

DEVELOPMENT OF SOIL TESTING IN THE NETHERLANDS

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Introduction

Soil testing methods as a basis for fertilizer recommendations have been developed at the Institute for Soil Fertility in The Netherlands by means of one-year field experiments, long-term fertilizer experiments and pot experiments. The one-year field experiments, normally conducted with one crop in a series of trials on one soil type (replicated over years to evaluate the effect of weather), have given the most direct information for evaluation of the soil analysis figures under normal field conditions. In the long-term experiments the nutritive needs of various crops can be compared and the changes in nutrient content of the soil under influence of continued yearly fertilizer dressings of different magnitude can be studied. In the pot experiments the influence of different factors on the response of the plant to a certain nutrient element can be studied under constant ecological conditions, e.g. a comparison can be made of different textural classes of the soil, different water regimes, etc.

In the one-year field experiments the sites of the field trials must be selected carefully. Information from earlier experiments can give an idea which factors could influence the response of the crop to the nutrient. Thus for potassium, the availability to the crop depends on the potassium status of the soil, but also on its exchange capacity and the lime status. Therefore the trial fields must be selected in such

way that there is a considerable variation in the potassium values as well as in the other factors mentioned [6]. Field sites should be chosen in such a way that no correlated factors are present. In other words the principle of stratified sampling for calculation of a regression model should be applied. For instance, soils with a low as well as high exchange capacity, each with both low and high potassium analysis figures, should be selected. The same applies to the choice of the best of several soil analysis methods for the same nutrient element, since the soil analysis figures will be also more or less highly correlated. The soil samples which show deviations from the average contribute most to the information leading to the selection of the best method of soil analysis [7].

The field trials themselves can be of simple design, provided that the range covered by the different fertilizer rates is wide. Prummel [8], used five rates of phosphate, c.q. potassium application with three replications for evaluating fertilizer recommendations for beans and spinach.

Because the size of the yield is determined by other factors as well, in most cases the relative yields give a much better correlation with the soil analysis method under evaluation. The relative yield is estimated for each field trial from the curve relating yields with fertilizer rates and is expressed as a percentage of the maximum yield.

Often effective use can also be made of nutrient deficiency ratings as well as the nutrient content of the plant or the leaves. The nutrient of the plant, which also serves to interpret high soil analysis figures, thereby improving the correlation test, shows moreover less scattering along the regression line, from which it appears that the relation is less susceptible to influences of other factors. Although the correlation of the two characteristics, viz., deficiency ratings and nutrient content, with the soil analysis figure is often higher, the relationship of these factors with ultimate yield remains yet to be established. For agricultu-

ral crops the Institute for Soil Fertility has done much work on the evaluation of soil analysis methods for phosphate, potassium and magnesium, and also for trace elements. In horticulture no such systematic work as described above for agriculture has been performed. Generally the critical nutrient levels found in agriculture have been tested in horticulture on a relatively restricted number of experimental fields only. Yet a rather reliable relation has been found between the response of horticultural plants to dressing with phosphate, c.q. with potassium and the relevant soil analysis figures [1,2]. Recently Prummel [8] evaluated the fertilizer need of vegetables grown on agricultural land as dependent on the nutrient status of the soil. Some features will be presented below of the development of soil testing in The Netherlands for potassium and phosphate with agricultural crops and with vegetables grown in agriculture and horticulture.

Soil testing for potassium

A soil analysis method for potassium has been developed, consisting of a soil extraction with 0,1N HCl in a soil: solution ratio of 1:10 [12]. A refinement of the interpretation of the soil analysis figures for the fertilizer recommendation could be obtained by taking into account the influence of the organic matter content for sandy soils and the influence of the clay content and pH for heavier soils. For practical advisory purposes the potassium analysis figure is converted on an empirical basis, to one number, the K-value, which takes the influence of the above-mentioned factors into account, the size of the correction coefficients being based on the results of numerous field experiments in agriculture. Thus, on sandy soils with a certain K-HCl figure the yield depression upon omission of potassium fertilizer increases in severity with increasing organic matter content of the soil. After correcting for the influence of organic matter content by dividing the K-HCl figure by $0.05 \times (\text{org. matter } \% + 10)$ the obtained K-values have the same meaning for interpreta-

tion of the fertilizer need, independent of the organic matter content of the soil. For clay soils, the availability of a certain uncorrected K-HCl figure rises with decreasing clay (particles $< 16\mu$) content and increasing acidity. The correction coefficients have been derived mainly from field experiments with potatoes. It is not certain that the same correction coefficients apply to all agricultural crops, although they are quite useful according to our experience. It is self-evident that in horticulture with so many crops and such great differences in nutrient needs, uptake capacity and ability to absorb less available potassium from minerals no complete insight has been obtained so far into the necessary magnitude of the correction factors. To get an estimation of the critical soil analysis figures for vegetables growing outdoors the results of fertilizer experiments on various sites and of many years were collected and compiled. The data have been grouped into sandy soils (less than 11% particles smaller than 16μ) and clay soils (more than 10% particles smaller than 16μ). There appeared to be a significant relation between the yield depression upon omission of potassium fertilization and the potassium status of the soil (Table 1).

Table 1. Yield depression upon omission of potassium fertilization in outdoor vegetable production as dependent on K-content of the soil (0-20 cm)

Average yield depression (%)	K-HCl of the soil (mg $K_2O/100$ g dry soil)	
	sandy soil	clay soil
15	10	
10	18	37
5	26	63
0	34	89

If the potassium content of the soil is 35 mg $K_2O/100$ g dry soil (HCl-extractable) in the top layer (0-20 cm), on the average no yield depression is expected upon omission of a

potassium application in the case of sandy soils, but on clay soils the yield depression will be 10% [1]. Figure 1 shows the relation between relative yield of vegetables grown

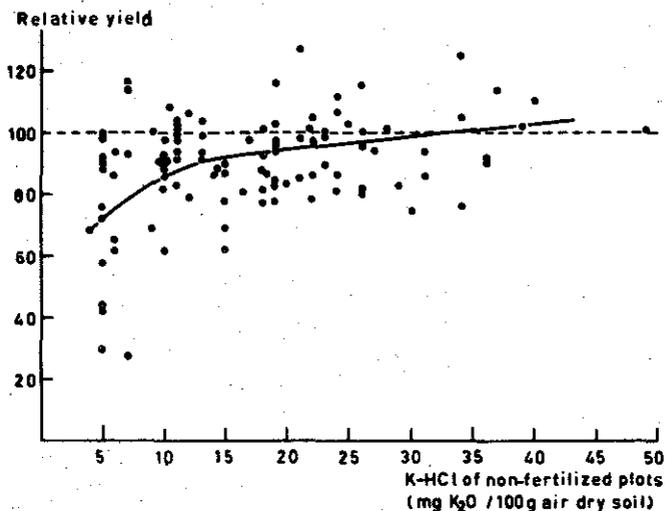


Fig. 1. Relation between the relative yield of vegetables and K-HCl of unfertilized plots on sandy soils

on sandy soils without added potassium and the potassium status of the soil. In table 2 the vegetables are arrayed into decreasing order of yield depression on the unfertilized plots. In this table all available data are used, without distinction according to soil type, potassium status and experimental year. The lowest number of experimental years per vegetable amounted to 9 and the highest to 58. Knoppien [5] found on river clay soil, poor in K-content, a sharp response to potassium dressing of lettuce, garden beet and spinach, a distinct response of early potatoes and cauliflower and a moderate response of broad bean, endive and leek. After mutual comparison of experimental data and observations made in practical horticulture, and considering the need for simplification the following three

Table 2. Classification of annual vegetables according to the yield depression caused by omission of phosphate and potassium respectively

Average yield depression	Effect of omission of phosphate	Number of trial fields	Effect of omission of potassium	Number of trial fields
20%	Endive	27	Spinach	30
19%	Dwarf snap bean	46		
18%			Slicing bean	10
16%			Cauliflower	21
14%			Early potato	58
			Dwarf snap bean	45
13%			Carrot	18
12%	Slicing bean	10		
11%	Broad bean (sandy soils)	10	Broad bean	11
	Carrot	17		
	Borecole	12		
10%	Lettuce	20		
9%	Early potato	48		
8%	Spinach	28	Lettuce	22
			Celeriac	9
			Endive	28
			Witloof Chicory	9
7%			Borecole	12
6%			Red Beet	10
2%	Cauliflower	12		

groups of potassium fertilizer recommendations for horticultural soils have been made: high potassium requirement: early potatoes, cauliflower, celeriac, carrots and spinach; normal requirement: broad beans, snap beans, lettuce, witloof chicory and other, unmentioned crops; low requirement: endive and strawberry. The difference between the quantities of fertilizer recommended for the first and third group amounts to, e.g., 100 kg K_2O /ha in the case of marine clay soils of low and moderate potassium status.

From 1950 to 1959 the potassium fertilization of early potatoes was studied on marine clay and silt soil in a horticulture centre with well managed and heavily dressed holdings [2]. Five experimental fields with 7 rates of potassium

ranging from 0 to 600 kg K_2O /ha with three replications were laid out. The clay content of the soils varied from 11 to 62% particles smaller than 16μ and the K-HCl content from 21 to 75 mg/100 g dry soil.

It has been concluded that for early-potato growing a K-HCl figure of 45 mg K_2O /100 g dry soil was optimum (Fig.2). Even

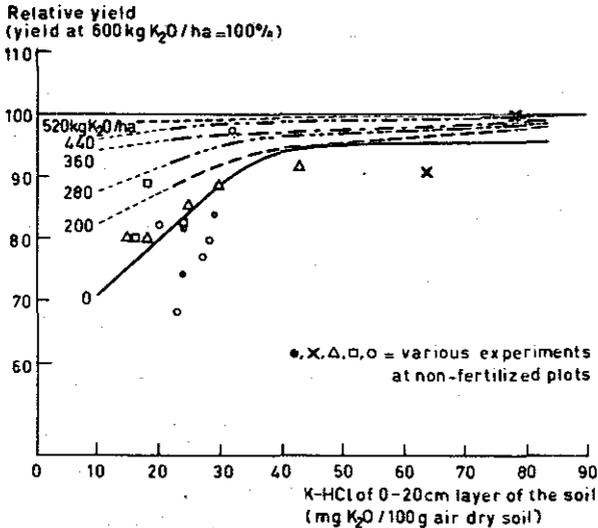


Fig. 2. Relative yield of early potatoes in relation to potassium dressing and K-content of the soil

for higher potassium values of the soil a fresh potash dressing increased the yield. It is not clear why fertilizer in such cases still has a favourable effect. Possibly it promotes early growth under rather unfavourable air and soil temperatures in spring. The critical K-HCl level which was found here, is higher than on arable land. This may be a consequence of the favourable growing conditions and the high fertility status of the horticultural soil, which interact with the plant's response to potassium. For this rather limited amount of experimental material the relation of the relative yields of the unfertilized plots with the K-value

(i.e., the K-HCl figure corrected for clay content and pH) was scarcely, if any better.

The size of the economically optimum dressing depends not only on the potassium status of the soil, but also on the yield increase, resulting from the potash dressing, the selling price of the potatoes and the cost of the fertilizer. Per field trial and experimental year the economically optimum rate of dressing was calculated (Fig.3). The optimum occurs

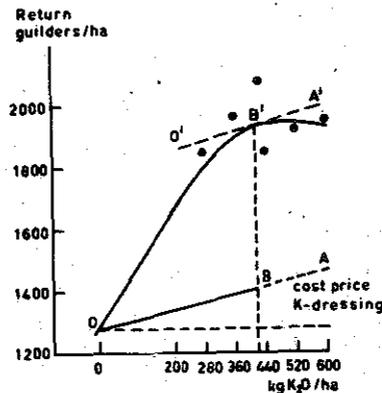


Fig. 3. Computation of the economically optimum potassium dressing per field trial

the point where a small increase in fertilizer rate gives an increase in yield, the benefit of which equals the extra cost of the dressing. For a still higher fertilizer rate costs surpass the profits. Table 3 is given as an example of relevant economical considerations. For a high potassium status of the soil there is a greater difference between economically optimum applications in dependence on the production level of the crop than in the case of a low potassium content of the soil. For the former the risk of not giving the right amount is greater than for the latter. This is the consequence of the fact - as Figure 2 indicates - that at a certain potassium level of the soil the yield was increased relatively to the same degree by the dressing, irrespective of the parcel involved. On the other hand, if the monetary

return is high, there is only a small variation in economically optimum amounts. A small relative increase in production from a heavy potassium dressing then already pays. In recent years vegetables have been increasingly grown on arable lands. This is a consequence of the increasing demand of the processing industry. Because several factors, such as soil fertility, production level and selling price of the product differ from those in horticulture, the question arises to what degree the fertilizer recommendations for horticulture are applicable. The low selling prices for processing products lead to the expectation that fertilizer applications to crops grown on high-potassium soils with as consequence of a weak response will not be profitable (compare Table 3). Frummel [8] laid out 26 potassium experiments with spinach, and 32 with beans, on arable land. Spinach grown on marine clays and silts gave a clear response to potassium application. Yield depressions of up to 60% occurred on low-potassium soils when no potassium was applied. The economically optimum dressing is related to the potassium level of the soil (Fig.4). The scattering of the points along the average line has been caused, among other things, by the inherent inaccuracy in the determination of the optimum yield for each experimental field. The corresponding optimum fertilizer dressing cannot be determined sharply in the more or less horizontal part of the yield curve, where the response to fertilizer is small. Below a K-value of 20 mg $K_2O/100$ g dry soil the response of spinach to a potassium dressing was stronger than that of potatoes. It is necessary to give spinach at least 100 kg K_2O/ha more. Above a K-value of 35 no potassium dressing is necessary; a small amount, 50 kg K_2O/ha , however, is recommended as a margin of safety. The fertilizer need of beans on marine clay and silt soil was smaller than that of spinach, although at low K-levels of the soil amounts as high as 250 kg K_2O/ha are desired. Potassium increased the nitrate and the soluble oxalic acid content of the

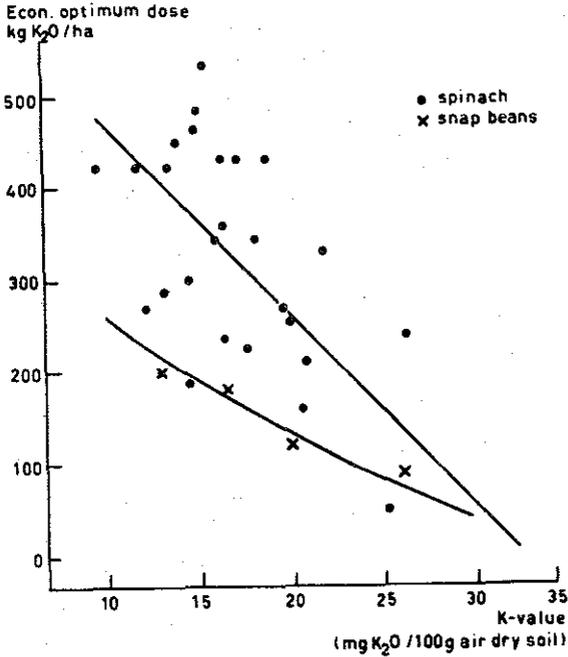


Fig. 4. Economically optimum potassium application for spinach and snap beans in relation to the potassium content of a marine clay and silt soil

spinach only to a small degree. Increasing potassium dressings from 0 to 480 kg K₂O/ha increased the nitrate content on the average from 1.94 to 2.09% and the soluble oxalic acid content from 2.35 to 3.18%. These levels are, however, not so high that the consumption of the spinach would constitute a health hazard. On sandy soils, in contrast, the response of beans to differences in potassium supply was only small. In 2 of the 10 experimental fields with a low K-status there was a positive response; the maximum yield was obtained at rates of 60 and 90 K₂O/ha respectively. It is possible, however, that the need for potassium on the slightly acid arable land is lower than on the horticultural soils with a higher pH.

Soil testing for phosphate

Outdoor vegetable crops grown on horticultural soils show a stronger response to phosphate dressings than arable crops. Omission of dressing for horticultural crops is only possible when the phosphate status of the soil is high [1]. The magnitude of the depression in yield caused by omission of fertilizer depends on the phosphate content of the soil (Table 4).

Table 4. Yield depression of vegetables caused by omission of phosphate dressing in relation to soil phosphate content (0-20 cm)

Average yield depression (%)	P-number (mg water-soluble P_2O_5 /100 g soil)	P-AL (mg acid-soluble P_2O_5 /100 g soil)
20	3.4	47
10	9.5	86
5	12.5	106
0	15.6	125

There are two methods for phosphate analysis in use in horticulture: P-number (extraction at 50°C of the soil with water 1:10 soil/extractant ratio) and P-AL (P-Engel-Rhiem-Domingo extraction with ammonium lactate and acetic acid), the former giving the easily available soil phosphate, the latter also the less easily available phosphate. For fertilizer recommendations in horticulture both methods are used together with the idea that in this way an estimate is obtained of the needs of both short- and longseason vegetables as well as of plants with a good or a poor capability of solubilize difficultly available phosphate. As shown in Table 4 no phosphate dressing is necessary, if the phosphate content of the soil exceeds 16 mg water-soluble P_2O_5 /100 g soil, or 125 mg acid-soluble P_2O_5 /100 g soil. These figures are averages obtained with many species of vegetables over all experimental years. Endive and beans showed the greatest response, much more than spinach and potatoes, which are

also known to have a high phosphate requirement (Table 2). At a low phosphate status of the soil, optimum phosphate applications are rather high, on the average 250 kg P_2O_5 /ha or more. At higher phosphate contents the optimum amount decreases more or less regularly; beyond a P-number of 7 mg P_2O_5 /100 g soil or a P-Al of 70 mg the optimum rate lies between 0-100 kg P_2O_5 /ha, depending on the phosphate status of the soil and the ability of the plant to absorb phosphate. For practical fertilizer recommendations, the following three groups of vegetables are distinguished; a group with a high phosphate demand, including broad bean, snap bean, endive and summer carrot, a group with a normal demand, with early potatoes, cauliflower, celeriac, winter carrots, and spinach, and a group with a low phosphate requirement, consisting of strawberry and witloof chicory. At a very low phosphate status of the soil the fertilizer recommendation for the first group is 100 kg P_2O_5 /ha higher than for the third group. At a low and moderate phosphate content of the soil the difference is 50 kg.

As already mentioned, two methods for phosphate analysis are in use for horticultural soils. The question arises if both are necessary. Some research work indicates that the P-number, characterizing the quantity of water-soluble phosphate, gives a better indication of the phosphate response of the plant than the P-Al method. Therefore the influence of lime and iron hydroxide on phosphate availability to lettuce and endive was studied [9]. To simulate iron-rich, phosphate-fixing soils, bog-ore was mixed with the soil. This material, however, obtained from a water company was found later to contain a small amount of phosphate (about 2% P_2O_5). Lime and iron appeared to decrease the availability of phosphate to the plant. (Table 5). The P-number reflected this decreased availability, but P-Al was increased by the addition of lime. P-total was increased by the addition of calcium as well as iron, the latter being a consequence of the P content of the bog-ore. Another indication that water-sol-

Table 5. Influence of lime and iron hydroxide on soil phosphate availability to lettuce

Addition	pH-KCl	P-number mg P ₂ O ₅ /100 g soil	P-Al	P-total	Yield (mg dry weight)	P ₂ O ₅ % of the plant	P-uptake (mg P ₂ O ₅ / plant)
- Ca - Fe	4.7	8.9	42	110	12.3	0.87	122
- Ca + Fe	5.2	1.6	33	153	11.0	0.69	89
+ Ca - Fe	5.8	4.8	48	112	11.3	0.81	110
+ Ca + Fe	6.2	1.1	41	161	8.2	0.58	62

Table 6. Influence of horticultural peat on soil phosphate availability in unfertilized plots

Cm of peat applied	P-number		P-Al mg P ₂ O ₅ / 100 g soil				P-uptake (mg P ₂ O ₅ per plant)	
	pH-KCl 4.6	pH-KCl 5.0	pH-KCl 4.6	pH-KCl 5.0	pH-KCl 4.6	pH-KCl 5.0	pH-KCl 4.6	pH-KCl 5.0
0	0.5	0.7	22	28	50	50	48	79
4	1.2	0.8	23	25	50	50	57	86
8	1.3	1.4	22	21	50	50	76	108

uble phosphate is a better measure of phosphate availability to fast-growing vegetables than acidsoluble phosphate, has been obtained in a study of the effects of mixing the soil with various quantities of frozen black peat, referred to as "horticultural peat" [3]. Mixing the topsoil with horticultural peat to improve soil structure and growing conditions for horticultural crops resulted in enhanced phosphate availability, even on unfertilized plots (Table 6). The water-soluble phosphate content increased with increasing peat supply; while the P-Al figures remained the same or showed a small decrease as a consequence of dilution of the soil with the low-phosphate peat. Liming affected growing conditions favourably, giving increased yield and also higher phosphate uptake although there was little change in the water solubility of the phosphate. Greater root activity probably caused the higher phosphate uptake and not the fact more phosphate as calcium phosphate was present, as indicated by the P-Al figures, which differed only slightly. Also farmyard manure has an influence on the phosphate availability; the P-number increases more than would be expected from the increase in the P-Al figure following the manure application [10]. This may be the reason for the favourable effect of farmyard manure on fast-growing vegetables under widely varying conditions [4]. However, the P-Al method is thought to be indispensable for practical fertilizer recommendation, in horticulture as an index of the more or less available phosphate supply in the soil. A low P-number/P-Al ratio indicates a high phosphate fixing capacity of the soil and a higher requirement for phosphate fertilizer at a given P-Al figure.

Recently, a new phosphate analysis method for arable crops was developed whereby soil is extracted with water in a wide soil: water ratio (1:60) at 20°C. The suspension is shaken intensively for one hour. The dry soil is premoistened for a period of 22 hours prior to extraction. The results of pot and field experiments, mainly with potatoes, showed

that the relation between the phosphate content of the plants and the Pw-value of the soil was very close and independent of soil type, organic matter, clay and lime content of the soil (Fig.5). This means that the three last mentioned factors

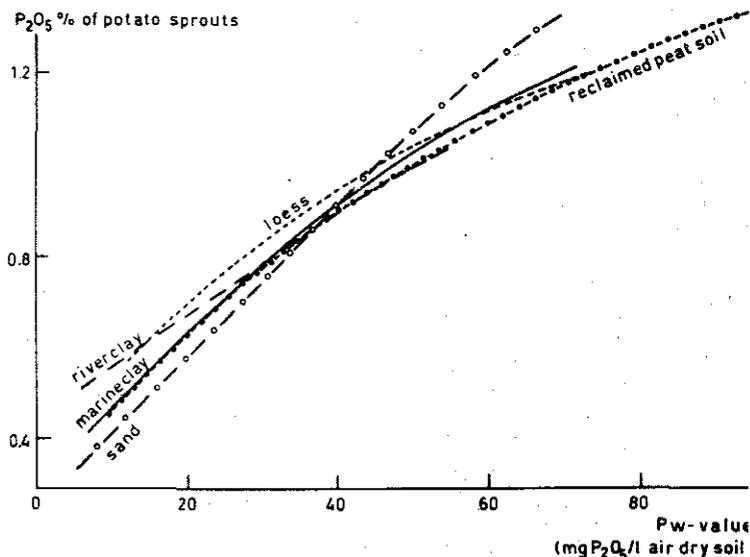


Fig. 5. Relation between phosphate content of potato tops and Pw-value for five different soil types

tors affect the Pw-value and plant uptake in the same way. No deviations were found for phosphate-fixing soils, except those containing much iron. The agricultural interpretation of the Pw-value is therefore independent of soil type, clay and organic matter content and pH of the soil; borderline cases between soil types no longer give any difficulties. Differences in the recommended fertilizer quantity at a given Pw-value remain possible depending on clay content, phosphate fixing capacity etc. Recent experience has shown, however, that these differences for arable crops are relatively small. For vegetable crops on arable land, Prummel [8] stu

ed the relation of the response of spinach and beans to phosphate dressings with the Pw-value of the soil. On marine clay and silt soils, omission of potassium fertilizer gave more severe depression in yields of spinach than did omission of phosphate. At a low soil fertility status, the yield depressions amounted to 60 and 20% for potassium and phosphate, respectively. The economically optimum rates were 10 kg P_2O_5 /ha and for potassium 420 kg K_2O /ha. There was good relation between phosphate response and Pw-value of the soil (Fig.6). The response of beans to phosphate appli-

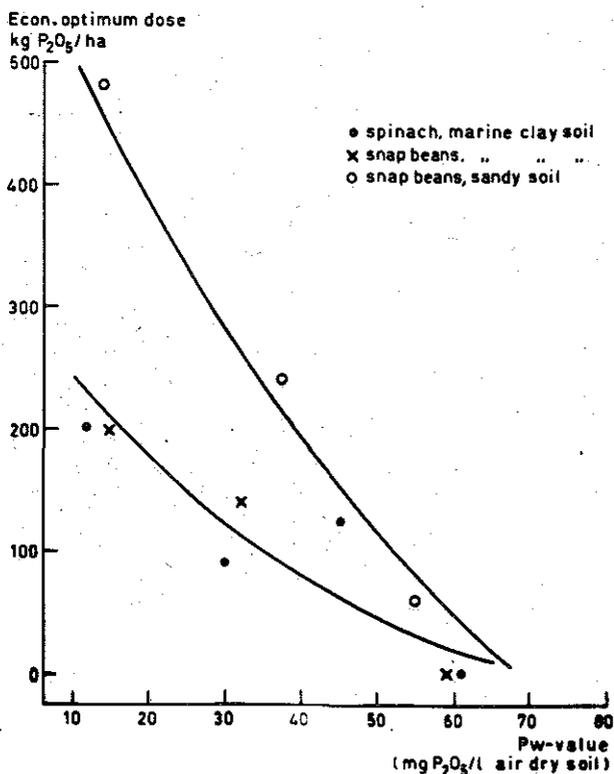


Fig. 6. Relation between economically optimum phosphate dressing and Pw-value of the soil for spinach on marine clay and silt soils and for snap beans on marine clay and silt soils and sandy soils

cation was stronger on sandy soils than on marine clay soils. On sandy soils yield depressions of up to 60% occurred when no phosphate was applied. At a Pw-value of 15 mg P_2O_5 /l dry soil the economically optimum rate was 480 kg P_2O_5 /ha for sandy soils and 200 kg P_2O_5 /ha for marine clay and silt soil. Thus the Pw-value proved to be a good measure of the fertilizer required for vegetable growing on arable land. More information is needed before it can also be used for other plant species and before it can replace the current fertilizer recommendations for vegetable production on horticultural land, which are based on a combination of the P-number and P-Al. In view of the rising competition from vegetables grown on arable land, and declining selling prices special attention should be given to the problem of determining if, and to what extent, fresh applications of fertilizer to high-fertility soils are still profitable.

S u m m a r y

For field crops soil analysis methods have been developed in The Netherlands for various nutrients using one-year and long-term field experiments and pot experiments. The action of other soil factors upon the response of the plant to a certain nutrient element has been estimated as accurately as possible.

In horticulture these methods, developed at the Institute for Soil Fertility, have been tested less systematically on a relatively restricted number of experimental fields. The results of these trials, in combination with practical horticultural experience, gave rise to fertilizer recommendations based on soil analysis values.

Recently fertilizer experiments have been performed to estimate the fertilizer need of vegetables, grown on arable land for the processing industry.

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Развитие аналитики почв в Голландии

Р е з ю м е

В Голландии разработана система химических анализов почвы по отношению к пахотным землям. Эта система основана на результатах полученных в сосудных опытах, а также в одно- и многолетних полевых опытах. Исследовали с возможно большей точностью влияние различных почвенных условий на усваивание питательных элементов растениями. В Институте плодородия почв проверяли пригодность разработанной для сельского хозяйства методики анализов с точки зрения возможности ее применения в овощеводстве. Эта методика проверялась, однако, только в ограниченном числе опытов.

Удобрение в голландском овощеводстве проводится в настоящее время на основании сочетания практических знаний с результатами химического анализа.

Проведенные до сих пор опыты касались определения удобрительных потребностей овощей открытого грунта, возделываемых для переработочной промышленности.