ADJUSTING FERTILIZER RATES TO SOIL FERTILITY LEVEL ON THE BASIS OF SOIL TESTING

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Introduction

Soil testing as a basis for dressing of fertilizers has probably in no other country taken such a flight as in the Netherlands. It seems worth while to bring into general discussion the reasons why this has happened, the results and their importance on circumstances not quite similar to those in Holland.

The density of the population, and also the restricted size of the farms, have necessitated a highly intensified form of agriculture. Furthermore, fertilizer consumption is high and represents an appreciable part of the costs (approx. 10%). For these reasons a careful dosing of fertilizers is needed. This must be adapted to the differences in soil fertility found in practical farming.

The application of soil testing is especially relevant if the level of soil fertility in agricultural regions is very diverse. Such a diversity was especially brought about by a continuous cultivation with individual variations or by a varying state of degradation on different plots of originally fertile soils. This tendency was intensified by a completely uncontrolled use of fertilizers in the first part of this century. These differences have to be taken into consideration if a most effective use of fertilizers at each separate site is wanted.

The necessity to meet the difficulties in practical farming was early recognized by workers of the State Agricultural Experiment Station at Groningen (1). This station was situated in a region especially confronted with the problem. It became clear that the application of artificial fertilizers had to be guided scientifically, and those early investigators expected that soil testing would be the way. The development has strongly been stimulated by the establishment of a Soil Testing Laboratory, owned by the Farmers Associations but closely tied to the Experiment Station — as early as 1927 —. Reliable tests for mass investigation had to be developed. It was realized, however, that especially these tests would need calibration under the very conditions of practical farming. That the most careful attention is paid to this point is probably the most characteristic feature of soil testing in the Netherlands. For tens of years research has been directed to the elaboration of a system of fertilizer recommendations based on field trials and spread over all soil types of the country.

Essentials of the soil testing method

A method like soil testing has to meet at least some principal requirements. One of these is that the magnitude of the soil factor, as estimated by the test, must be representative for the amount of fertilizer needed. This means that the relating factor should not be disturbed by interactions of the widely varying factors of soil and climate. In an absolute sense this will never be realized, but for practical purpose it may be sufficient if this demand is fulfilled to a considerable extent. Interactions are less disturbing if they are determi-

(1) Precursor of the present Institute of Soil Fertility at Haren-Groningen.

nable. In that case their effects can be taken into account. An example of this is the antagonism of potassium and magnesium. When including the level of the second factor into the calculation the diagnosis of the effectivity of the former may be refined and vice versa.

Another requirement to make efficient use of soil testing is that an essential aspect of a factor, through which it actually works, must be characterized. In some cases the whole quantity of a nutrient in the soil may be relevant to the plant, but it may only be a restricted portion of the latter in others. In such cases this portion must be represented by the test. It may be questioned whether it will be best represented by the concentration of the soil solution, or by the rate at which the level of the latter is supplied. Certainly, a true localization of the working agent is largely responsible for the effectivity of a soil test index. In some cases the inapplicability of soil testing may be due to the fact that too little of the said requirements is fulfilled. The apparent lack of success with methods used to assess the nitrogen status of the soil, for instance, might be ascribed to such an imperfectness.

Though it may sometimes be justified to claim the superiority of a certain method to another on merely theoretical grounds, it is nevertheless certain that the final decision as to its efficiency has to be made in the field. In a similar way the recommendations of rates of fertilizers must be learned from field trials conducted under conditions similar to those of practical farming. The reason is that the actual field conditions are decisive for interactions which cannot be deduced from general rules.

Application of soil testing data

In general soil testing is not restricted to the assessment of isolated single factors. The goal in the Netherlands is a complete recommendation of fertilization. Factors are evaluated in relation to each other; the amounts of potassium and magnesium fertilizer and of lime, for instance, are recommended in mutual relation. Characteristic soil factors, such as pH, contents of humus and clay particles are taken into account.

At a higher pH, but an equal content of exchangeable potassium, the availability of potassium to the plant is lower. It seems plausible that this decrease of availability results from a physiological antagonism between K on the one hand, and Ca + Mg on the other. In the case of P, an increase of pH causes a lower solubility of phosphorus in the soil solution which declines the absorption by the plant.

With the incorporation of pH in the diagnosis of available K and P two different lines have been followed. In the case of K the interaction has been determined purely empirically in field trials as well as in pot experiments. The research was conducted with different soil types and crops. The object in view is still a more satisfactory solution by which the changes in availability effected by pH, or some other soil factor, are incorporated in the test. It could, however, be realized with phosphorus. When a method of a high standard was used the phosphorus absorption by the plant corresponded to the P-indices determined. It follows that the P index concerned makes it possible to diagnose the availability to the plant exactly. Possible interactions need not be corrected.

A full discussion of soil testing as applied in the Netherlands would include the assessment of the lime status and magnesium and trace elements (copper, cobalt, boron). The lime status, determined as pH-KCl, gives a general information about the nutritional, physical and biological status of the soil. Graduated amendments of lime can be recommended on the basis of extensive field research, considering factors like the extent of the exchange complex and its quality, depth of arable layer and the needs of crops grown in the rotation.

Magnesium may limit crop production, especially on sandy soils. Its economical importance is still higher on grassland, as the magnesium content in the blood of cattle is a controlling factor in health of cattle (grass tetany) and milk production. Studies made on the interaction of Mg and K, the N content of grass and the botanical composition of the meadow, are exemplary for the treatment of such problems (SLUIJSMANS, KEMP).

A likewise extensive project dealing with the assessment of physical soil factors has an optimum state of soil structure as its ultimate goal. It is recognized that especially the distribution of clay and sand particles, content of organic matter, lime status and drainage are important factors. Recent research made possible an evaluation of these interacting factors with respect to the different aspects of soil structure, such as the resistance to mechanical forces, soil slaking, resulting in surface crusting of the soil (especially important for seedbeds), the suitability for plant growth (actual structure) and the importance for crop yield (BOEKEL).

Finally, mention should be made of recent attempts to obtain valid estimates of available nitrogen in the rooting zone.

Thorough discussion of all these factors is beyond the scope of this paper. The purpose of the present discussion is to demonstrate the principal lines of research (see also FERRARI). By confining myself to the solutions found with respect to the fertilization with potassium and phosphorus, I shall attempt to elucidate the objectives of soil testing in the Netherlands.

Potassium

Experience gained in Holland and elsewhere has shown that the exchangeable form of potassium is an acceptable index of the availability of this nutrient. As has been said, its value is affected by the magnitude of the exchange complex. In a similar way the availability of K depends on a physiological antagonism with Ca and Mg. It is realistic to account for these factors. To include the exact determination of each of these factors would exceed the requirement that soil testing has to be simple and cheap. The content or organic matter on sandy soils and that of mineral particles $< 16\,\mu$ on clay soils are used for the approximate measures of the magnitude of the exchange complex. For a similar reason pH is taken as a measure of adsorbed bivalent cations. The interrelations between the three factors, namely content of exchangeable potassium, content of organic matter and mineral particles, and pH have to be investigated in the field. Series of field trials were conducted which meet these requirements. In such a case, plots were preselected which widely ranged between low and high for each of these factors. Mutual correlations must also be kept as low as possible.

The same crop was grown, by preference potatoes of the same variety and origin.

Crop responses were measured as yield differences, but additional information was obtained from chemical crop analysis, visually assessed scores of deficiency symptoms, etc. The results of such an experiment are demonstrated (fig. 1).

Though the effect of K-content was the most pronounced, clear relations to pH especially at low values, and also to the content of clay particles, were found. The same K content appeared to be most effective to the plant when the pH was low. In this case the antagonistic effect of other cations was lowest. The same was found at a weak magnitude of the exchange complex.

From similar series of field trials, performed in different regions and years, a K index was deduced which incorporates the relation of the three factors with the potassium response of the crop. The equation from which the K index is computed reads like this:

$$\text{K value} = \frac{\text{K-exchangeable} \times \text{b}}{0.15\ \text{pH} - 0.05}$$

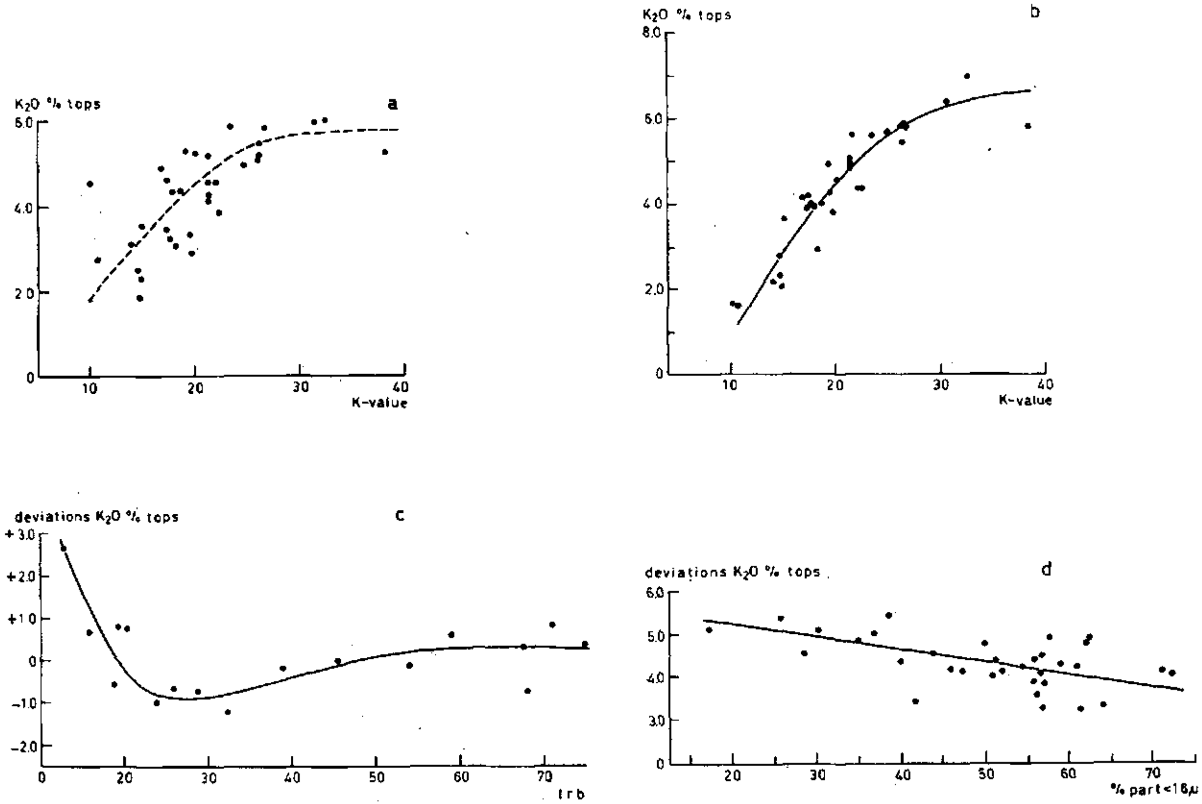


FIG. I — Analysis of relation between soil factors and K_2O content of potato tops grown on zero-K plots of series field trials conducted on alluvial marine soils.

a) Relation between content of exchangeable K and K_2O content of tops.

b) Same after elimination of effects of lime status (c) and clay content (d) on K_2O content.

c) Relation between lime status (indicated as factor lrb) and deviations from curve of K_2O content (a).

d) Relation between clay content (particles $< 16\ \mu$) and deviations from curve of K_2O content.

The influence of the clay content is expressed by the value b which decreases at increasing clay content.

The factor pH is only considered if lower than 7. In case it surpasses 7 it is arbitrarily reduced to this value. In these cases the denominator equals unity.

River clay soils are often characterized by a high capacity of potassium fixation. The question has arisen whether the latter has also to be taken into account. The answer is negative as this factor is also expressed by the intensity of the K-value (which represents the combined effects of K, pH and particle size), taking the response of the crop as a criterion.

Similar empirical equations have been drafted for other soil types. Arable land and pastures had to be distinguished. A reliable diagnosis of K-availability was made possible in this way. It must be observed, however, that research of this kind is laborious. It was therefore hardly possible to repeat the investigation with other crops. Besides, difficulties have arisen with soils of a transitional type.

The next step is the estimation of the rates of fertilizer to be recommended at any K value of the soil. The way in which this is done will be discussed in the next paragraph.

As a rule, soils are tested when the main crops will be grown. For this crop a rather exact recommendation can be given; but the exactness is less for following crops, due to the relatively rapid change of the K content under cropping conditions. This is especially true for light soils where the stock of available potassium is small.

Phosphorus

In the past a considerable number of methods for the assessment of plant available phosphorus were developed. In so far as extraction methods were involved, the extractants used varied between pure water and very strong solvents.

The background of this uncertainty was the lack of insight into the process of phosphorus assimilation. Though the latter has increased, uncertainty still remains up to the point whether the same aspect of phosphorus supply is a controlling factor under different conditions. In field trials a remarkable difference was indicated between arable crops and pasture.

In the first case, water appeared to be the most efficient solvent under Dutch climatic conditions. This conclusion was underlined by more fundamental research which indicated that values of isotopically exchangeable soil phosphate, determined under laboratory conditions in a soil-water system (E-value) and in pot experiments (L-value) appear to be of the same order of magnitude (SISSINGH). The conclusion was that water mobilizes the same components of soil phosphate as those which are in a mobile state in the soil in contact with the soil solution.

However, on permanent grassland better results have been obtained with stronger solvents, like 1% citric acid or a mixture of ammonium lactate-acetic acid, which is used with the so-called PAL method (EGNÉR, RIEHM and DOMINGO). This may indicate a higher phosphorus absorption from a densely rooted superficial layer under permanent grass. Evidence was obtained from a pot experiment with grass which was grown in a restricted volume of soil and frequently cut. It appeared that the correlation between Pw value and P response of the successive cuts was steadily declining, whereas the correlation with P-AL value grew higher. The result seems to indicate that, when P absorption is very intense, the phosphorus present in the labile pool may be a more strongly controlling factor than the level of mobile phosphate.

The clear indication that water is to be preferred to diagnose the phosphorus status on arable land does not include that the procedure of the extraction would be of less importance. On the contrary, very different correlations with crop response were obtained when factors like soil-water ratio, time of extraction and temperature were varied. Taking the response of potatoes, grown in a pot experiment conducted with widely different soils, as a criterion the most appropriate combination appeared to be an extraction with a wide ratio of water and soil, namely 60:1 on a volume basis, with intensive shaking during 1 hour at 20°C. Premoistening the soil sample during 22 hrs. gave a further improvement as the original properties of the most soil were probably restored. A high correlation of this value with crop response was found independently in a considerable number of trials conducted with a diversity of soils. Appreciable advantages of the method are its non-specificity for soil type and the fact that the regressions are not affected by such characteristic soil factors like the contents of humus, clay particles and carbonate, and phosphate fixing capacity. Its dependence on pH and the deviations found in soils extremely high in Fe content are almost negligible.

To prove the efficiency of the method for a wider range of soils a pot experiment with wheat was conducted with soils gathered from different parts of the world (Europe, America, Australia) (Van der Paauw, 1971). The result was similar also under these conditions (fig. 2).

The results appear to indicate that the process of phosphorus supply to the plant is closely related to the dissolution process of soil phosphate in an excess of water. The fact that no equilibrium was obtained in the 1 hour extraction implies that a rate process is involved. Higher values obtained with a longer duration of the extraction proved to be less correlated with crop response.

The merits of the method were also checked under farming conditions. Series of one-year field trials (197) were conducted in 6 different years. A comparison was made with the P-AL method used formerly. Using the visual response of the rather young crop, assessed and scored in a scale 0 to 10, or the P_2O_5 contents of the shoots as a measure of the response, the correlation with P-water values appeared to be satisfactory and appreciably better than with the P-AL values

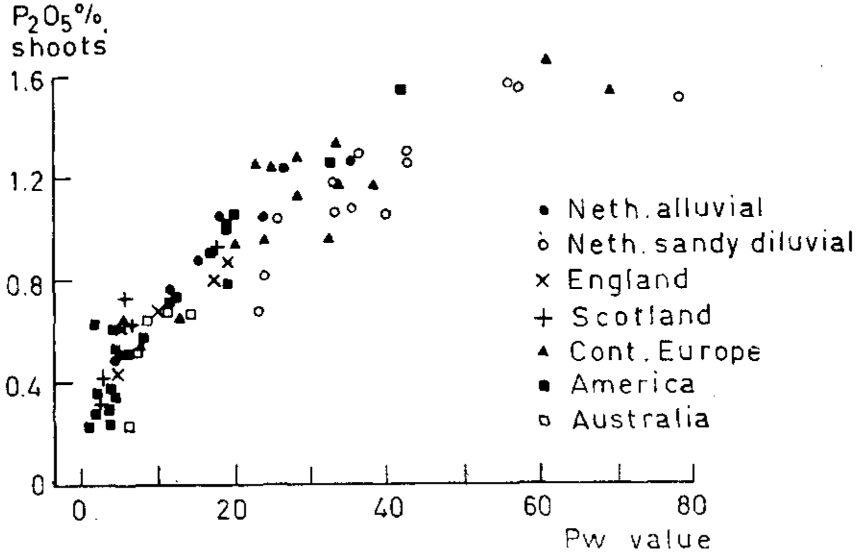
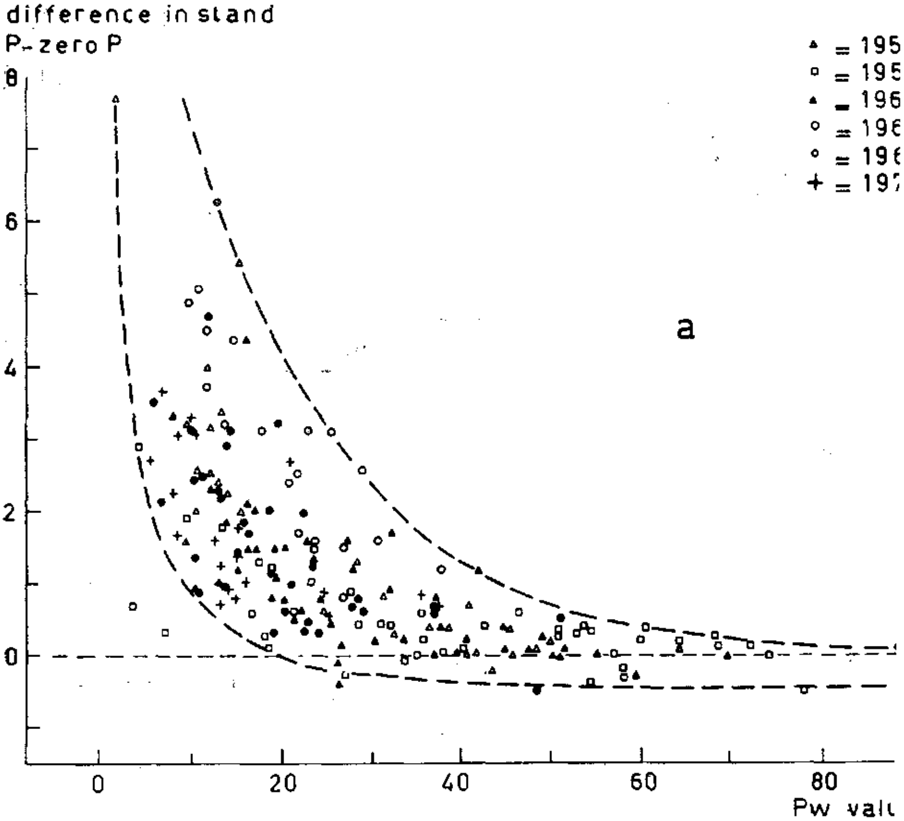


FIG. 2 — Pot experiment with wheat. Relation between Pw value of soils collected from different parts of the world and percentage phosphate in shoots.

(fig. 3). However, clear indications were found that the responses were higher under moist weather conditions. If allowance was made for the differences between years, the correlation with Pw value was much improved (fig. 4).

Using yield differences between crops amply dressed and the controls as a measure of the response, the correlations are generally lower (fig. 5). The lower correlation can be largely attributed to the variable weather conditions during the growing season and to the different climatic conditions occurring during the test years. As the P-water method has proved to be superior, it has replaced the P-AL method as a basis for fertilizing recommendation. An exception is still made for pastures.

The scheme used to recommend fertilizer rates has been


difference in stand
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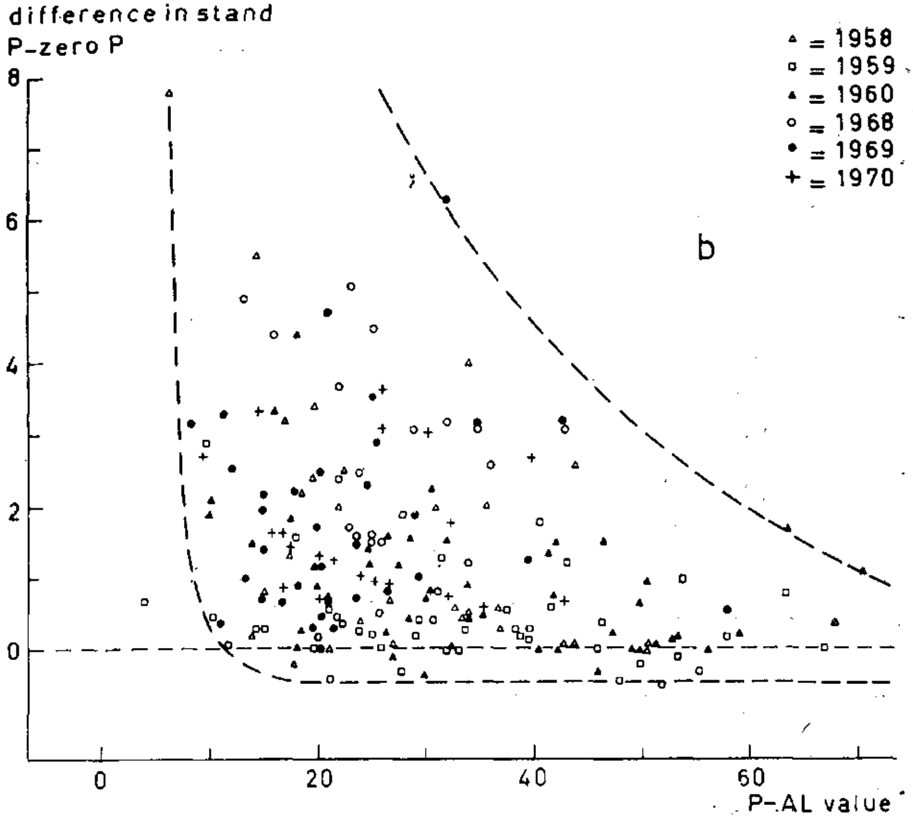
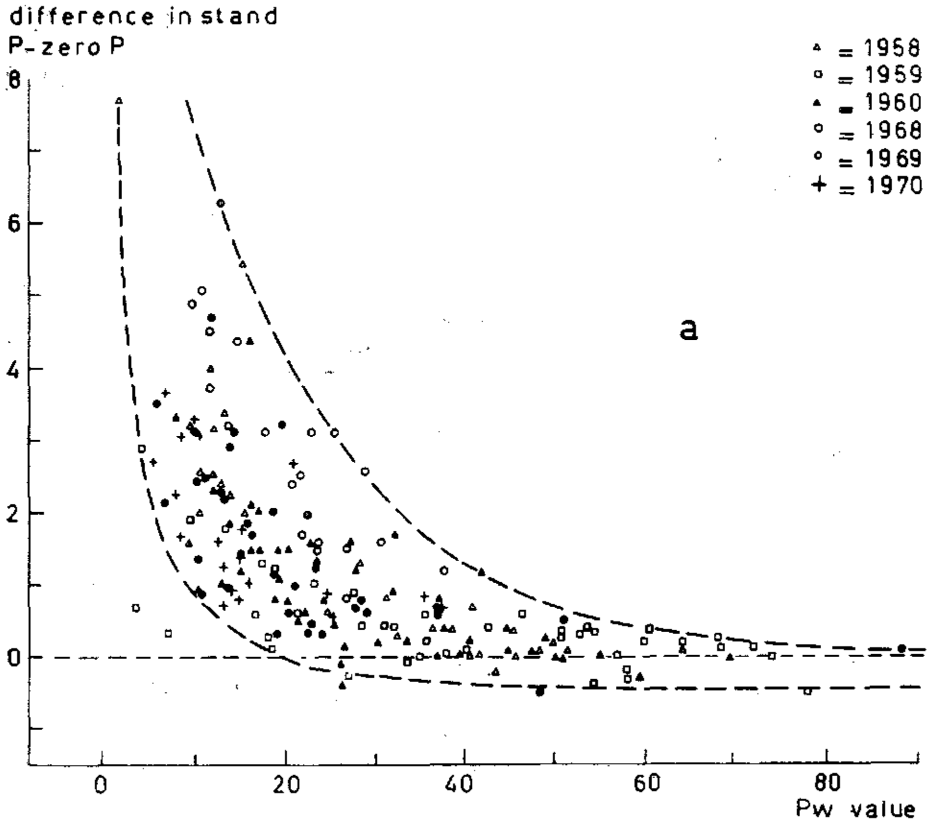


FIG. 3 — Field trials with potato in six separate years. Relation of Pw value (a) and P-AL value (b) with difference in visual score (scale 1 to 10) of potato plants dressed with approx. 300 kg P_2O_5 per ha compared with control plots, differentiated into years.


difference in stand
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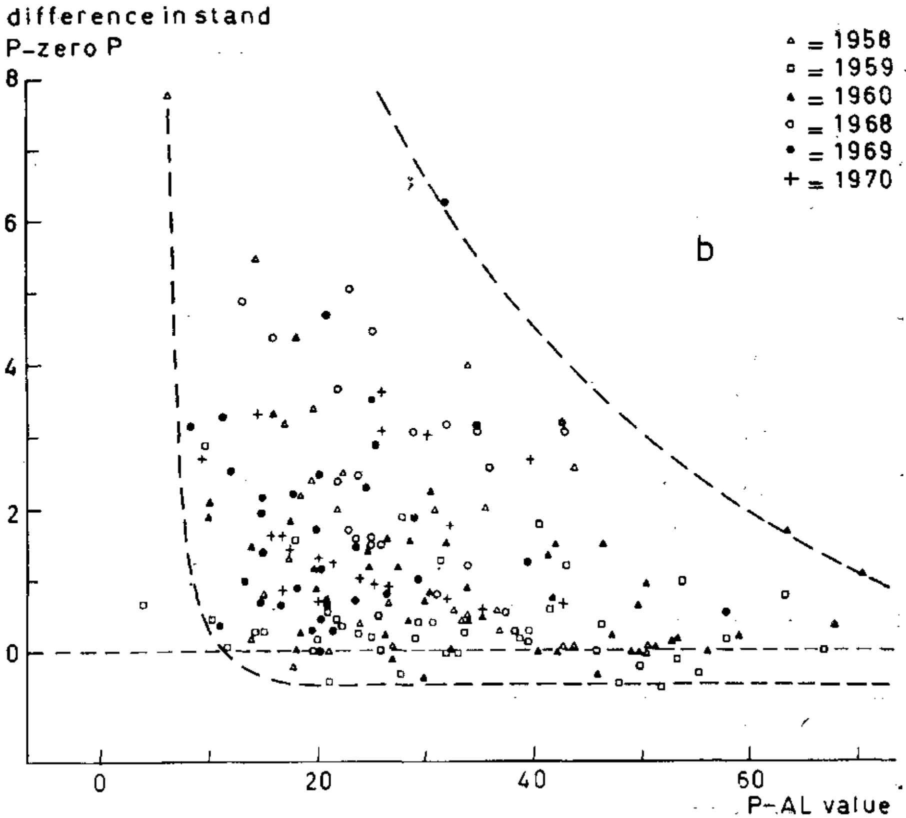

FIG. 3 — Field trials with potato in six separate years. Relation of Pw value (a) and P-AL value (b) with difference in visual score (scale 1 to 10) of potato plants dressed with approx. 300 kg P_2O_5 per ha compared with control plots, differentiated into years.

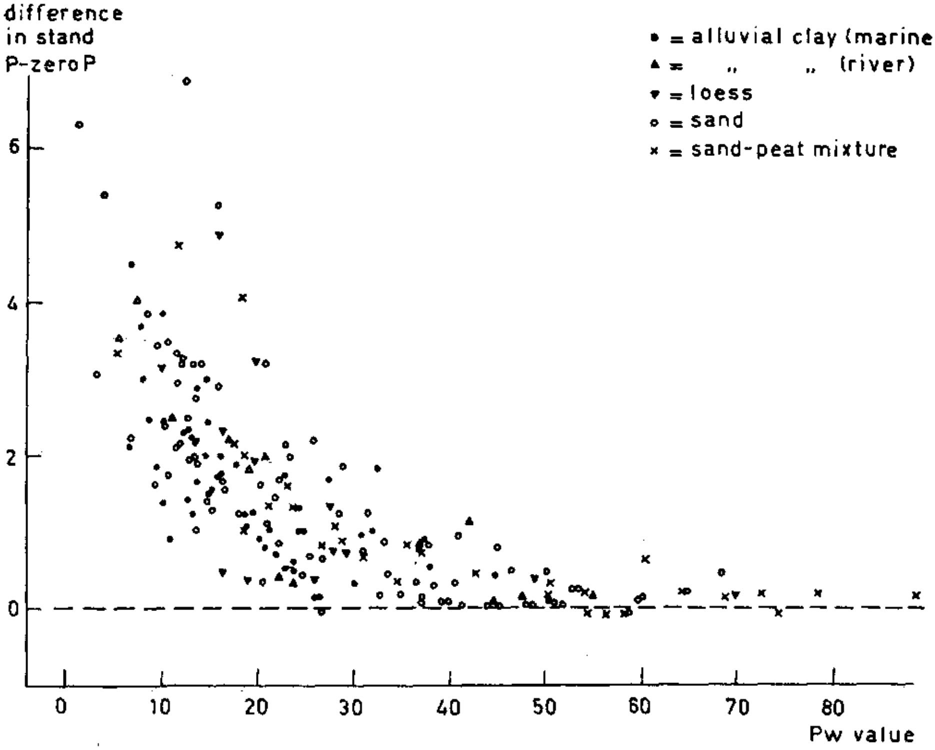

FIG. 4 — Same as fig. 3 (a) after correction for year differences.

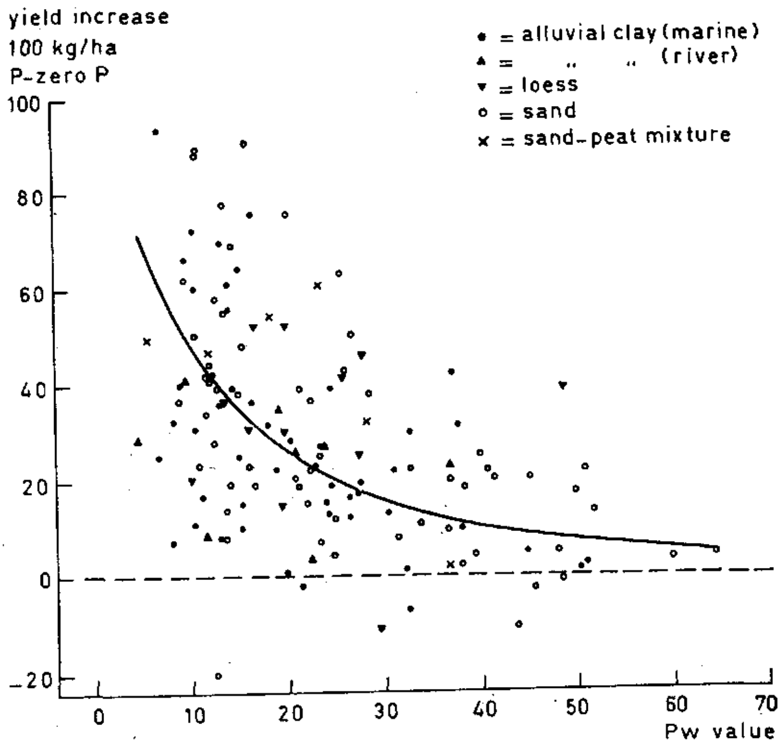

FIG. 5 — Same field trials as in fig. 3. Relation between Pw value and yield differences caused by ample P dressing (approx. 300 kg P_2O_5 per ha).

deduced from the results of the 197 potato field trials already mentioned. Rates recommended for other crops were deduced from a comparison between their responses and those of potatoes grown in the same rotation on longterm field trials. In all cases the rates of dressings widely varied. It must be remarked that potassium recommendations have been deduced in a similar way.

For each trial plot of the first group already mentioned, the rate of P dressing was plotted against the value of the yield and the costs of the fertilizer, both expressed in guilders (BAKKER and RIS). An increase of the rate of dressing is economical as long as the yield curve is rising more steeply than the line representing the costs. The optimum rate is indicated by the point of contact (fig. 6). Next, the Pw values of all trial plots were confronted with the optimum rates. With the exception of one extremely dry year (1959), the responses in the other years corresponded fairly well. The average is represented by fig. 7. It also appeared that the differences between soils are negligible. The important conclusion can be drawn that at all soil types of Holland the same phosphorus dressing can be recommended if the Pw value is equal.

In general P levels are more constant under cropping

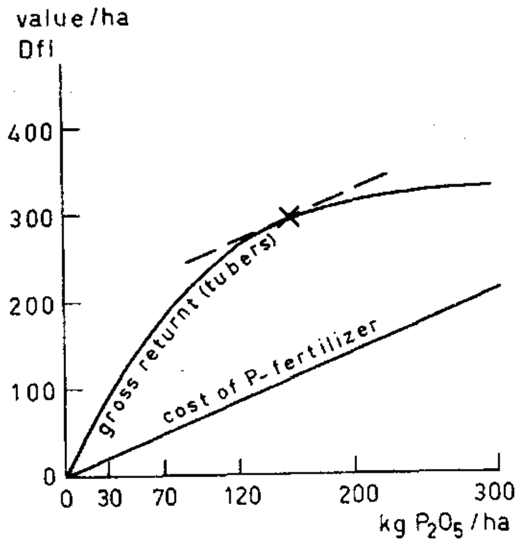

FIG. 6 — Assessment of optimum P dressing on a field trial. The optimum is represented by the contact point of yield curve and cost line (in the case represented = 160 kg/ha P_2O_5) (BAKKER and RIS, 1971).

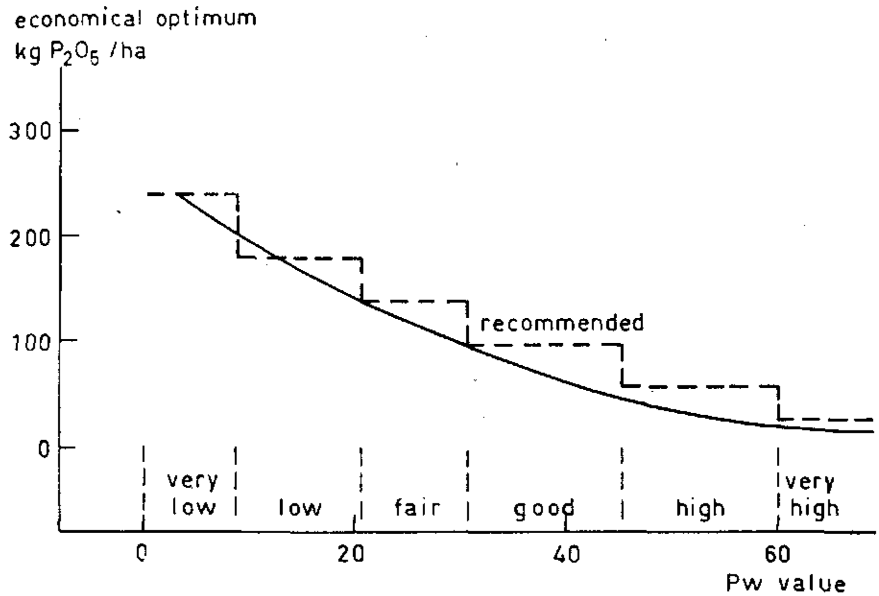

FIG. 7 — Scheme of recommendation for P dressing. Relation between Pw value and economically optimum yields. The dotted line represents the recommendations given (BAKKER and RIS, 1971).

conditions than K levels. Pw values are therefore also tolerably acceptable for fertilizer recommendation of the next crops grown in the rotation.

Schemes for fertilizer recommendation

Two schemes will be given for the recommendation of P and K dressing now being used. The second only relates to alluvial soils covering a wide range in particle size distribution. Crops are classified in groups of different need.

TABLE 1 — *Scheme for P dressing (kg. P_2O_5 per ha).*

indication	Pw-value	potato maize vegetables	beets flax	leguminous crops, lays barley	cereals except barley seed-crops
very low	< 11	240	220	180	140
low	11-20	180	160	130	90
fair	21-30	140	120	90	60
good	31-45	100	80	60	30
rather high	46-60	60	50	30	0
high	> 60	30	20	0	0

TABLE 2 — *Scheme for K-dressing on alluvial clay-soils (kg. K_2O per ha).*

indication	K-value	potato onions vegetables	leguminous crops, lays other vegetables	sugar beets flax	cereals maize seed-crops
very low	< 11	380	280	160	110
low	11-12	330	220	140	80
fair	13-15	280	170	120	50
good	16-20	230	120	80	20
rather high	21-26	170	70	40	0
high	27-34	110	20	0	0
very high	> 34	60	0	0	0

The desirable level is indicated as "good". The rates recommended at this level are economically warranted and also meant to suffice for maintaining the K status of the soil at this level in the long run.

Especially for potassium it has recently been doubted whether the last requirement is fulfilled for all types of alluvial soils and for all crop rotations (PRUMMEL). Especially the low rates supplied to cereals, although being sufficient in itself, may result in a fall of K content below the level desired. It is now being studied how these changes are related to such factors as origin and nature of the soil (particle size, profile) and yields of the crops grown.

In case of phosphorus, the quantities of fertilizer required to increase the phosphorus level are connected with the fixing capacity of the soil and the leaching of phosphorus which occurs in some cases. It is to be hoped that a method which has recently been developed (by SISSINGH) to estimate the fixing capacity, on the basis of the water extraction method, may supply the additional information.

Since 1961 the advisory work has been completely mechanized. Recommendations are delivered by the computer. Loss of the desirable connections between farmer and Advisory Service has been avoided by sending duplicate reports to the Advisor, so that regional or individual factors can be considered.

Discussion and concluding remarks

Dutch experience with the method of soil testing over a considerable period of time (half a century) appears to indicate that the efficiency of fertilizing can be appreciably increased by adapting the fertilizer rates to the individually varying nutritional level of the sites. The profit will be highest when the latter is very diverse. If, on the contrary, this variation is small, the necessity of soil testing is less. In that case its use may remain restricted to the diagnosis of possibly occurring exceptional cases.

The question arises whether a comparable intensive use of soil testing must be advocated elsewhere. It must also be borne in mind that the creation of an effective system of fertilizer recommendation on this basis will be a very laborious task. If this is not fully understood, the output may be disappointing.

However, in those cases in which such a development is seriously aimed at, the Dutch example may be very helpful. As already said in the Introduction soil testing is undoubtedly applicable wherever agricultural conditions are more or less similiar to those in Holland. Soil test methods that proved to be effective here, might also be considered for application elsewhere. Under the conditions concerned it will, as a matter of fact, not be advisable to adopt those methods without a renewed evaluation of the method.

When, however, climatic and soil conditions are more deviating from the Dutch, it may be less probable that the methods developed here will be of great use, though the basic principles underlying the methods may still be of interest.

The Dutch approach may arouse the greatest interest among workers involved in a similar development. It specially concerns the general validity of the methods applied for the development of soil tests, the way to evaluate methods and the drawing up of fertilizer recommendation schemes on this basis.

In view of the serious shortage on the one hand and the enormous wasting of fertilizers and the injurious effect this may have on soil fertility on the other and their effects on the economy of crop production, it might still be attractive to start similar approaches as in Holland. In so far as much larger agricultural areas may be concerned, the prospects will even be more favourable than in Holland where the profits of this work will remain rather restricted due to the limited size of the agrarian area of this country.

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DISCUSSION

Chairman: J. D. COLWELL

PRIMAVESI

We are perfectly in accordance with you regarding soil testing methods, i.e. that the final decision as to its efficiency has to be made in the field, that in a similar way the recommendations of fertiliser rates must be learned from field trials conducted under conditions similar to those of practical farming.

And we also agree with what you said in page 4, and here we consider especially important what you said in paragraph 3 about soil structure.

You gave a very good explanation about the situation in the Netherlands. I aspire to organise a similar approach in Brazil but this is only possible in a future programme for lack of sufficient experts and the area being enormous.

HAUSER

I have a small question here with regard to the phosphorus determination. You said that the best correlations and the most suitable methods were found with a very wide relation between water and soil, and it was a water extraction. In this case I feel that in the developing countries when we want to use this method there will not be sufficient phosphorus in the soil to make the determination.

VAN DER PAAUW

That is right. The method can be used in our country but I am not certain that it can be used on very poor soils, unless the accuracy of the analysis is improved.

HERNANDO

I should like to ask you about the results you present. You speak of a relation with the content in the stem and in the leaf, but not of the relation of the underground content in potato tubers. Do you know if there is some relationship between this potential value you give us and the potato yield?

VAN DER PAAUW

If there is a correlation?

HERNANDO

A correlation. Yes.

VAN DER PAAUW

We are using P contents of plant parts or colour of the leaves or anything else only to get an indication of the availability of the phosphorus. It is the same for potassium. Now in general my experience was that the correlation between soil K and potassium content of the leaves was usually slightly better than the correlation with potassium content of the tubers, and therefore we used it. We want a usable index and the correlation between potato yields and the potassium content of the leaves was found to be highest. Therefore the K content was the most appropriate index to distinguish between the effects of the three different factors, (exchangeable K, clay content and lime status). We can do the same with the yields but the variation of yields is generally larger than that of potassium contents of the leaf; for this reason the latter were used. But the results have always been controlled by yield determinations. However, it has not always been possible to establish similar influences of the three factors with the same evidence.

HERNANDO

I do not know whether you noticed it already. I believe van Diest of Wageningen published a paper, making a comparison between several techniques for the evaluation of phosphate in relation to the yield by studying different types of salinity soils, especially soils from the new-irrigated areas in north-eastern Spain. They get the best results with your technique and with the technique we are actually using in Spain, quite better results than with other wellknown techniques: the Olsen technique, the Bray technique etc.

VAN DER PAAUW

Of course there may be different correlations. I have told you that we have found the best correlation with a water extraction method. However not every water extraction method is as good. Large differences are due to the way in which the extraction is performed. If, for instance, the small ratio 3 is used instead of 60 (water-soil) then the correlations for each soil type apart are also high. But when different soil types are compared the results are different. An advantage of the present method is that the method is non-specific to soil type which is a very important point.

HERNANDO

I quite agree with you and say this paper presents very good results with salty soils obtained with your technique.

VAN DER PAAUW

I do not claim that it is generaly applicable to the whole world, I only say that it may be applicable in those countries where conditions are approximately similar to those in Holland.

SAALBACH

I am of the same opinion as Dr. VAN DER PAAUW, that the soil analysis is a good method for controlling the phosphate and potash level of the soil. In Western Germany we also used these methods with success. But this is my question, why do you not respect the extent of the yield difference in your recommendations for the fertiliser dressing, we do so in Germany?

VAN DER PAAUW

The last figure was showing the relation between the water method and yield differences, and the recommendation is based on this figure, not on the relation with P content of leaves. Those related to pot experiments. So we are doing the same in Germany and Holland.

WELTE

The graphs shown on the relationship between exchangeable potassium and yield are also valid for many soils in Germany.

But there is one exception and that I would like to mention here, that are soils derived from loess material. Here the exchangeable potassium does not mean anything if there has been reached a level of about 6 to 8 mgs K per 100 gms soil exchangeable potassium. This level cannot be easily corrected by potash dressings because all potash goes to some clay minerals (Illite-type). These 2:1 clay minerals with expanding interlayers show the phenomenon of potassium fixation. If we take these soils, then the non-exchangeable potassium is also in relation to the yield. It comes out from these interlayers and fixation capacity will increase. It is very interesting that the critical level of exchangeable potassium will not change. The potassium going to the plant comes only from the non-exchangeable form.

VAN DER PAAUW

I do not completely understand you but I do not claim that the exchangeable potassium is really used by the plants. I only claim that exchangeable potassium content can be used as an index for this purpose, and what the reason for this is, is quite another question. I did not say that we can use this potassium index for all soils. We make a distinction in Holland for different soils. The formula shown is used on the alluvial dry soils but the recommendation basis is different for sandy soils, in this case it is based on the relation between potassium and humus content. For grassland again different formulae are used. I know this is not ideal but in this way we can work. Certainly the solution found for potassium is less ideal than that for phosphorus because the effects of interacting factors are also expressed by the method.

COLWELL

From this discussion, it seems to me that we might record agreement on the need for studies on factors affecting the interpretation of soil tests, and I think I am fair to say that Dr. VAN DER PAAUW has pioneered this idea. I remember reading a paper of his presented in 1952 in Dublin, which startled me, and a lot of other people thinking along these lines.

BLANCHET

Comme le docteur WELTE, et comme l'a indiqué aussi le docteur VAN DER PAAUW, je pense que ce problème de rétrogradation et de libération d'ions potassium par les argiles (ou même par les fractions granulométriques de taille supérieure à celle de l'argile, c'est-à-dire des fractions limoneuses ou même sableuses, en particulier dans des sols d'origine granitique ou schisteuse), est extrèmement important. J'ai également observé souvent ces phénomènes de fixation et de libération d'ions potassium, dont la teneur en potassium échangeable du sol rend très mal compte, et je crois que dans les cas de sols comportant soit des argiles illitiques, soit des minéraux micacès en cours d'altération, ces phénòmenes présentent une très grande importance. Malheureusement, les méthodes susceptibles de tester ces problèmes sont assez délicates; il y a bien sur le tetra phénylborate de sodium ou des réactifs de ce genre, mais il me semble qu'on doit surtout raisonner en tant que possibilité pour les ions potassium d'atteindre les racines. La aussi, les phénomènes d'échange et la capacité d'échange jouent également un grand rôle, ce qui fait qu'on n'a pas toujours de très bonnes correlations entre les tests de potassium libérable et l'alimentation des plantes. Je crois que le docteur VAN DER PAAUW est d'accord sur cette conception.

As Dr. WELTE and also Dr. VAN DER PAAUW have indicated, I think that this problem of retrogradation and liberation of potassium ions by clays (or even by granulometric fractions of larger size than that of clay, i.e. of silt or even sandy fractions, particularly in soils of granitic or schistous origin) is extremely important, I, too have often observed these phenomena of fixation and liberation of potassium ions whose exchangeable potassium content of the soil gives a very bad account, and I believe that in cases of soils bearing both illitic clays and micaceous minerals in the course of alteration, these phenomena are of greatest importance. Unfortunately the methods susceptible of testing these problems are quite delicate; there is certainly the tetra sodium phenylborate or the reactives of this kind, but it seems to me that one ought to argue especially about the possibility for the potassium ions to reach the roots. There the phenomena of exchange and the capacity of exchange likewise play a big role so that there will not always be very good relations between the tests of liberable potassium and the plant nourishment. I daresay that Dr. VAN DER PAAUW agrees with this conception.

PESEK

I have a comment and a question. The comment is: it is my feeling, and I hope one that I share with most people here, that a good method for assessing soil nutrient availability is a critical condition to moving toward a scientific agriculture in any country, especially if it relates to the application of fertilizers. The question is this: in case of potassium we have found that its fixation and/or release is an important factor in assessing the value, especially of the contribution of the subsoil, to the potassium nutrition of crop. To get around this problem we have adopted the procedure of keeping the soil field moist prior to analysis and this has the effect of causing the subsoil potassium supplies to remain low as they really are when they are correlated or calibrated in pot culture experiments. It was not clear from your paper whether your procedure does or does not leave the soil in field moist condition or whether the soil is dried before extraction for potassium, and what is your extraction solution?

VAN DER PAAUW

The extractant is hydrochloric acid (HCl.sn). We do not use premoistening with potassium, we have introduced this in the determination of phosphorus recently. It might be that we must try this also with other methods. It has clearly improved the determination of phosphorus. Without premoistening correlation with crop responses differ at different soil types, but the slopes of response curves are equal when the sample is premoistened for 22 hours before the extraction.

PESEK

Our experience indicates that the effect of air drying is greater on the availability of potassium than its effect on the availability of phosphorus. We find that long storage and warming effects are greater for phosphorus than long term storage and dry warming for potassium, in other words heating affects the phosphorus availability index more than it does for potassium.

COLWELL

I might add in connection with this pre-treatment of samples whether they should be dried or kept moist, we ran into a problem recently in Australia. We were studying phosphate in the glasshouse and one soil behaved in quite an extraordinary manner, and eventually we tracked it down, we had got an enormous release of manganese due to drying. We did not want to study manganese but it was manganese release that spoilt our pot experiment. So one has to be on guard after drying a soil.

VAN DER PAAUW

It might be of interest to Mr. PESEK that already rather slight differences in the humidity of the air in which dried samples were stored, considerably influenced the final result.

HERNANDO

Our experience in relation to this is that with potash we got even more different results than with phosphate when we dried the soil samples. With phosphate we have found not much difference but with potash a very large one.

PESEK

We have seen experiments in which there has been demonstrated a clear interaction of nitrogen applied as fertilizer and water supply or moisture supply, these have been demonstrated by Domingo and Laird with wheat in Mexico and published there, and in some of our experiments in the western corn belt we find that moisture supply and nitrogen also interact. This brings me to the point of saying that it is critical to keep in mind what moisture supply is, it is not necessarily equivalent to rainfall, keeping in mind the conditions in the corn belt where our rooting zone is approximately 5ft deep to 6ft almost $1\frac{1}{2}$ to 2 meters and the available moisture if the root zone is filled to field capacity, is adequate to produce approximately one half of a good maize crop before the seed is planted. In one experiment which I recall clearly, we observed the effect of nitrogen as being one of « water sparing » so to speak, and after further probing of the soil we found that the fertilized corn exploited the moisture down to a depth of approximately 2 meters while the corn without fertilizer exploited the soil moisture down to only one meter. The following year, when the subsoils were not recharged with moisture before maize planting, there was approximately the same amount of precipitation, but there was no effect of nitrogen while in the previous year the effect of nitrogen was tremendous.

COLWELL

This question of water-nitrogen interaction seems to be something we have all been thinking about. Perhaps this is something we might agree needs quite a lot more research.

HERNANDO

This is a comment in relation to the paper of Dr. WELTE. In regard to the organic matter, it would be interesting to maintain the organic matter following the method I indicated yesterday. In tropical conditions Dahr showed that it is not necessary to increase the quantity of nitrogen when you leave the straw in the soil. His theory is that nitrogen is not needed for decomposing the straw because some nitrogen is fixed by a photochemical process. I do not exactly know that but my experience in Spain, not in tropical conditions, is that we need not increase the nitrogen in the soils when we leave the straw on the surface during the whole summer, not completely down in the soil, and at fall mix it with the soil on the top. This material will be decomposed during the growing season of the crop, and we did not deem it necessary to increase the nitrate of the ammonium sulphate during the last 15 years, and this is quite good. I remember, when I was in Brazil with Professor PRIMAVESI that there they had good results also without increasing the nitrogen applied to the soil. This is very important because the fertilizers with nitrogen are more expensive than other fertilizing material, and in underdeveloped countries it is very interesting to use such a technique. No wonder the theoretical aspects are not very clear.

WELTE

It is very complicated indeed but what is the principle? If you put straw into the soil, from the chemical point of view that is a material of very wide carbon-nitrogen ratio, let us say about 80:100:1. By micro-organisms attack the carbon decreases and nitrogen will be fixed. (Biological and biochemical fixation). The micro-organisms themselves have a very narrow carbon nitrogen ratio, bacteria about 5:1, and fungi nearly 8-10:1 and you see the ratio becomes more in favour of nitrogen. During this process the available nitrogen in the soil will be incorporated in the metabolic reactions. The atmospheric nitrogen only can be brought into this process by microorganisms in lower plants which are able to fix atmospheric N_2. It may be that some inorganic N-compounds come out of the atmosphere by precipitation (N-oxides, Ammonia). But nevertheless, if we consider all these processes the yield will be limited by the amount of nitrogen available in the soil during the growing season. You cannot take more out of the system than there is in the system.

HERNANDO

Our experiences are surprisingly different. I don't know where the nitrogen is coming from, but we do not have to apply more nitrogen than normal. The only difference I try to explain here is: we leave the straw like that, we do not put it in completely, and with this method it is not necessary to apply higher amounts of ammonium sulphate, which is only needed when we put the straw approx. 5 cm deep into the soil. In this case the straw remains near the surface and you can see the straw when going to the field. We saw that this material had decomposed during the whole growing season until spring-time, and with this method there is no need to apply a higher amount of nitrate or ammonium sulphate to the wheat than usually. I do not know if this is because there is a photo-chemical process or a microbiological one. I have no real explanation, but I think it is a very important point for practical purposes in developing countries.

BRAMAO

A propos of the method of increasing nitrogen in the soil proposed by Professor DAHR from India. He claims that his method is very successful if basic slag is applied. I believe he says that if you do apply basic slag after burying the straw, then there is no need to apply nitrogen. Am I not right?

HERNANDO

I try to explain something in relation, to that. Our soils are very high in calcium carbonate. You see the soil with which we made our experiments contains from 30 to 40% of calcium carbonate, therefore we apply only superphosphate and we get the same results as DAHR using natural rock phosphate or slags.

In tropical areas where conditions are such, that there is a low level of calcium, they ought to apply calcium phosphate liberally, but we found that it was not necessary in our conditions because we have a very high level of calcium carbonate. Thank you, but I did not present the whole story and this is a very important point.

WELTE

I think both aspects of the story are true. At first I repeat once more, you cannot take out more than there is in the system. Secondly I did not mention the velocity of the decomposition rate. This is very important. If the process of straw decomposition is not finished before the vegetation period begins, a strong competition comes into existence between the microbes and the higher plant nitrogen. On the other hand if the ecological conditions are in favour of a high decomposition rate so tnat the straw has been transformed into humus of high quality (N/C=ratio about 10-12:1) before the growing season starts, the mineralization comes into being as a benefit for the growing plant. Mineralization means that now the nitrogen comes out from the changed organic material. The amount depends on the quantity and quality of humus and mainly on the rate of the mineralization. If you apply basic slag or liming material to the straw on the surface of the soil the activity of micro-organisms will be strongly accelerated — supposing humidity is sufficient, especially the bacterial will find the best conditions for their work. Basic slag with its high content of lime (about 35-40% C or O), besides phosphorus and minor elements, is an excellent fertilizer to increase bacterial activity, the activity of atmospheric N-fixing bacteria included. We have to study this problem very carefully because it is strongly influenced by the local climatic conditions, the culture practices included.

HERNANDO

It is not that because after fifteen years we have a higher level of organic matter in the soil than before and the nitrogen content is also higher than before. This means that the nitrogen must come from another place because the yield is higher than the control plot. This is a surprising result, but I think it is true because results are results.

LATKOVICS

Much has been said about the environmental factors which considerably influence the efficiency of fertilization. Now, let me point out on the basis of our results that in some instances, so in Hungary the well-known low fertility of salt affected soils could markedly be increased by irrigation and fertilization, and we obtained good hay yields on them.

The experiments were carried out on heavy-textured solodized solonetz, well provided with organic matter and plant nutrients. This soil had disadvantageous chemical, physical properties and water regime. In our experiment the effects of increasing nitrogen doses were studied on pastures and meadows with and without irrigation. The effect of the treatments manifested itself throughout the growing period of the plants. As a response to irrigation and fertilization, some changes took place in the composition of the plant associations. So, the percentage of the more valuable grasses, as meadow foxtail (Alopecurus pratensis), meadow grass (Poa pratensis) and perennial rye grass (Lolium perenne) has increased. At the same time, due to regular irrigation, the leguminous plants have recently become dominant on the untreated plots and on those receiving 54 kg N/ha.

When evaluating the data, the highly positive effect of irrigation was established. The hay yields increase in the first and subsequent years after the application of increasing calcium nitrate rates, under both irrigated and non-irrigated conditions. After the third year, a considerable yield increase could be observed on the irrigated control plots and on those treated with 54 kg N/ha. In the last years, these increases were nearing or sometimes even surpassing the yields reached as a response to heavy N-dressing. This phenomenon may be explained by the fact that, owing to regular agrotecniques and primarily to irrigation, the nutrients were mobilized in the soil and a considerable change has been brought about in the composition of plant associations of the grassland, the dominance of leguminous plants has increased and this resulted in higher yields of hay with valuable nutrient contents.

FRIED

Prof. BLANCHET and myself are chairman and secretary of the session on the final discussion, the general conclusion on Friday afternoon, and we would like to have some help in drafting something for discussion during that afternoon. We have suggested a committee consisting of BORNEMISZA, BRAMAO, PESEK, RUSSELL and WELTE. In addition to those people who I see are willing and available, we would like the help of any of the others of you who are willing. We would like you to hand over to us in writing any suggestions or remarks that you would like to see included in the conclusions of this meeting. I think people here are ready and willing to type anything at any moment that you hand it over, so if it is rather a long thing you may want to get it typed first, but in any event, if you give it to anybody on this committee they will take it from there. If there are any other suggestions as to what might be done I would certainly appreciate hearing from you.

ARATEN

I would suggest that the people who wrote down their talks they gave us, should hand over their extracts to Prof. FRIED and Prof. BLANCHET. This would be very helpful in getting the extracts of all the papers.

FRIED

Well, we have abstracts of all of the papers, but it would be helpful if authors would summarize some of the important things they think came up during the discussions on their own paper. That might be helpful for the committee to consider in relation to drafting the conclusions. Can I ask all of you to summarize, please, any of the important points that you think might want to be included in the conclusions that came out during the discussions of your individual papers.

COLWELL

Of course we have to be careful that we don't have everything: we want some highlights. Does someone have a specific point on this matter that Dr. FRIED has raised? If not, I think Prof. THERON had a comment to make.

THERON

I was just thinking of the problem that Dr. HERNANDO and Dr. WELTE were argueing about. Surely you have all the necessary conditions there for nitrogen fixation by azotobacter. You have the organic matter there to provide the needed energy to bind the nitrogen from the air and you have got the lime there to neutralise whatever acids they may produce.

PRIMAVESI

Referring to the paper of Prof. WELTE, I agree with what you mention in your paper, page 3, paragraphs 4 and 5 and paragraph 1 on page 4. You showed very well the situation in the tropics. In the last page you mentioned the importance of the education of the farmer for the success of the extension service. I think it is a very important point.

HERNANDO

My question is to Prof. VAN DER PAAUW. We found in the areas where we use a high level of fertilizer for intensive agriculture, great trouble in finding the method to get the correct interpretation of the soil analysis to give the right amount of fertilizer to apply to the next crop. Do you have problems like that in

Holland? After we had made the soil analysis in areas where the farmers use very high amounts of fertilizers, we found difficulties in getting the correct interpretation of the soil analysis to know the level we need to apply next year for the next crop. The only thing I would like to know is if you have the same problem or if you can give me a suggestion or some method to resolve this problem. The problem is in areas with very intensive agriculture in the east of Spain where we apply a high level of fertilizer, like you do in Holland, but I said we found that for us it is very difficult to get a good correlation between the soil analysis in one year and the need of fertilizer for the next crop. Have you a problem like that in your country and how do you resolve it? That is my question.

VAN DER PAAUW

In this respect very often none or only weak correlations between soil tests and crop responses were found. It has been a very long way from bad to more efficient methods. Therefore, it is very normal that no correlations between soil tests and crop responses are present. You have to find the improved methods yourself, though this is not so easy.

PESEK

I think that there are many countries in which intensive agriculture has gone on for some time, where test levels for fertilizer elements in the soil are so high that nothing is needed and the simple answer is: do not add anything. I suppose that this is most likely to occur on soils growing potatoes, tomatoes or other high value crops. I believe that the place of tissue analysis in all of its various forms becomes important as a refinement of agricultural practice after the use of the soil test has been exhausted in terms of predicting needs. At this time, a base level or an optimum level of fertility has been established and if an imbalance in the nutrient status of your crop remains, you do analyse the tissue and use the results of the analyses for the following year.

HAUSER

I just want to make a final point. I think there are some ideas which are not quite correct about soil testing calibration. The soil analysis is not difficult but the calibration is, and that is what Mr. HERNANDO has said. In any one country where a good soil calibration is done it has taken 40 years or more for that. Let us keep that in mind. Unless we find a quick method which would then be new, we have to think in terms of 20, 30 or 40 years. It is easy in countries where this has been worked out but in countries where no correlations are worked out you cannot do it with the present methods in a shorter time, as Mr. VAN DER PAAUW said. The Netherlands started in the 1930's. I say that only to prevent a misunderstanding among us regarding the calibration of soil tests.