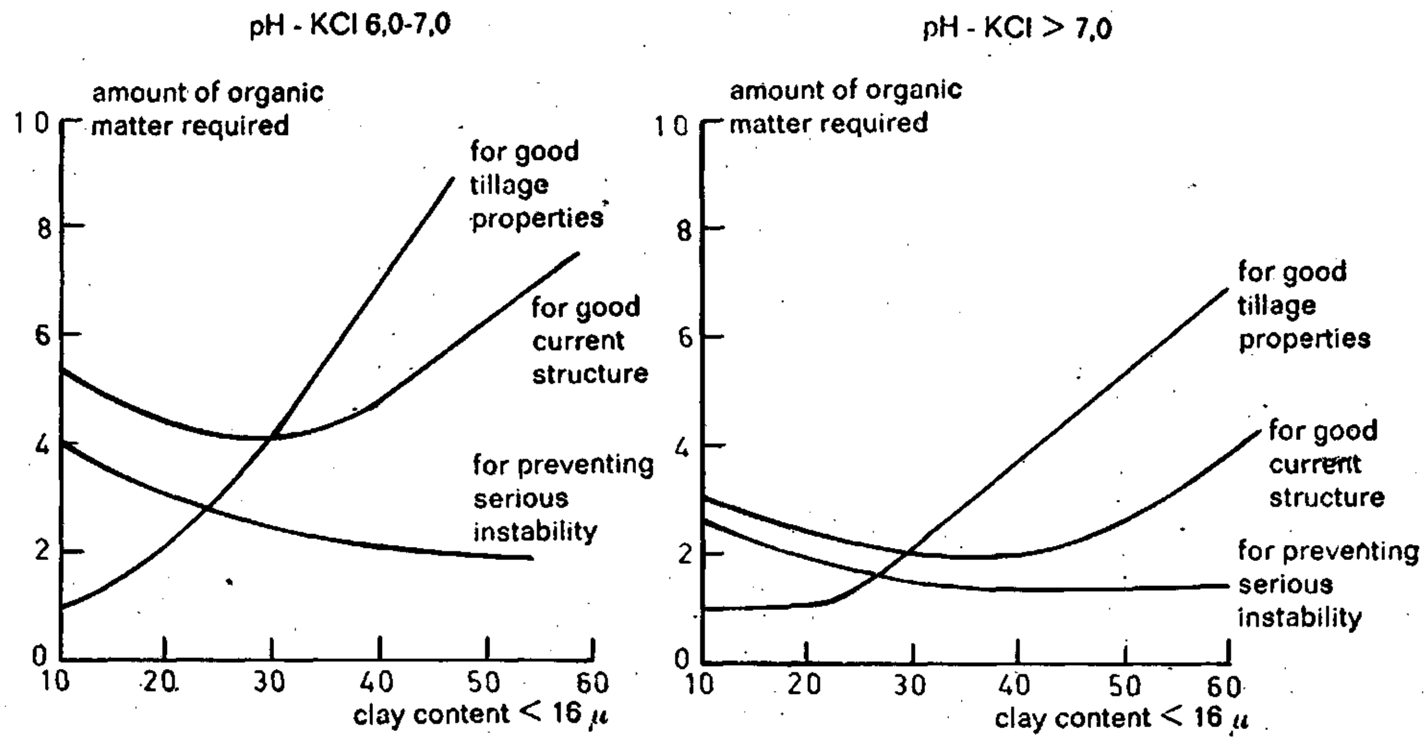


Fig.4 Relations between clay content of the soil and the amount of organic matter required for some qualities of a good physical condition of the soil at two stages of lime status.

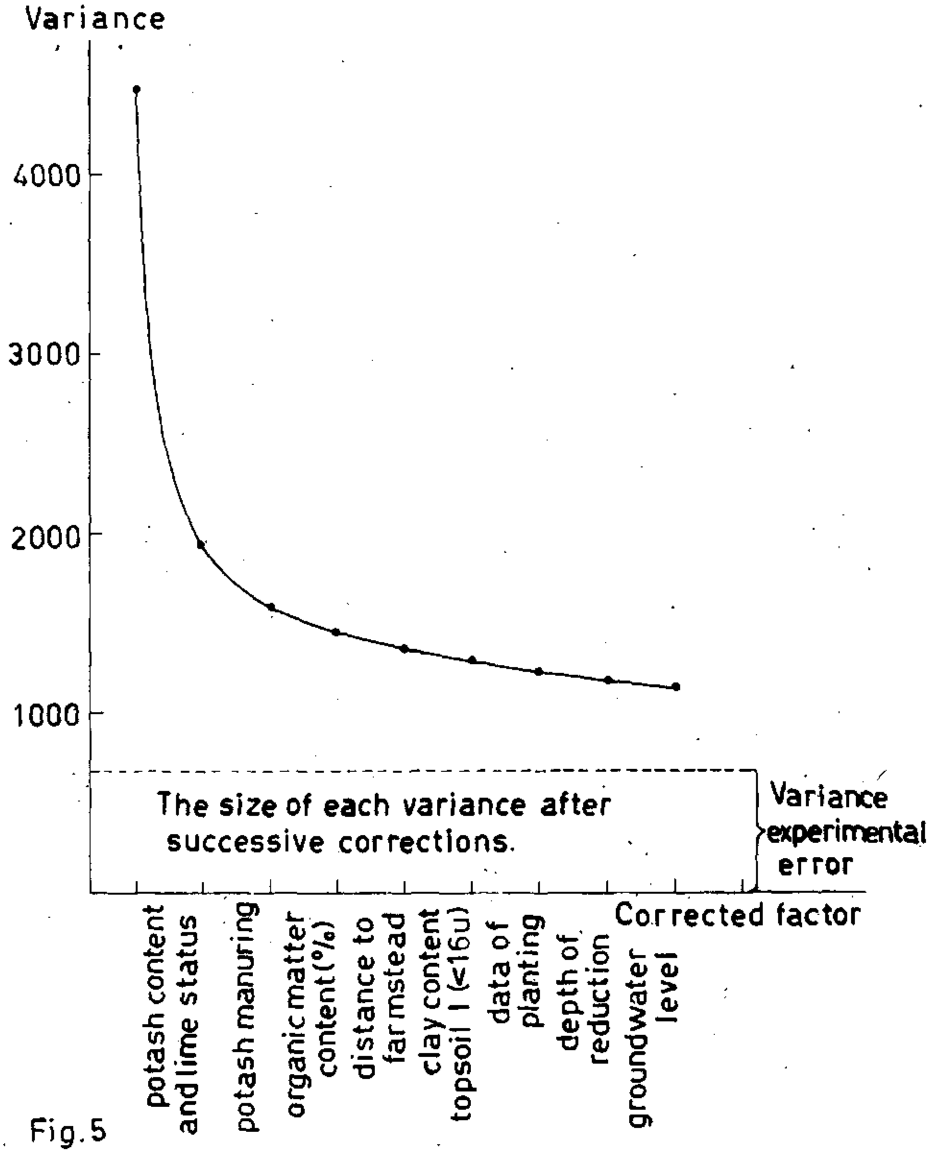

Variance
4000
3000
2000
1000
The size of each variance after successive corrections.
Variance experimental error
Corrected factor
potash content and lime status
potash manuring
organic matter content (%)
distance to farmstead
clay content topsoil I (<16u)
data of planting
depth of reduction
groundwater level

Fig.5

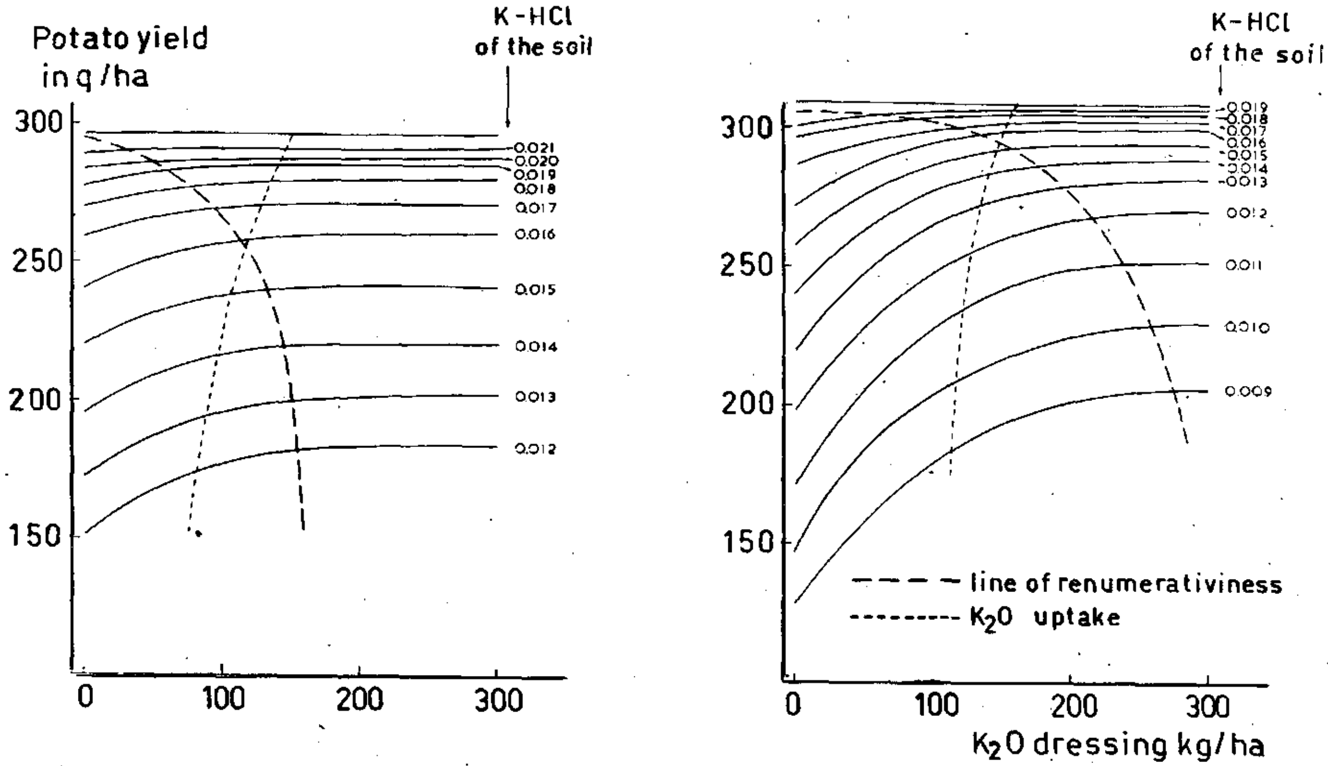


Fig. 6 The influence of the potash dressing on the yield at different potash contents of the soil and at two pH-levels.

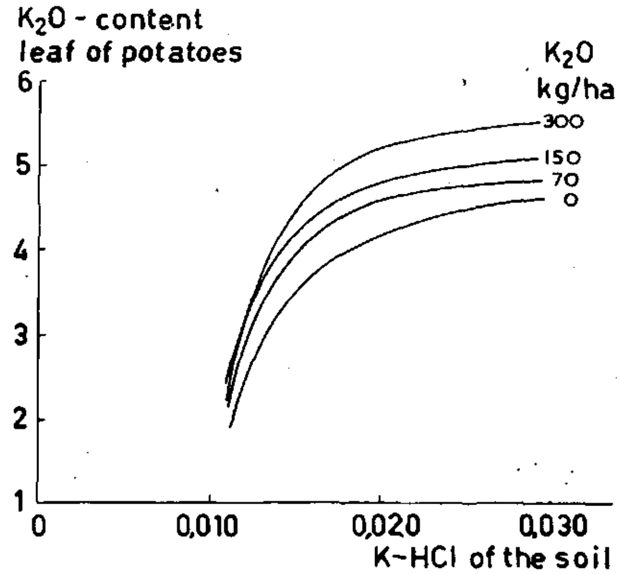


Fig. 7a Potash fixating river clay soils

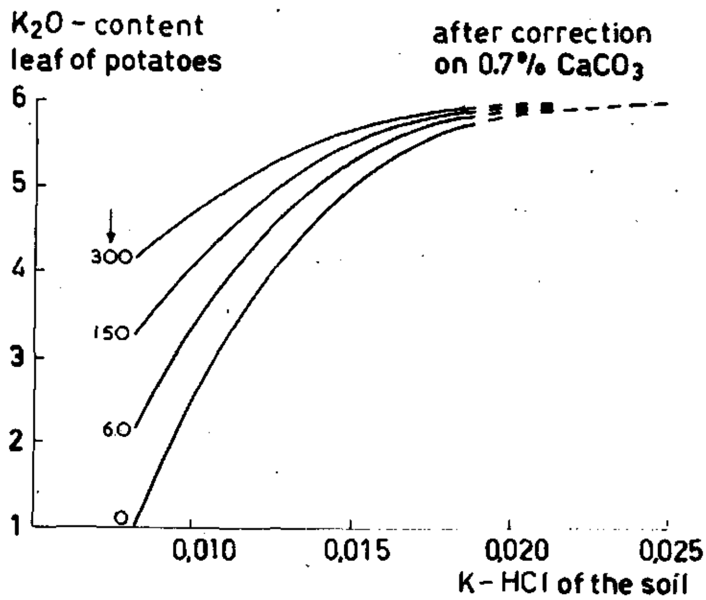


Fig. 7b Marine clay soils without potash fixation

Relations between potash content of the soil and of the leaf of potatoes.

Yields of winter-wheat with relations to the ageing of polders.

Polder	Year of embarkment	Average over 1962-1967 Yield kg/ha	N-dressing kg/ha
1	1924	5130	55
2	1862	4880	80
3	1819	4790	80
4	1769	4600	90
5	1701	4500	100
6	1665	4350	105

Fig. 8

Soil fertility research on the basis of soil characterization

Another distinct development of soil fertility research has taken place where problems of soil fertility deterioration have occurred during ageing. This development has been associated with studies of various stages of ageing, or with studies of the effects of regularly changing meteorological conditions on the same deposits. In these studies, the research involves a more general and also a more intensive characterization of the soil, taking account of such factors as the weathering of silicates, mechanical composition, adsorption capacity, humus quality, lime status, and also agro-hydrological conditions of the profile, physical properties, etc. This approach has been applied in the study of deposits of different age in delta countries, and might be applicable to meteorological influences on loess deposits in various countries.

A suitable example of an investigation on soil ageing is one undertaken in the north-east of the province Groningen (marine clay soil) in the Netherlands, by Van Bemmelen, Hissink and Maschhaupt (15) (Soil survey in the Dollard area). The effect of ageing of

Fig. 8 the soil on the yield of winter wheat is illustrated in Figure 8, information obtained by the Advisory Service of the province Groningen. Yield decreases as the age of the polders (from the year of embarkment) increases, despite increasing nitrogen dressings which were applied to obtain high yields. The hypothesis put forward to explain this decreasing yield, attributes the loss in yield to decreasing fertility in the whole profile, especially with regard to the nitrogen and humus contents of the various layers of the profile, the regular losses of carbonates from the upper layers and the resulting deterioration of soil structure. The nitrogen uptake of the plants occurs throughout the whole profile. On undressed plots on these marine clay soils the nitrogen uptake by a wheat crop occurs predominantly in the lower layers of the soil profile where mineralization of the nitrogen in humus takes place. This process is particularly important during periods of drought, and demonstrates the advantage of a deep rooting system under dry conditions. Maschhaupt analysed soil samples taken from layers of the soil profile in polders of different age to acquire more insight into the soil fertility changes that took place in the course of the centuries. Maschhaupt calculated that during the first sixty years after embarkment, losses of about 90 kg N per hectare per year occur, with corresponding losses on humus. These losses decrease with time and amount to 25 kg N per ha/year in the next century.

There is no possibility of preventing these losses of nitrogen, lime, potassium and phosphate. Maschhaupt considers the losses to be a sign of "healthy life", but it is important to know when, and by what method intervention will be necessary to prevent large decreases in yield.

Returning to the main theme of this paper, it is relevant to consider whether these results may be generalized. Although in the opinion of the author, generalization of these results is out of the question. There may be, however, an expansion in co-operative research using the same research models applied to similar problems. Experience shows that besides analyses of soil and plant samples, nitrogen/yield field trials must be carefully planned, and set up according to a scheme that tests the hypotheses most effectively.

- Figure 9 -

Fig. 9
Fig. 10

Figure 9 gives an example of the use of the scheme. In Figure 10 each point represents one of the field trials shown in Figure 9 (16). In this example the fields have been selected so that a range of soil structure values was investigated. The graph shows the relationship between soil structure and the amount of N required to give the maximum yield of potatoes. Many other observations and determinations relating to quantity and quality may be made at the same time.

The function of the International Working Committee on Soil Fertility

The International Working Committee on Soil Fertility under the auspices of the International Society of Soil Science (Commission IV) is considering the possibilities for expansion of soil fertility research towards the use of schemes of experimentation and of models for the treatment of results which are to be applied in international co-operation. This committee was founded at the international soil science congress at Paris (1956) (17). It was believed that the work of the committee would further the degree of contact among the different schools of thought in soil fertility research. The general aim of the committee embodied in the project entitled: "A study of the influence of physical, biological and climatic factors on the nitrogen status of the soil and the supply of nitrogen to crops". This project was limited to the "grey brown podsolics" of the temperate region of Europe. Although the study was originally restricted on a particular problem of soil fertility, it has evolved into a methodological study of ecological field research, and attempts to achieve some insight into the effects of soil and climate (also "weather") factors on the fertility of the soil and the yield of crops over an extensive area. The influence of factors which could be eliminated relatively easily by a rational fertilization has not been considered.

Two experimental schemes denoted by INV (Internationale N-Versuche = international nitrogen trials) and IDV (Internationale Dauerversuche = international permanent experimental fields) were the basis of the research. The INV scheme consisted of one-year series of trials with oats as a test crop and with increasing applications of nitrogen. The fields belonging to one series (about 30) were selected so that a wide range of soil conditions such as humus content, soil structure, texture, etc. was included among the experimental fields. Nitrogen yield curves obtained from these trials not only record the nitrogen condition of the soil but also provide parameters that may be used successfully to define the relationship between yield and soil factors or between yield and meteorological conditions (Fig. 9, 10). The IDV scheme involved more comprehensive experiments continuing for many years in different "Standorte" (= habitats), with a fixed rotation of three test crops (oats, potatoes, winter-wheat) and with four fertilization intensities ($N_0P_2K_2$, $N_1P_1K_1$, $N_2P_2K_2$, $N_3P_3K_3$). Besides detailed standardization of the experimental schemes, a central seed supply was employed, and was shown to be necessary from the results of a preliminary investigation.

Eight series of the INV, composed of a total of 250 field trials were set up in 1958 in the vicinity of Rostock, Oldenburg,

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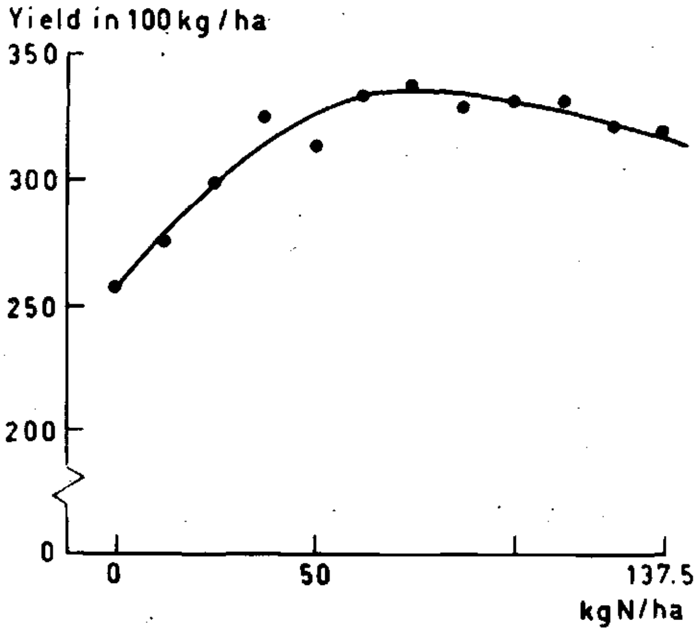

Fig. 9 Relation between nitrogen dressing and the yield of potato tubers for one field trial

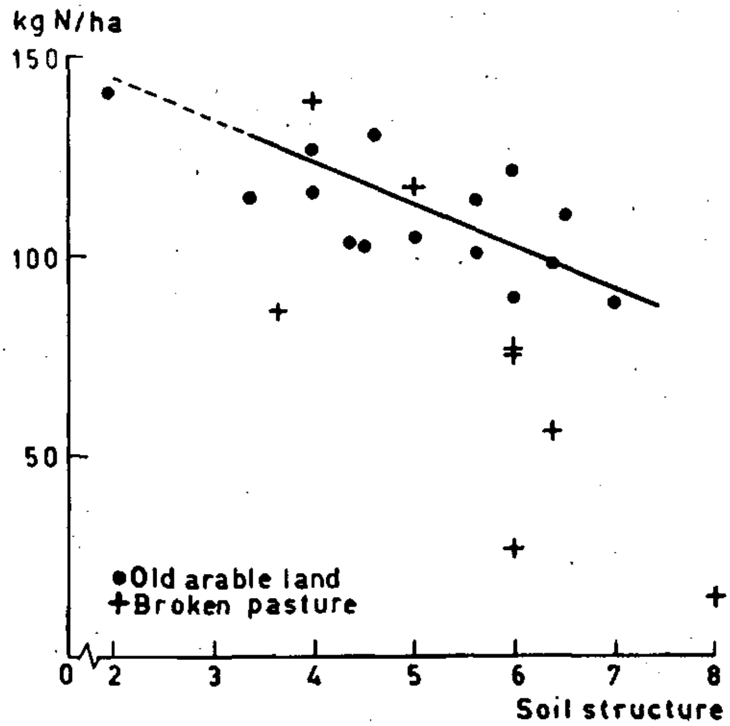

Fig. 10 Relation between soil structure visually determined and the nitrogen amont for reaching the highest yields of potatoes on the separate trials of one series.

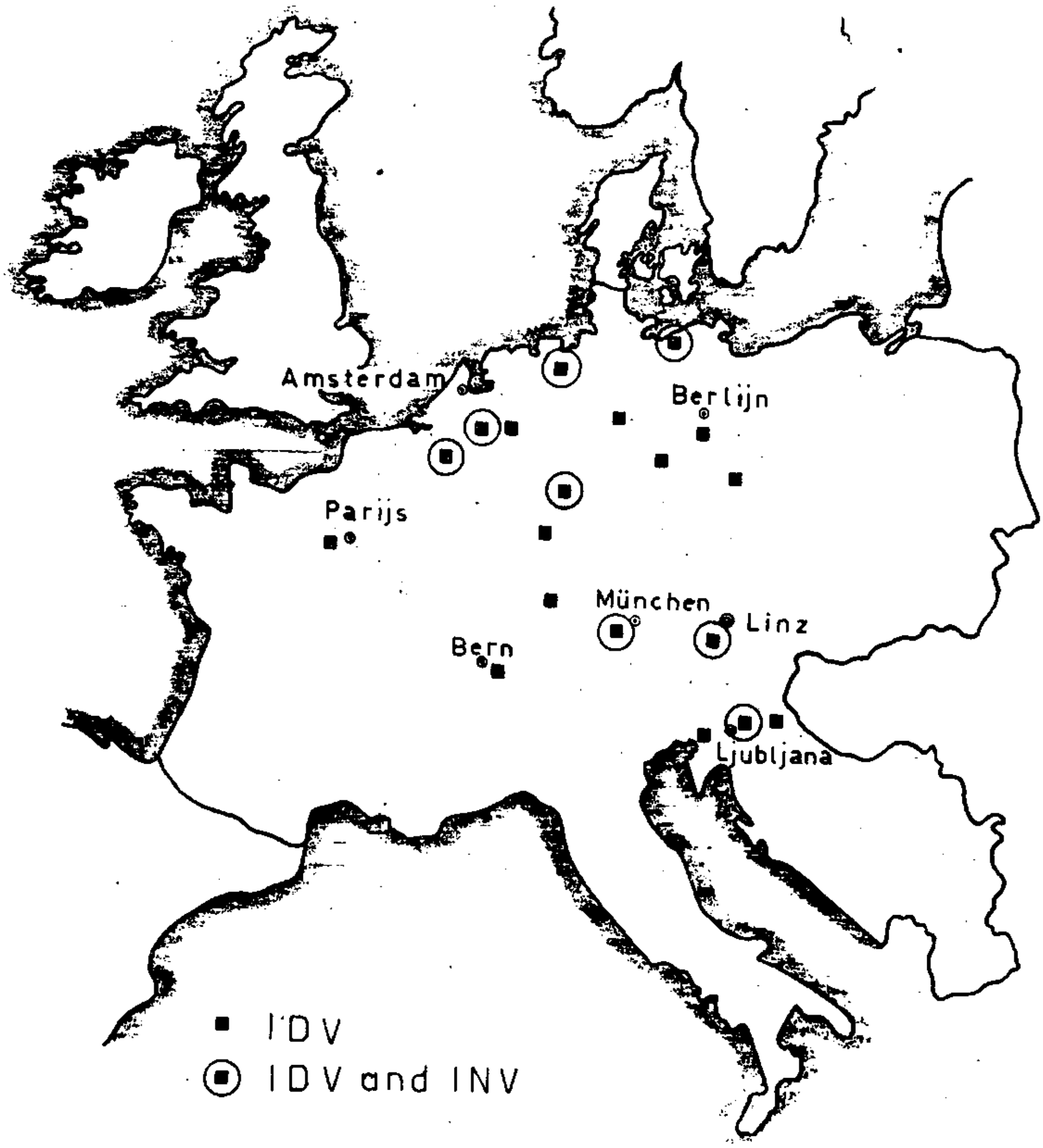

Fig.11 The geographical situation of the IDV – series and the INV – series respectively.

Ottersum (Netherlands Limburg), Louvain, Rauisch-Holzhausen (near Giessen), Munich, Linz (Austria) and Ljubljana, thus situated from the North-West to the South-East of Europe. The IDV series consisted of twenty experimental fields, the trials on eighteen of which, were completed. These trials were also situated from North-West to the South-East of the temperate region of Europe.

Fig. 11. The overall arrangement is shown in Figure 11.

The IDV series continued for twelve years and during the three subsequent years the residual effects of the fertilizer treatments, and of the absence of farmyard manure applications, were studied. A new series of field trials has now commenced extending beyond the temperate region. In this new series (ISDV; S denotes Standorte = habitats), spring barley as a test crop (one variety), a wheat cultivar adapted to local habitat and a crop with the highest expected dry matter yield (free choice), are included.

The analysis of the results is very complex and gives many difficulties. The results of the INV-series are of a soil scientific character. Ferrari has applied a factor analysis and a multiple regression analysis to six of the series. Regarding the factor analysis, it was demonstrated that the procedure should not be restricted to yields alone, but should include the N-content of the crops and the amount of N taken up, since these measurements reflect the nutrient metabolism in the plant. Ferrari showed that the following soil factors given in order of decreasing universal relevance, were important in relation to the yield differences: soil structure, total N and C content (organic matter), rate of mineralisation of nitrogen, clay content ($< 2\mu$) p_H. It appears however that on average, only 30% (range 20%-50%) of the total variance could be accounted for by the effects of the chosen independent factors. Experience gained from other investigations by using the same experimental scheme, shows that this percentage may vary from 25% to 85%. The large percentage of the unaccountable variance in the INV series may be caused by interactions between soil factors and local weather conditions which were excluded from consideration, and also by the particular choice of independent factors which was guided by an inadequate method of determining the relevant aspects.

The scheme of the IDV series may suitably allow a quantitative analysis of the yield-determining meteorological factors. If this approach is taken, the nitrogen/yield curves serve only as a guide to the achievement of maximum yields. The study of the nitrogen turnover of the soil and the nitrogen supply to the crops is a self-contained problem. With the information available on the meteorological effects on yield, it is necessary to link the physical and meteorological development of the subject with the ecological investigations in the field.

In the report of the working group on the effect of meteorological factors on the quantity and quality of crop yields, and on methods of forecasting yield (submitted to the Commission for Agricultural Meteorology of the World Meteorological Organization, Geneva, October 1971) Dr. E.S. Ulanova (USSR) made the following criticisms of this field of research:

" 1. In most cases the physiological results obtained are of a qualitative nature and, moreover, are chaotically scattered.

- 2. -

2. Statistical methods often lack a biological basis. Their results are therefore specific for each area, and cannot be used for other areas or, if so, only conditionally.

3. The biological and meteorological information available was in most cases obtained from various areas or at different times. "

These remarks add weight to the criticism given by Dr. E.G. Hallsworth which was mentioned earlier in this paper. Dr. Ulanova however, added to her critical remarks the following view: "In future research work, therefore, the aim should be to collect physiologico-biological as well as phenologico-meteorological data simultaneously, and in the same areas, through co-ordinated joint operations."

The international working committee on soil fertility research has done and continues to do what Dr. Ulanova asks. Great difficulties are however presented in the over-all treatment and interpretation of the data aimed at finding quantitative relationships between the influence of yield determining factors and plant growth. When considering the possibility of a multi-factorial analysis, the problem of underidentification of the investigated system arises by which a separation of direct and of indirect influences of independent factors, is difficult or impossible. The interaction of soil, climate, and plant, for example, is not well understood. Besides this, quantitative analysis of the factors determining the yield differences among the IDV trials is greatly complicated by the correlations between the independent factors.

Brettschneider-Herrmann has made a first approach to a compilation of results by means of a multiple regression analysis (18). Von Boguslawski has also attempted a number of methods of analysis (19). Much attention was devoted to meteorological factors. So far, only some general results have been obtained on the influence of rainfall and temperature, and on influence of intensity and seasonal distribution of the radiation on potatoes has been suggested.

A fuller consideration of the standard deviations (S%) of the yields may provide information about the relative significance of the various soil and meteorological influences on the yields. "Soil", "climate" and "weather" may be distinguished as groups of yield determining factors("climate" and "weather" together encompass the total meteorological influence). From the yields of the eight INV series the S% caused by soil factors can be calculated (about 13% with oats). An examination of the ranges of the various important soil factors in the INV series and in the IDV series, suggests that the standard deviations derived from the INV series can be introduced into the IDV series. In this way soil and climatic influences can be separated.

Fig. 12 Figure 12 illustrates the scheme by which the above approach is stated. The scheme is based on the yields obtained in twelve habitats during twelve years. An impression of the magnitude of the S% is given by the variances of the grain yields of oats between twelve years in every habitat (indicated by A), and by the variances of the yield between all the habitats in every season (indicated by C). The mean values A = 28.5% and C = 35.5%, were very high. It therefore becomes pertinent to consider the possibility of making a distinction between the standard deviations

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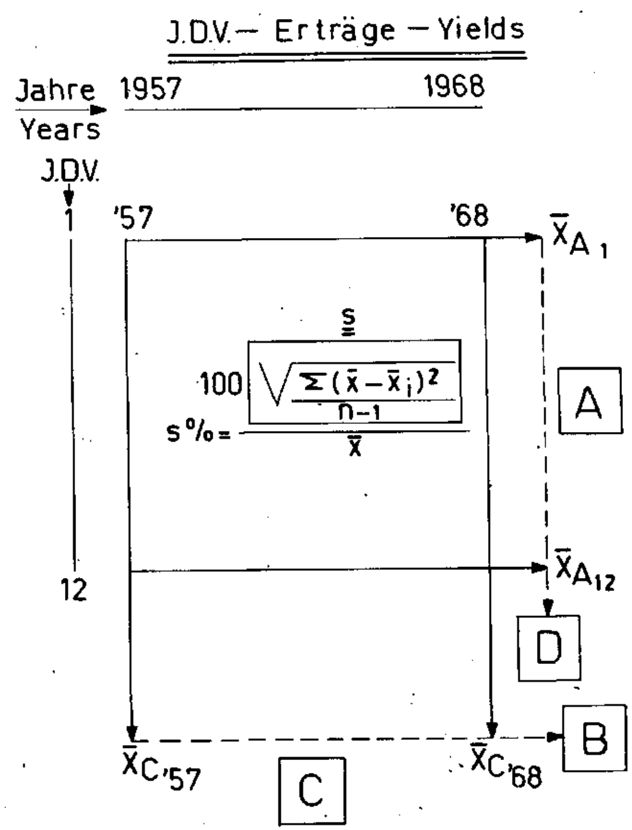

Nummerierung der JDV

Numbering of the JDV

1 Rauisch-Holzhausen
2 Gross - Gerau
3 Völkenrode
4 Oldenburg
5 Ottersum
6 Oberer Lindenhof
7 Puch
8 Rostock
9 Linz
10 Bern
11 Lubbeek
12 Versailles

Fig. 12 Model for calculating S%-values of the oats yields of a series of 12 IDV over 12 years as to the different yield determining factor complexes

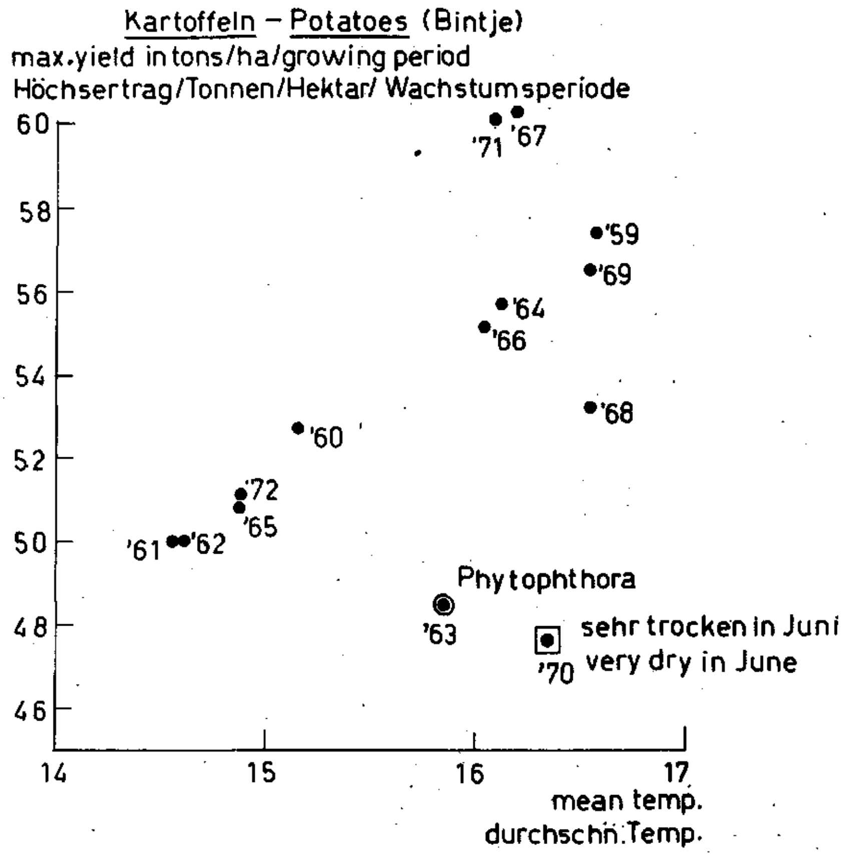

Fig. 13 Relation between the annual mean temperature and the maximun yield of potatoes for a nitrogen-rotation-experiment in the North East Polder (the Netherlands)

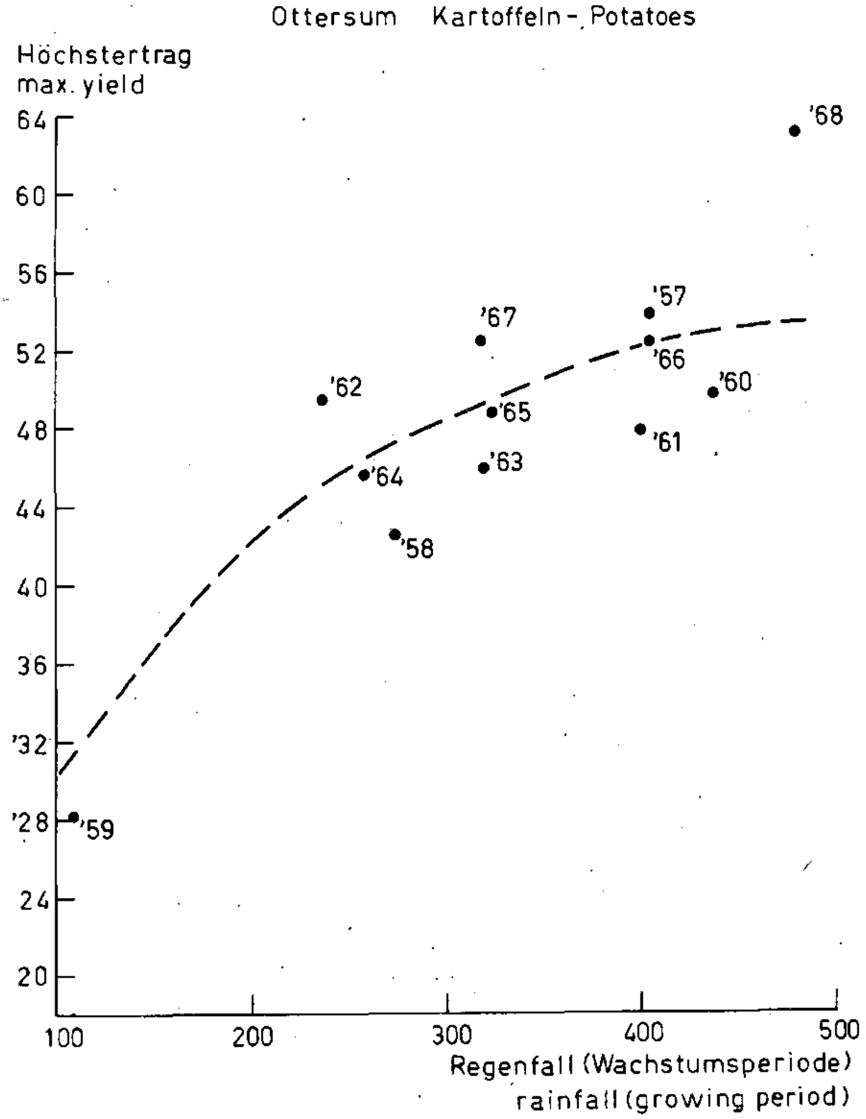

Fig. 14 Relation between the annual mean temperature and the maximum yield of potatoes for the IDV - experiment at Ottersum

resulting from the different important factor complexes especially the meteorological factors. The A-values will be closely related to weather influences and the interactions between weather and soil and the C-values will be closely related to climate, soil and weather influences. The difficulty is that it is not possible to analyse the remaining variance from which the interaction between year and habitat cannot be separated.

Attempts to solve this problem continue to be made, by using the results of some nitrogen yield rotation experiments which have been carried out in the Netherlands for many years and are still continuing. An example of the type of data used in this method is the effect of temperature (mean of minimum and maximum during the vegetation period) on the potato tuber yield measured in a rotation experiment in the North-East Polder. The results obtained in two of the years of the experiment may be rejected owing to a heavy

Fig. 13 attack of Phytophthora in 1963 and a severe drought in June, 1970. There seems to be a rather narrow relationship. A multiple regression analysis with six variables (the means of three temperatures and the means of three rainfall intensities at three growth stages) showed that 87% of the total variance was be accounted for. A value of 72% was likewise calculated for the grain yield variance of winter-wheat and 20% for spring barley. In the ID-experiment at Ottersum (the Netherlands participation of the IDV series) no relation between temperature and potato tuber yield was found

Fig. 14 initially; rainfall seemed to be the dominant factor.

It is hoped that the treatment of the Netherlands data will provide indication of how to select characteristic meteorological factors in the analysis of the international results. Useful information for the selection of these meteorological factors can also be derived from the work of W. Brouwer in Germany, Penman in England and from the work of the Institute for Land and Water Management Research in the Netherlands. It is also the intention to test the ecological relevance of the physicometeorological approach at the same time.

Finally, it is important to point out that crop samples from the INV and in particular from IDV experiments have been used in many different additional studies. Members of our working committee investigated the baking quality of wheat (20), the diverse aspects of the quality of potatoes (21), the quality of oats in the preparation for the rolling of oats (22) and on the composition and properties of straw (23). In these studies, the effects of climate and nitrogen status of the crops were always taken into account.

Interest outside the committee has also been aroused, and crop samples from the international field experiments have been taken for further analysis. Thus wheat grain samples have been analysed to determine the effects of climate on protein quality (24).

Not only crop samples but also soil samples have been taken from the INV and IDV experiments for separate studies, such as microbiological surveys.

All these activities are mentioned to demonstrate the usefulness of international co-operation in field research as a starting point for various specialized studies. In all about forty reports and publications connected with the co-operative research have appeared.

Last but not least, mention must be made of the comradeship fostered by this work despite differences in background, language and personality.

- Summary -

Summary, conclusions and propositions

This paper considers the desirability and feasibility of expansion in soil fertility research from a localized interest to a world-wide interest and from a specialized to a generalized approach. Frequently voiced criticism of fragmentary research schemes and lack of coherence in soil fertility research had lead to this consideration.*)

The following points successively were discussed:

1. the specific methodology of soil fertility research;
2. the influence of soil type and of climate on the specific development of this research;
3. the work of the International Working Committee on Soil Fertility;
4. some conclusions and propositions which will be underlined in particular in this section.

1. The aim of the research on soil fertility (which is indicated by crop growth) is to give a broad scientific description of the nutritional status of the soil in various climates in terms of physical, chemical and biological variables and parameters. Soil fertility research embraces soil physics, soil chemistry, soil biology and plant nutrition as principal disciplines and makes use of factors which are derived from these studies and which further the integration of soil fertility research.

From the point of view of the farmer, advice is required on how to achieve the highest possible productivity, both quantitative and qualitative. This advice is based on measurements of various growth determining factors. Insight into the manner in which soil equilibria are continuously shifting, makes it increasingly clear that the distinction between "natural" and "artificial" soil fertility is arbitrary and not essential.

2. One methodological approach in soil fertility research which is characterized by the slogan "From a system of soil testing by means of single values towards a system of soil fertility analysis" was illustrated by a sketch of its development in the Netherlands. It involves an integration of advice schemes for the improvement of farming practice and soil fertility research.

Netherlands agriculture may be characterized very briefly as follows: a delta country formed from alluvial and diluvial deposits; large differences in natural drainage according to where peat was formed; podsolization in the course of the centuries by surplus of water in autumn and winter; many "man made soils" (peat and heather reclamations, improvement of poor clay soils). Fertilization advice schemes for farming practice could be compiled successfully using physical, chemical and biological single values.

- Some -

*) In this paper we especially cited the criticism given by Dr. E.G. Hallsworth and by Dr. E.S. Ulanova.

Some total soil fertility analyses on the basis of single values have been tried out with varying degrees of success. It appeared that 25 to 85% of the total variance could be accounted for by the chosen independent factors.

The possibility of applying a similar approach in countries with very different autochthone deposits has to be considered critically.

The methodology defined as "soil fertility research on the basis of soil characterization" is illustrated by a soil survey in the Dollard area (North-East of the Netherlands). Essentially, this approach involves a series of nitrogen trials (complete nitrogen/yield curves) on various plots. A relationship between the parameters of these curves may be found using single values derived from physical, chemical and biological data based on analysis of the root-penetrated soil profile. This approach may be recommended especially for areas of the same type of deposits but different in age, as in case of the Dollard area, and might be suitable also for loess deposits with different climates (besides soil single values climatological parameters are to be used also).

3. The co-operative research of the International Working Committee on Soil Fertility (under the auspices of the I.S.S.S.) was originally intended to be a "study of the influence of physical, biological and climatological factors on the nitrogen status of the soil and the nitrogen supply of the crops". This research has however developed into ecological and agro-climatological research. It concerns indeed European co-operation on "Expansion of soil fertility research" by different "schools" in this field of knowledge. Differences in the concept of co-operative field research carried out in various countries have influenced the experimental schemes. The scheme of the INV series (Internationale N-Versuche = international nitrogen trials) running for one year only is a reflection of the ideas mentioned in 2 above. The scheme of the IDV (Internationale Dauerversuche = international permanent trials) running for 12 years in the temperate climate of Europe, now succeeded by the ISDV which extends beyond the temperate climate region are originated in countries with very different soil types and climates (S denotes Standorte = habitats).

Many results obtained during the development of these schemes have been published. However the final treatment of all the accumulated data presents considerable difficulties.

4. This paper gives examples of attempts to universalize soil fertility research and to generalize its results and makes a stand against a too sharp criticism as to shortcomings on these points. The demand of farmers in many countries and regions with varying climatic conditions for private advice on the cultivation of their soils and crops, encourages the localized character of soil fertility research and the collection of data of limited significance. As farming practice becomes more closely related to the world foodsupply of mankind, it will require a more coherent universal approach in the experimental schemes and more generalization of the results obtained.

- Under -

Under auspices of the ISSS, much work has been devoted to the determination of characteristic values which can be used in studies on soil plant and climate. Coherent ecological field trials, which are fundamental in soil fertility research, are however too few. The International Working Committee on Soil Fertility intends to satisfy the need for more of this work.

An important result of the experiments completed by the Committee is that the variation of the yields brought about by yield determining "weather" factors (weather and the interaction between weather and soil over many years) is much larger than the variation of the yields caused by soil differences in the various areas which were investigated. The standard deviations were 28% and 13% respectively. It follows that in the application of numerical or graphical regression analysis, the relation between yield and meteorological factors is one of the most important to be considered.

A large number of independent soil factors which influence soil fertility differently from place to place, will always require that localized field trials are set up besides coherent experiments on a universal scale (an adequate combination of INV and IDV series). This method will ensure the standardization of characteristic values and will give some general insight into soil fertility problems.

It seems that there is a greater possibility of the successful determination of the relationship between crop yield and weather conditions on a universal scale, than for the determination of the relationship between crop yield and soil factors. The study of meteorological factors in general and weather conditions in particular must be increased to meet the trend towards greater generalization. Once again this does not mean that uniform methods of determining the relationship between plant and soil, are not important or without future outlook, but determination of the relationship between crop yield and weather factors is of prime importance. In so doing it is necessary to be aware that besides that the latter relationship may be direct, weather conditions may also exert an influence on crop yield via the soil (25).

In this paper the simulation technique made possible by the computer (26) has not been mentioned. With this technique physical and physiological processes can be taken into account and simulated. A more general approach along these lines is under way in many research establishments at present. The results obtained by the use of simulation models must be tested against empirical data whether from controlled or uncontrolled experiments. Perhaps the data obtained by the international committee will also be useful for testing simulation models.

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