APPENDIX II

FACTORS AFFECTING GROWTH AND METHODS OF EXPRESSING GROWTH RESPONSE DATA

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It is apparent that a paper on the factors affecting growth and method of expressing growth response data should be presented and discussed at a seminar dealing with "Economic optimum fertiliser consumption." The adviser who advises and the farmer who decides on a fertilising programme make use of conclusions derived from relationships between fertilising and nutrient status of the soil on one hand, and amount and quality of the yield on the other. The ultimate decision has technical, economic and phychological aspects - this is the domain to which the words of the mathematician Bross, in his book "Design for Decision", may refer, "It is much more difficult to be a good farmer than a good mathematician because the farmer must deal with so many vague and complex problems."

This paper is based on the reasonable assumption that a functional relationship exists between yield and growth factors. These growth factors include soil nutrients and also the nutrients added as fertiliser. In common with other investigations we assume that the plant will always react identically under the same growing conditions. This reaction may be expressed as follows:

$$y = f \ (x_1, \ x_2, \ \text{------} \ x_n)$$

the yield being an unknown function of a great number of factors.

Some idea regarding the form of this function is necessary for giving useful advice. The use of experimental fields on every possible site necessitates the expenditure of too much time, money and organisation in determining the quantities of fertilisers that are necessary. Soil testing is based on the assumption that experimental fields, on every individual site, are no longer necessary once the relationships between nutrient status, fertiliser dressing and yield are established by research. Soil testing has meaning only if research succeeds in finding relationships of general validity by which it is possible to predict response and to advise farmers. It is our experience that it is possible to work in this way.

The form of the reaction curve must be known, not only for technical but also for economic advice. If a farmer with limited capital can earn 2 guilders for every guilder spent on farm activities other than fertilising is informed by a simple nitrogen experiment that his return by using 60 kgs of nitrogen will be 1.5 guilders per guilder spent on fertiliser it is clear that he will not use his limited funds on nitrogen fertiliser. However, if he knows that the response curve shows that his return for the first 20 kgs of nitrogen is 2.5 guilders per guilder, for the second 20 kgs 1.5 guilder per guilder, and for the third 20 kgs 1.0 guilder per guilder, he will then decide to invest in at least 20 kgs of nitrogen. It is a pity that many experimental fields are laid out with only two treatments.

The problem of finding the fertiliser response functions must now be discussed. The general function may be defined as:

$$y = f(F_1 / F_2, F_3, \text{-----} F_n, X_1, X_2, \text{----} X_n // Z_1 Z_2, \text{----} Z_n)$$

where

y = yield response

F_1 = fertiliser nutrient under investigation

$F_2, F_3 \text{--} F_n$ = other fertiliser nutrients which are held constant

$X_1, X_2 \text{--} X_n$ = other variables which are held constant over the experiment, e.g. soil type, soil nutrients, variety, cultural practices, seeding rate

$Z_1, Z_2 \text{--} Z_n$ = other variables, such as weather, moisture, temperature, which cannot be controlled

An important factor is that the uncontrollable factors influence the action of F_1, so that the response curves vary between the years (inter-action). Almost nothing is known about the distribution of these curves over the years. This question is not considered further but the variations must be known for making decisions which are valid economically.

The function in the general formula is not further defined. The question arises which function has to be taken in a particular case. As far as I know a biological foundation to accept any particular response function is lacking in the literature. The rectilinear function is often used but in my optinion such a line has to be rejected. Most research workers agree that plants react to fertilising in most cases according to a curvilinear function. Some of them use in these cases a form of the Mitscherlich curve $y = A(1-e^{cf})$. An objection to this formula is that the elasticity in response is less than unity over all ranges of fertiliser application, that is, there is no range of increasing return. The second objection is that the Mitscherlich equation in its original form does not assume inter-actions, a hypothesis not agreeing with reality. The same objections hold both for the Cobb-Douglas function $y = aF^b$ and the Danish equation $y = \frac{ax}{b + x}$. The quadratic and square root equations, such as $y = a + bF^2 - CF^2$ and $y = a + b\sqrt{F} - cF$, are more flexible and can work with maximal yields followed by decreases.

An objection still remains that these functions do not assume inter-actions. An inter-action exists when the performance of a certain factor is influenced by another factor, e.g. when the response to 50 kgs of nitrogen at a low pH is not the same as the response at a high pH. If the inter-actions are taken into consideration the products of the factors must be included in the formula, e.g. $y = a + bF_1F_2 + cF^2 + dF^2$. However, these functions are much more difficult to adjust.

The advent of the electronic computer may minimise the difficulties of adjusting and calculating. The formulating of yield in relation to growth factors is still defective and much more physiological research on this point is necessary. Perhaps I may suggest that the seminar could recommend more research on this point in each participating country. The meaning of the inter-actions and their ratios should not be underrated, especially as the ratios of the quantities of fertilisers are dependent on the changes in price ratios via the inter-actions. The Danish report does not consider these inter-actions.

The need for a formula including the inter-actions was realised from the beginning of soil fertility research in the Netherlands. Because of difficulties the search for a general formula has been abandoned and another method is being investigated. The suggestions which may be derived from experimental data are graphed (in most cases these suggestions are also used to formulate the mathematical function). A curve is fitted using a least squares method. The form of the function is not fixed beforehand and the interactions can be found by using a special procedure, this method is literally more dimensional. The lines are drawn at different levels of the other relevant growth factors. Our experiences with this method are very good, especially as we are now able to calculate the significant differences. Some research workers object to the graphical method, but it is apparent from the above arguments that there is little difference in subjectivity between the numerical and graphical methods.

Furthermore, the problem of obtaining experimental data for the plotting of response curves and the building up of manurial advice is important.

The usual method is by starting with the general formula using the model in which all factors are possibly influencing the yield. We include not only the factors which are easy to change, such as fertilisers, but also the factors, such as organic matter content, moisture content, which are neither easy to change nor investigate on the normal experimental field. The experiment runs as follows: A large number (200-250) of single plots are used, each individual plot is laid out on a different site, so that each plot has different soil properties. When the influence of fertilisers, e.g. phosphate and potash, is to be ascertained, some plots receive the following treatments: low phosphate low potash, low phosphate high potash, high phosphate low potash, and high phosphate high potash. For the sake of simplicity an example with only two treatment levels has been taken but in reality more levels are necessary to construct the response curve. This method combined with statistical analysis is called polyfactor analysis. By using this graphical analysis it is possible to unravel the influences of the several factors and their inter-actions. (Fig. 1). Absolute yields can be used. The great difficulty in the analysis is that there are very strong correlations between most of the factors as the natural variability is being used; it is sometimes very difficult or impossible to indicate the causal relations. On the other hand, generalisation and interpolation are not so dangerous when taking into account so many factors. Our experiences with this method are very good.

Contrary to this method is that in which well-known experimental fields are used. An experiment is laid down on one or more sites, the variable factor being incremental amounts of fertilisers, and a relationship is established between yields and increments of fertiliser. It is unfortunate that frequently only two levels are used as this number is not sufficient to construct a response curve - 4 or 5 levels at least are necessary. If the emphasis is laid on the possibility of finding treatment differences with a high statistical significance the large number of replications necessary limits the number of treatment levels. The literature on this subject gives the impression that the statistical significance is striven after more as an end than a means to an end.

The results of one experimental field apply only to that particular site. Without a further analysis of the factors which cause the differences in reaction between the experimental fields the applications of the results obtained to other sites is senseless. The intricacy of factorial designs often limits the number of experiments that can be undertaken. The first difficulty then is to define the population to which the results apply. It is necessary to know the geographical area, the soils, the cultural practices and all factors which are not taken as treatments. These problems belong to the sampling theory. Caution must be exercised when interpolating from sites chosen in a systematic way.

If the experimental fields used are a good sample of the whole population how can the results of these experiments be used for advising the individual farmer? The responses on the fields are different because the factors influencing the response vary between the sites. Without a scientific analysis of the causal factors an individual approach to the results is impossible - the results are only useful to give a general answer for the average situation. The Danish report is an example of this.

The responses or treatment differences usually vary from place to place, time to time, or with a number of other factors. Apart from the influence of the experimental error three cases may be distinguished.

- the causes of the differences in response are unknown. In this case a good sampling without bias is the first requirement.
- the causes of the differences are known but the instances cannot be predicted, e.g. weather effects.
- the causes of the differences in response are known and their incidence can be predicted (soil factors) - it is desirable from a practical viewpoint that many factors belong to this group.

Plant nutrition research in the Netherlands has always devoted much attention to the investigation of these last factors. The system of research developed is a combination of the two described methods. The conditions necessary for high statistical significances have been abandoned and the emphasis is placed on the analysis which tries to indicate the causal influences of several factors on the response.

A number (30-40) of experiments have been laid down to investigate plant response to, e.g. potash. The experiment has a large number of treatment levels so that the response curve for each experimental field can be drawn. The emphasis is not placed on statistical significances and therefore the number of replications is small (generally 2 replicates are used, and for the control and highest treatment 4 replicates). If necessary more than one nutrient can be investigated. Another difference is that the experimental sites are not a sample of the population. On the contrary the choice of sites is systematic. The reasonable expectation in this case is that the response to potash dressing will depend on the potash status of the soil - with high soil potassium levels there will be no response and with low soil level the plant will react strongly. For constructing the whole curve, high, moderate and low potassium levels must be present in equivalent numbers. A complete total nutrient status should be obtained so that a response can be established over the total nutrient status range of the soil. Such a choice is easy if a fertility survey is available. Other factors, such as pH, moisture content, etc., that influence the response must be considered in the same way.

The analysis of the data is a combination of the analysis of an experimental field and of a polyfactor analysis; both operations are graphical. The response curve for each experiment is first determined graphically; normally a maximal yield can be found. The maximal yield is taken as 100 and the other yields are expressed as a percentage of the maximum. It is expected that the yield of the no potash treatment on a site high in soil potassium will be about 100 and less than 100 on a low potassium site. The assumption is that there is a relationship between the nutrient status of the soil as expressed by soil analysis and the relative response. To determine this relationship the relative yields of, e.g. the control treatments of each experimental area, are plotted against the corresponding soil analysis. An average line is drawn through these points. Apart from experimental errors a point above this line means that the response on that particular area was lower than could be expected from the potash status of the soil. Such deviations must be related to other factors.

Generally absolute yields are not used. This reduces the spread in results as the influence of a number of factors not affecting the response is eliminated. Relative yields cannot be used if the yield levels of the experimental sites are very different. The method using relative yields does not give complete certainty that maximum yields have been attained.

The essence of this method is the possibility of relating crop response with a soil test result. Much information is obtained in this way into the causal relationships between response, fertilising and soil properties. Advice that is based on this method is very reliable, and this also holds for the nutrients, phosphate, potash and several trace elements. With regard to nitrogen the situation is more difficult as no satisfactory analysis of the nitrogen status of the soil exists. In two series of experiments nitrogen response has been related to other factors, e.g. structure, moisture content, and humus content, which are known to be correlated with nitrogen release in the soil. The results are very promising.

My ideas regarding factors affecting growth and methods of expressing growth response data had of necessity to be presented here very incompletely. It was impossible to treat all problems which are related to crop response, the influence of residual effects, etc. I hope I have made clear that the last method which I described is preferable, but the ultimate choice depends on the existing situation in each country.

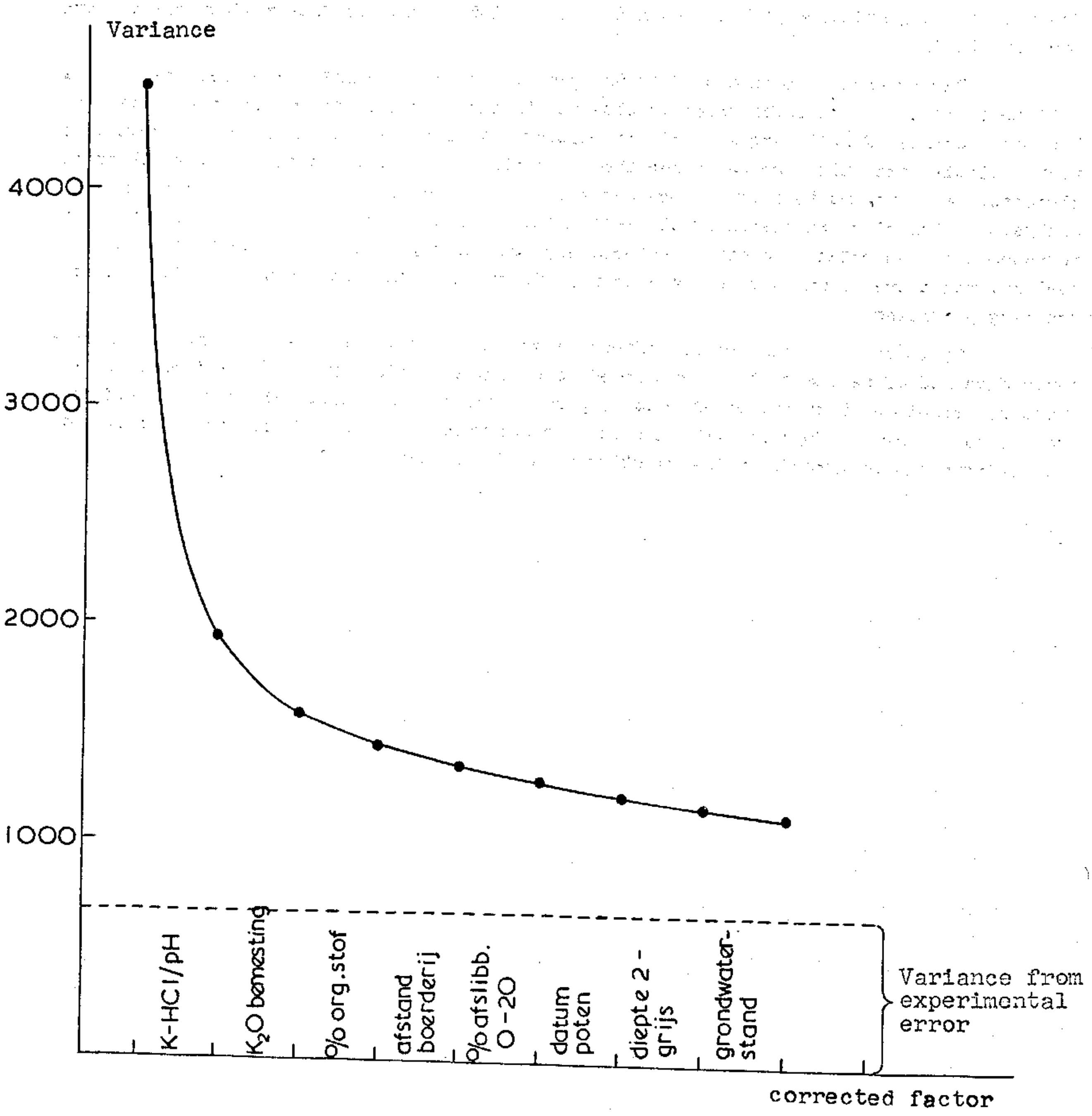


Figure 1
The decreases of the variance of yields of potatoes after successive eliminations of the influences of growth factors found by polyfactor-analysis.

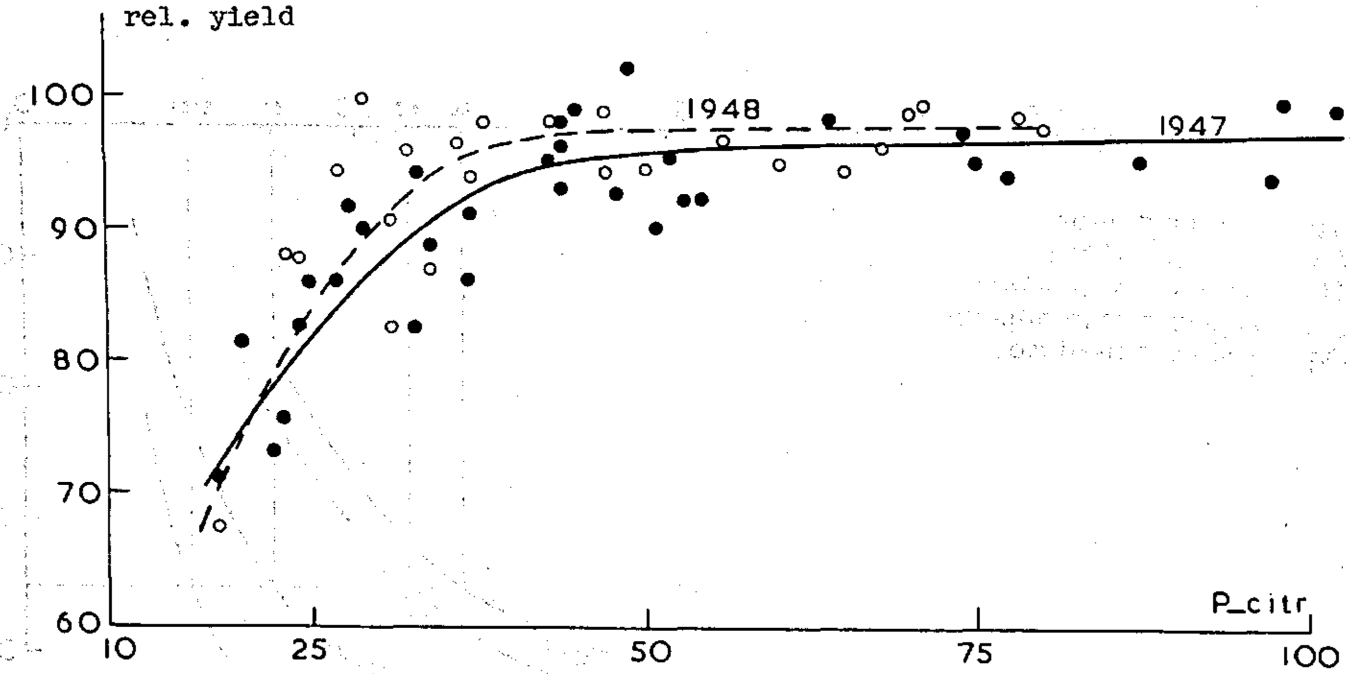


Figure 2
The relation between soil phosphate contents, determined in laboratory, and relative yields (yield without phosphate dressing expressed as percentage of maximum yield with phosphate dressing). Each dot is one experimental field. Data from the years 1947 and 1948.

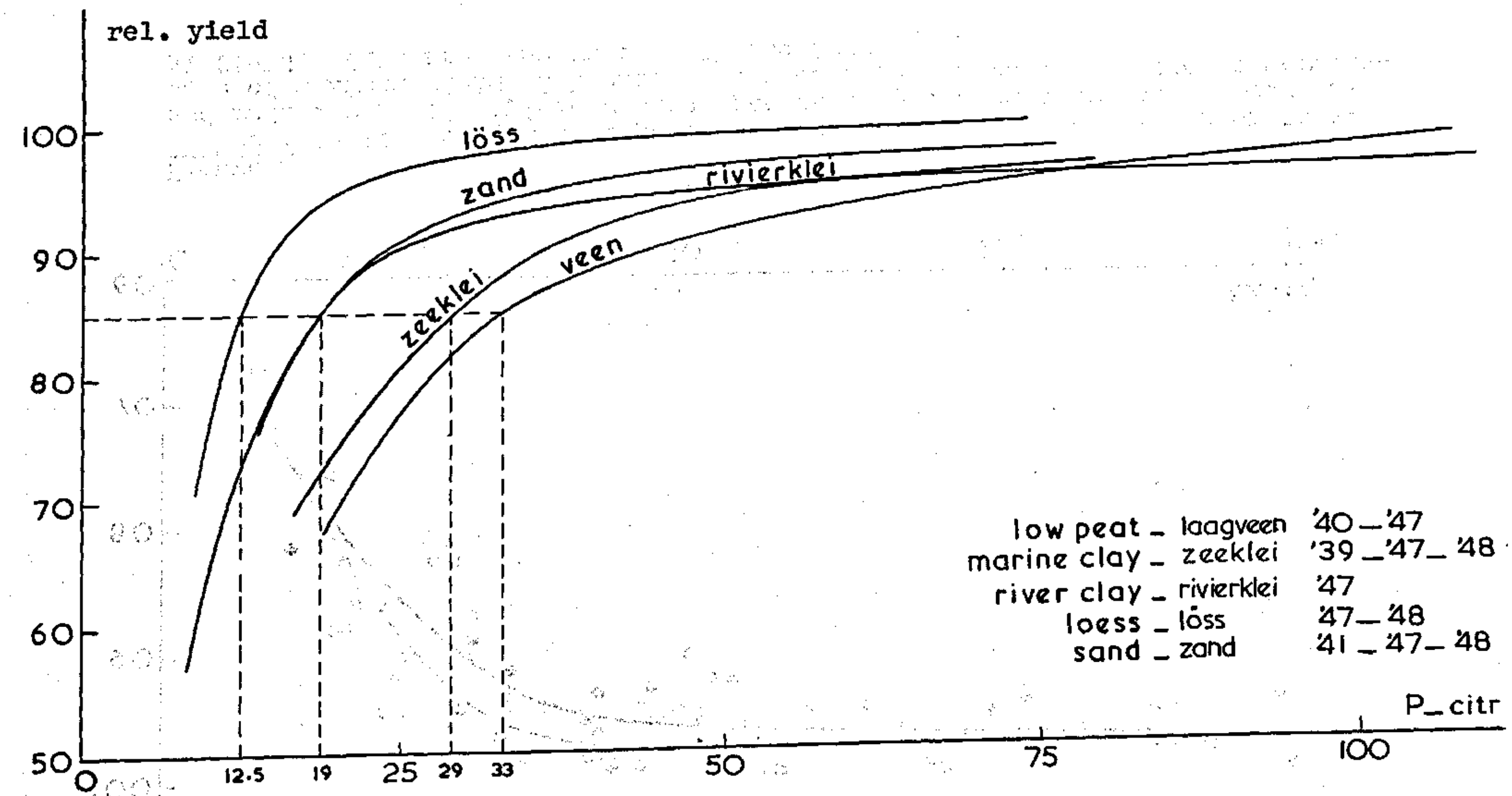


Figure 3
The same relation as given in figure 2, respectively for low peat, marine clay, river clay, loess and sandy soils.

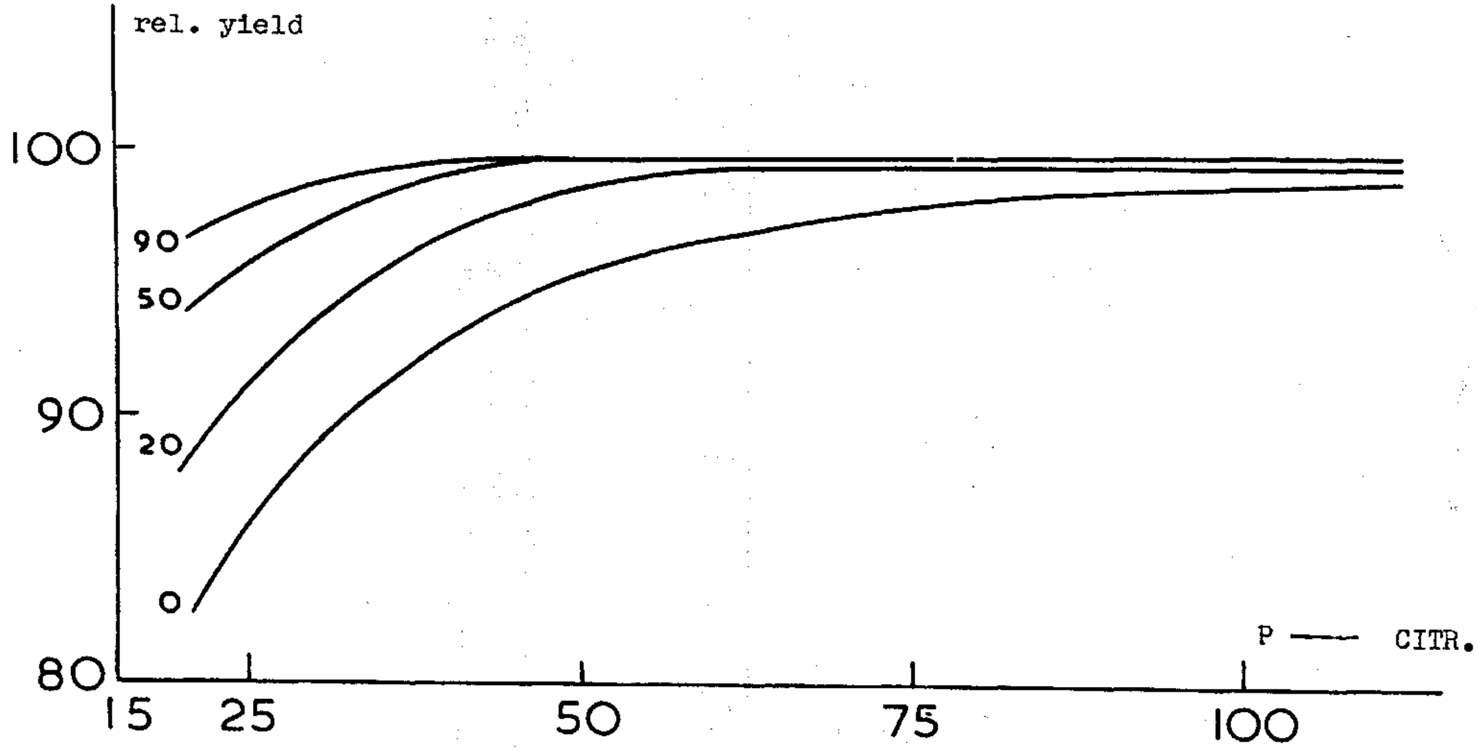


Figure 4
The same relation as given in figure 3, respectively for yields obtained without and with 20, 50 and 90 kgs/ha P_2O_5 dressing. The necessary quantity of dressing can be assessed with such graphs.

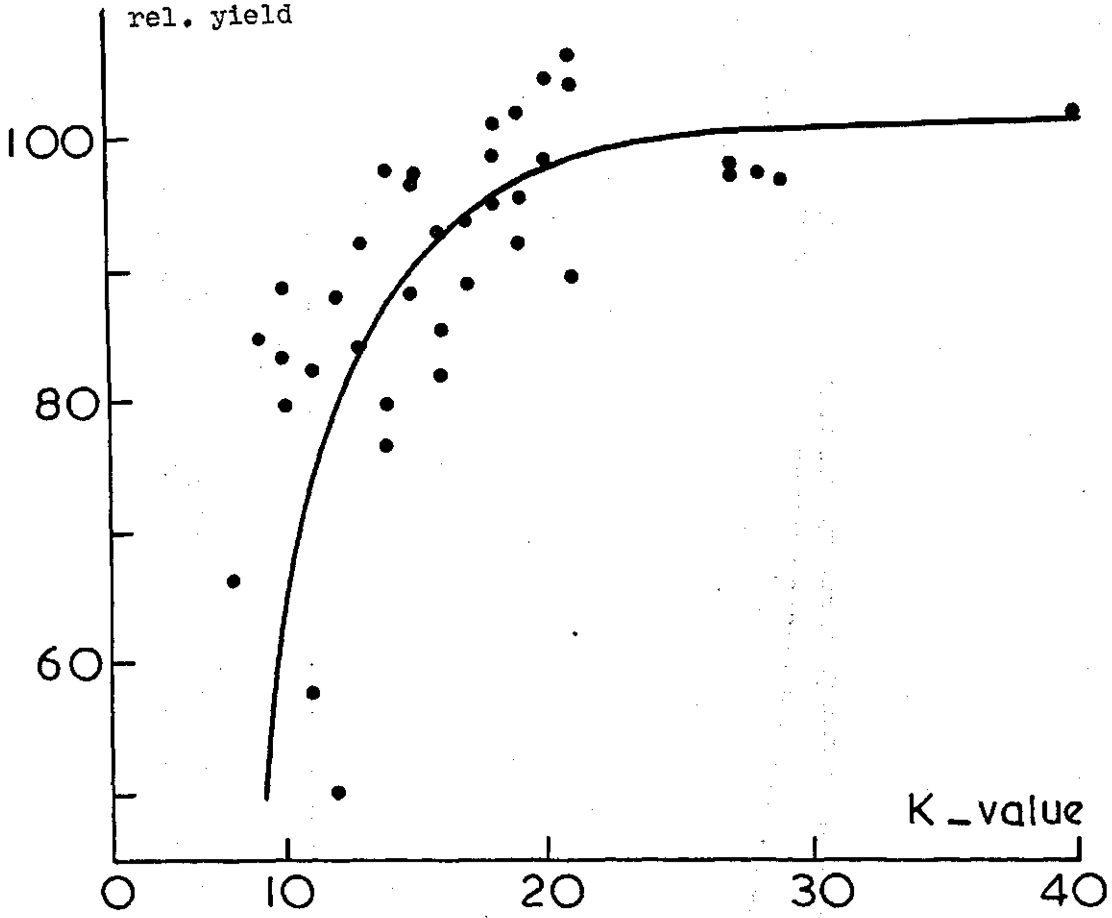
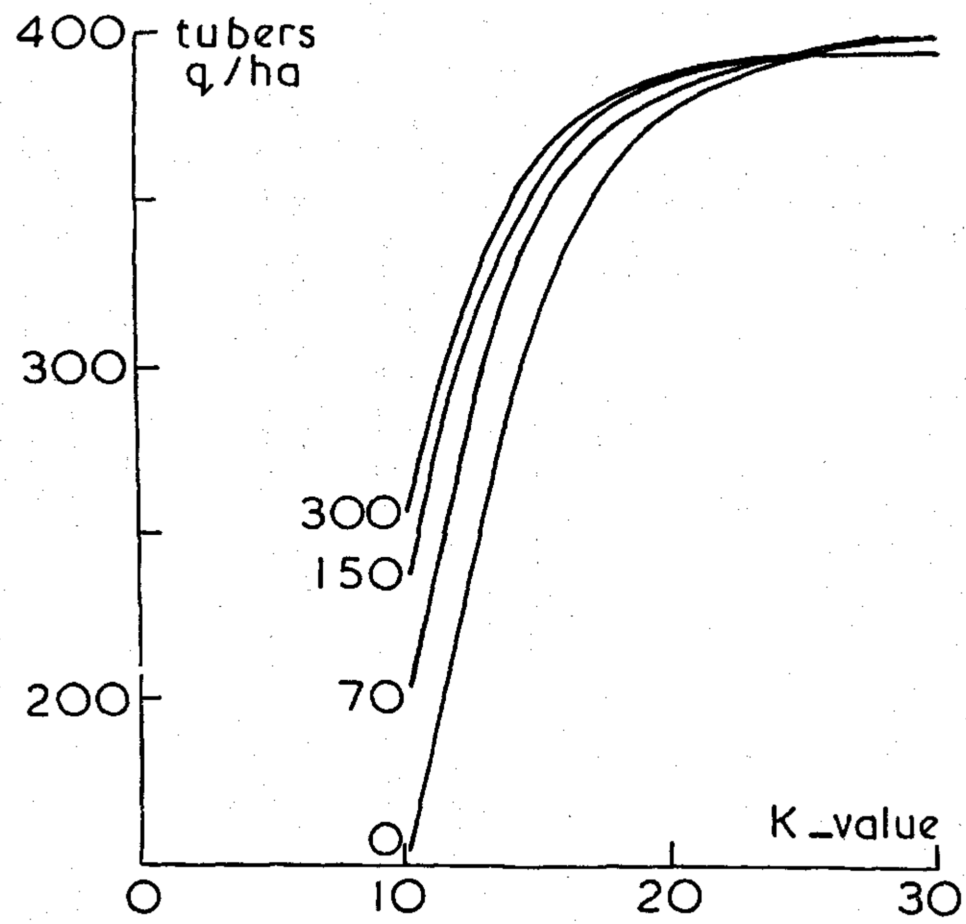


Figure 5
The relation between soil potash contents, determined in laboratory, and yields of potatoes without potash dressing, expressed in percentages of the yields obtained with 150 kgs/ha K_2O dressing.



<u>Figure 6</u>

The method of using relative yields (figure 5) does not always give complete certainty whether the maximum yields are attained in fact. In this diagram the relation is given between soil potash contents determined in laboratory, and the <u>absolute</u> yields of potatoes obtained without potash dressing (o), and with 70, 150, and 300 kgs/ha K_2O dressing. Fig. 5 is constructed independently of fig. 6, but it is possible to get the graph of fig. 5 by expressing the 0-potash yields in percentages of the 150 kgs potash yields.