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Determination of the phosphate status of soils in the Naaldwijk area for growing lettuce in glasshouses

Met samenvatting
Beoordeling van de fosfaattoestand van gronden in het Zuidhollands Glasdistrict voor de teelt van kropsla onder glas

Mit einer Zusammenfassung
Auswertung des Phosphorsäuregehaltes der Böden im Naaldwijker Gebiet beim Anbau von Kopfsalat in Gewächshäusern

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Abstract

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During the years 1962–6, trials were carried out in 55 glasshouses in the Naaldwijk area, on sand, loam and peat soils, which were taken partly at random and partly selected for low and high phosphate status. Triple superphosphate was given at rates of 0, 5, 10 and 20 kg per 100 m^2. Phosphate in soil was determined by all methods used in the Netherlands and by some still under investigation. Resulting values, except P-total, were closely correlated. Correlation between soil phosphate and phosphate content of lettuce on untreated plots was reasonably high. For each method of analysis, 'threshold' values were calculated, above which lettuce should not be dressed with phosphate. Optimum rate of application, according to top growth, was poorly correlated with soil phosphate, as determined by any method, but correlation with the age of the glasshouse was closer. Diagrammatic schemes are represented from which the optimum dressing, based on P-water or P-AL, can be estimated.

Contents

1 Introduction

During 1957 and 1958 in the southeast of the Netherlands the effect of triple superphosphate on the growth of glasshouse lettuce was studied (Roorda van Eysinga, 1961). Higher phosphate dressings than generally accepted were found necessary and weak acid extractants for the determination of soil phosphate predicted the crops' response to phosphate fertilizer better than water extracts.

This paper reports similar trials on other soils with intensive watering, with carbon dioxide enrichment and with different lettuce varieties. The number of replicates was increased from three to four. As more heated glasshouses were available, the lettuce was also grown in autumn and winter.

2 Materials and methods

The investigations included 55 trials on sand, loam and peat soils (Table 1). Each trial included 16 plots of about 10 m², each with 140 plants, giving about 100 heads for yield determination. The glasshouses for the first season were chosen at random; in the second season they were selected for soil with low phosphate content and in the last season for a high phosphate content.

In contrast to the mostly acid soils in the previous experiments (Roorda van Eysinga, 1961), the new trials were characterized by a high pH and, mainly, by a considerable calcium carbonate content (except the peat; see Appendices 1–4).

Table 1. Survey of the trials.

Soil type		Number of trials	Year	Location
sand		8	1962/63	's-Gravenzande
		10	1964/65	Monster
		4	1965/66	Naaldwijk
	subtotal	22		
loam		6	1962/63	De Lier
		12	1964/65	De Lier
		4	1965/66	Naaldwijk
	subtotal	22		
peat		10	1962/63	Rotterdam
		1	1965/66	Gouda
	subtotal	11		
total		55		

The soil water level was constant at about 75 to 90 cm; in the previous experiments it had fluctuated widely.

After the soil analyses, to obtain a clear differentiation between sand and loam, all cases with 10–20 % particles $< 16\ \mu$ were classified as a fourth type 'loamy sand'. This resulted in 18 trials on sand, 7 on loamy sand, and 19 on loam.

Each trial used four quantities of triple superphosphate (0, 5, 10 and 20 kg per 100 m^2) with an average of 43 % P_2O_5. In addition only nitrochalk was applied, in amounts depending on the readily soluble nitrogen content of the soil. In a few cases lime was added. The fertilizers were applied from a few weeks to a few days before planting.

The first year, before fertilizing, two series of soil samples were taken from each plot, one from 0–20 cm, the other from 0–30 cm, to study the influence of sampling depth. As no significant differences were found, 0–25 cm was subsequently used. In these samples a few properties were determined for a homogenity test and, as the results were satisfactory, the samples for each field were combined for full analysis.

Phosphate was determined by various methods (Table 2). Tepe's ion exchange method was only applied to the undried samples taken the first winter; in all other cases the soil was previously dried, crushed and sieved. The determination of the Pw-value was recently developped at the Instituut voor Bodemvruchtbaarheid (Institute for Soil Fertility) at Haren-Groningen (van der Paauw, 1969; Sissingh, 1969).

For crop analysis, whole lettuce heads were taken at random from the plots. The heads were cut just above the soil and stripped of rotten, soiled or yellow leaves as customary during a normal harvest. The samples were analysed for dry matter content and the usual chemical analyses were carried out, sometimes with complementary analyses on nitrate, sodium and chloride. The remaining plants were then graded according to the rules required for public auction and counted and weighed per grade for each plot, to estimate the mean head weights.

To compare the methods of soil phosphate determination, correlation coefficients were calculated and regression lines were drawn for the data from trials on sand, loam, and peat, separately. The trials on loamy sand were too small to be considered, but when justifiable, they were included with the mineral soils.

The phosphate dressing giving the highest mean head weight in each trial was called the 'optimum application'. The relation between optimum application and phosphate content in the soil according to various methods, the phosphate content in the crop, and the number of years the glasshouse had been in operation, was studied.

The treatment means were plotted on graph paper, a line was drawn through the dots to estimate the highest yield. 'Relative yield', defined as yield of treatment without phosphate as a percentage of the highest yield, was calculated. In a few cases where the treatment without phosphate gave the highest yield, this yield was expressed as a percentage of the average yield of other treatments. If so, relative

Table 2. Applied soil phosphate analyses.

Laboratory	Indication	Unit	Extractant	Extraction ratio	References
Bedrijfslaboratorium voor Grond- en Gewasonderzoek, Oosterbeek (Soil and Crop Testing Laboratory)	P-value	mg P_2O_5 per 100 g dry soil	water 50°C	1:10	de Vries & Dechering (1948, 1960)
	P-citr	ditto	1 % citric acid, final concentration	1:10	de Vries & Dechering (1948, 1960)
	P-AL	ditto	NH_4-lactate 0.04 N acetic acid buffer pH 3.75	1:20	Egnér et al. (1960)
	P-total	ditto	Fleischmann acid	1:4	de Vries & Dechering (1948)
Proefstation voor de Groenten- en Fruitteelt onder Glas, Naaldwijk (Horticultural Experiment and Research Station)	P-water	ditto	water 18°C	1:5	van den Ende (1952), den Dekker & van Dijk (1963) *
Instituut voor Bodemvruchtbaarheid, Haren-Groningen (Institute for Soil Fertility)	Pw-value	mg P_2O_5 per 100 ml dry soil	water 20°C	1:60 by volume	van der Paauw (1969) Sissingh (1969)
Laboratorium voor Landbouwscheikunde, Wageningen (Laboratory of Agricultural Chemistry)	P-Morgan	p.p.m. P in extract	Na-acetate, 3 %, acetic acid buffer pH 4.8	1:2½	Schuffelen et al. (1961)
Institut für Bodenkunde, Geisenheim (W-Germany) (Institute of Soil Science)	P-Tepe	Austaucher Einheiten (AE), mg/24 h	water, ion-exchange resin	water saturated	Knickmann et al. (1960), Tepe (1956)

* Report available at Proefstation voor de Groenten- en Fruitteelt onder Glas, Naaldwijk.

yield exceeded 100.

In calculating the relations between the relative yields and the phosphate content in soil or crop there was no motive to attach different weights to the data as done in the 1957/1958 investigations.

3 Relation between soil phosphate figures obtained by various methods

The coefficients of the correlation between the various phosphate determinations are given in Table 3. A rectilinear relation was assumed, which was, with the

Table 3. Coefficients of correlation for the various methods of soil phosphate determination.

	P-water	P-value	Pw-value	P-Morgan	P-AL	P-citr
Sand (n = 18, all coefficients highly significant)						
P-value	0.98					
Pw-value	0.99	0.97				
P-Morgan	0.84	0.77	0.88			
P-AL	0.93	0.93	0.92	0.86		
P-citr	0.94	0.93	0.93	0.86	0.99	
P-total	0.90	0.90	0.88	0.80	0.98	0.99
Loam (n = 19, all coefficients highly significant)						
P-value	0.96					
Pw-value	0.97	0.98				
P-Morgan	0.97	0.96	0.98			
P-AL	0.93	0.90	0.92	0.97		
P-citr	0.93	0.91	0.93	0.96	0.99	
P-total	0.83	0.82	0.85	0.88	0.93	0.95
Minarel soil (n = 44, all coefficients highly significant)						
P-value	0.96					
Pw-value	0.97	0.94				
P-Morgan	0.87	0.79	0.91			
P-AL	0.89	0.87	0.90	0.89		
P-citr	0.90	0.88	0.92	0.89	0.99	
P-total	0.67	0.64	0.73	0.67	0.81	0.85
Peat (n = 11)						
P-value	0.84**					
Pw-value	0.93**	0.95**				
P-Morgan	0.82**	0.83**	0.86**			
P-AL	0.71*	0.86**	0.87**	0.91**		
P-citr	0.51	0.76**	0.73**	0.75**	0.93**	
P-total	0.29	0.48	0.43	0.40	0.54	0.78**

exception of peat, justified by graphical reproduction. Within each soil type the correlations are as a whole high, except those for P-total on peat soils. Those in which P-Morgan is one of the variables are lower than the others. The figures for P-total are lowest on loam.

The correlation coefficients on peat are slightly to considerably lower, especially where water is used as an extractant. This may be explained by the curvilinear character of the relation between the phosphate figures (see e.g. Fig. 1).

In general, high correlations exclude important differences between the various methods in predicting the response of the crop to phosphate supply for a certain soil type. However, it may occur that for all mineral soils together, or even for all soils, one of the methods shows off markedly better, as here correlations between the soil analysis figures will be higher. Especially in the later case such a method has to be considered more suitable as a general base for the fertilizing advice.

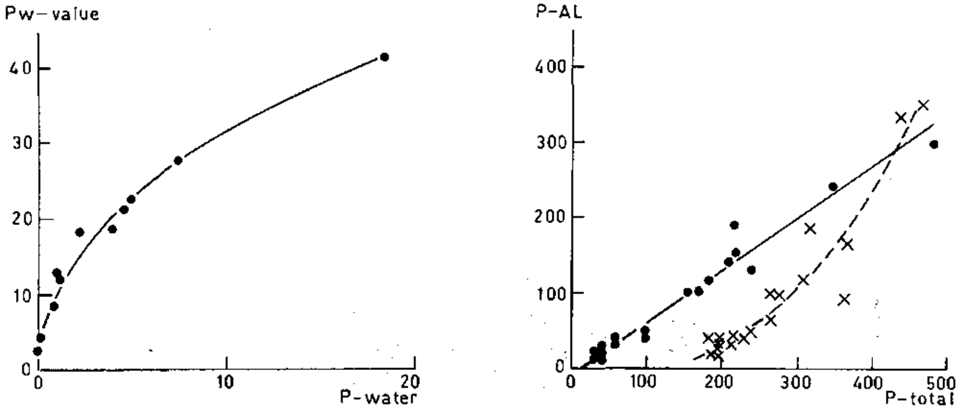

Fig. 1. Relation between P-water and Pw-value on peat (left) and (right) between P-total and P-AL on sand (full line) and on loam (dotted line).

If all mineral soils, including the loamy sands, are taken together, the results with water as an extractant are highly correlated. This is also the case using other extractants, with the exception of the figures considering P-total (see also Fig. 1).

For all soils together (peat soils included) the correlation coefficients are too low for a prediction of one phosphate figure from another. Thus peat soils have to be considered as a soil type by itself.

The phosphate figures according to Tepe are not available for all trials and they are not included in the tables. A comparison with P-water for all soil types together results in $r = 0.59^{**}$ ($n = 24$), for peat only $r = 0.85^{**}$ ($n = 10$).

In previous investigations with pleistocene sands in the southeast of the Netherlands such a high correlation as mentioned above has not been found. There were also considerable differences in water soluble phosphate figures between the two experimental years (Roorda van Eysinga, 1961).

In choosing an extractant for phosphate analysis not only is its capacity to predict the response of the crop important, but also such factors as the speed of the analysing procedure and the accuracy of the analysis. So, it is necessary to limit the number of extractants in determining the various components and an extractant suitable for only one element must be rejected, unless it has great advantages above others.

4 Relation between phosphate and other soil-analysis figures

The soil analyses yielded many data from which the correlations between the various chemical components were calculated. Those involving the iron contents are recorded here, as it is sometimes supposed that they are connected with phosphate fixation.

Worth mentioning is the high linear relation between the percentage of particles $< 16\ \mu$ and the Fe_2O_3-content determined in an HCL-extract. For mineral soils

r is found to be 0.98**, for peat 0.65*. A relation between percentage clay (particles $< 2\ \mu$) and Fe_2O_3-content has been found by Knibbe & van den Akker (1966).

The figures for iron, and also aluminium, in Morgan's extract show negative, logarithmic correlations with the figures for phosphate content. The correlation coefficient for all soils together is highest (r = — 0.85**) for P-Morgan. Analogous figures have been found by Dawson (1956) for organic soils.

The correlations found in the present investigation in regard to the Fe figures are so high, that it is out of question to use these figures for improving the interpretation of the phosphate figures.

5 The relation between the phosphate content of the crop and soil phosphate as determined by various methods

In general the relation between the phosphate content of the crop and that of the soil determined with various methods is obvious. This indicates that soil testing provides a satisfactory determination of the available soil phosphate. Figure 2 gives an example for the P-water data. In Table 4 the correlation coefficients and the regression equations are given.

The correlation between phosphate in the crop and P-total is rather low, especially on peat. Though the mean P_2O_5-contents of the crop on sand and loam are similar, the P-total values differ greatly: the lowest value on loam is 190, the average on sand 152. So, the P-total cannot be a good measure for the available phosphate, as found previously.

The relation between phosphate in soil and crop has also been studied for all soil types together (see Table 4). But great caution is necessary in the interpretation

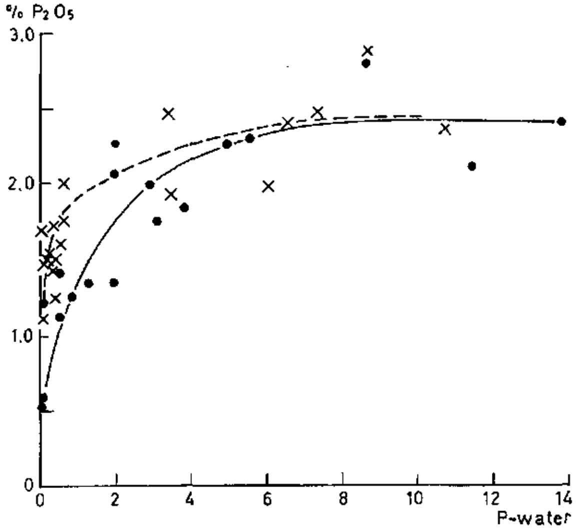

Fig. 2. Relation between P-water and phosphate content (% on dry matter) of the crop on 0-treatments on sand (full line) and on loam (dotted line).

Table 4. Correlation coefficients and regression equations for the relation between phosphate content of the crop (y = % P_2O_5 on dry matter) and that in the soil of untreated plots (x).

Sand (n = 18, all correlation coefficients highly significant)		
P-water	0.89	$y = 1.00 \log x + 1.5$
P-value	0.87	$y = 1.36 \log x + 0.7$
Pw-value	0.88	$y = 1.19 \log x + 0.7$
P-Morgan	0.90	$y = 0.99 \log x + 0.5$
P-AL	0.90	$y = 2.00 \log x - 0.4$
P-citr	0.89	$y = 1.18 \log x - 0.5$
P-total	0.84	$y = 1.39 \log x - 1.1$
Loam (n = 19, all correlation coefficients highly significant)		
P-water	0.86	$y = 0.60 \log x + 1.8$
P-value	0.92	$y = 1.08 \log x + 1.2$
Pw-value	0.86	$y = 1.05 \log x + 1.0$
P-Morgan	0.87	$y = 0.68 \log x + 1.1$
P-AL	0.88	$y = 1.10 \log x - 0.2$
P-citr	0.85	$y = 1.21 \log x - 0.5$
P-total	0.84	$y = 3.28 \log x - 6.1$
Mineral soils (n = 44, all correlation coefficients highly significant)		
P-water	0.81	$y = 0.71 \log x + 1.7$
P-value	0.84	$y = 1.12 \log x + 1.0$
Pw-value	0.87	$y = 1.16 \log x + 0.8$
P-Morgan	0.84	$y = 0.80 \log x + 0.8$
P-AL	0.88	$y = 1.16 \log x - 0.3$
P-citr	0.87	$y = 1.20 \log x - 0.5$
P-total	0.70	—
Peat (n = 11)		
P-water	0.94**	$y = 0.66 \log x + 1.8$
P-value	0.89**	$y = 1.14 \log x + 1.0$
Pw-value	0.95**	$y = 1.11 \log x + 0.8$
P-Morgan	0.87**	$y = 0.92 \log x + 1.0$
P-AL	0.91**	$y = 1.55 \log x - 1.5$
P-citr	0.85**	$y = 2.02 \log x - 3.1$
P-total	0.48	$y = 2.64 \log x - 5.7$
All soil types (n = 55)		
P-water	0.83**	$y = 0.70 \log x + 1.7$
P-value	0.85**	$y = 1.12 \log x + 1.0$
Pw-value	0.88**	$y = 1.13 \log x + 0.8$
P-Morgan	0.83**	$y = 0.80 \log x + 0.9$
P-AL	0.85**	$y = 1.08 \log x - 0.2$
P-citr	0.78**	$y = 0.94 \log x - 0.1$
P-total	0.57	—

of the outcome, in view of the large differences in the average values of the seperate soil types. On mineral soils, for example, the average P-AL is 103, on peat 205.

On Tepe's method only a few data are available for comparison with other methods. Here on peat the correlation coefficient between phosphate in the crop and that in the soil is 0.91** (n = 10).

6 The influence of phosphate dressing on the chemical composition of the crop

To investigate the influence of the phosphate dressing on the mineral composition of the crop, the percentages are arranged according to the relative yield classes

Table 5. Average chemical composition of the crop as influenced by triple superphosphate dressing and soil type.

	Soil	Number of observations	kg triple superphosphate per 100 m^2			
			0	5	10	20
% dry matter of fresh weight	sand	17	4.9	4.2	4.0	4.1
	loam	14	4.2	4.3	4.3	4.2
	peat	10	4.9	4.9	4.9	4.8
% N-total in dry matter	sand	18	4.84	4.98	4.96	5.00
	loam	15	5.28	5.31	5.30	5.26
	peat	11	5.19	5.24	5.19	5.24
% NO_3-N in dry matter	sand	13	1.06	1.16	1.15	1.20
	loam	10	1.47	1.48	1.45	1.41
	peat	—	—	—	—	—
% P_2O_5 in dry matter	sand	18	1.68	1.94	2.07	2.20
	loam	15	1.88	2.03	2.06	2.15
	peat	11	1.99	2.08	2.09	2.14
% K_2O in dry matter	sand	18	8.96	8.91	8.61	8.91
	loam	15	9.75	9.63	9.44	9.48
	peat	11	9.06	8.79	9.07	8.67
% CaO in dry matter	sand	18	1.81	2.02	2.07	2.02
	loam	15	2.04	2.11	2.08	2.11
	peat	11	2.16	2.17	2.25	2.19
% MgO in dry matter	sand	18	0.70	0.72	0.75	0.76
	loam	15	0.78	0.83	0.81	0.82
	peat	11	0.81	0.78	0.77	0.76
% NaO in dry matter	sand	8	0.88	0.87	0.87	0.88
	loam	8	0.88	0.86	0.87	0.90
	peat	11	1.25	1.27	1.24	1.24
% Cl in dry matter	sand	5	2.85	2.96	2.94	2.87
	loam	5	1.97	1.96	1.95	2.13
	peat	10	1.90	2.04	1.96	2.03

< 90, 90–95, 95–100 and > 100. Table 5 gives the influences of the phosphate dressing on the average chemical composition of the crop.

On loam and peat the average percentage of dry matter is not influenced by the phosphate dressing. The unfertilized plots on sand give a different result, especially in the trials DM and DR where plots without phosphate dressing failed (Fig. 3). The percentages of dry matter of these trials are given in Table 6.

On loam and peat the percentage of total nitrogen in the plants is not influenced by the phosphate dressing, whereas it is on sand, mainly due to the increase of nitrate in trials DM and DR (see Table 6).

The phosphate content in the crop is increased by the phosphate dressing, with a maximum P_2O_5 of about 2.2 % in dry matter.

An increase in phosphate dressing causes a small decrease in the average potassium content, but a distinct decrease in the trials with relative yields below 90 on sand and loam. Such interactions have also been observed with other nutrients but are most obvious with potassium, as illustrated by Table 7. Strongly reacting trials

Table 6. Percentages of dry matter and nitrate nitrogen as dependent on phosphate application in two trial on sand (extreme cases).

	Trial	kg triple superphosphate per 100 m²			
		0	5	10	20
% dry matter in fresh weight	DM	7.8	4.9	4.3	4.2
	DR	10.2	5.5	4.1	4.9
% NO_3-N in dry matter	DM	0.20	0.28	0.40	0.58
	DR	0.35	0.80	0.85	1.14

Table 7. Potassium content (% K_2O in dry matter) of the crop as influenced by phosphate dressings on sand and loam according to relative yield classes.

	Relative yield class	Number of observations	kg triple superphosphate per 100 m² 0	5	10	20
Sand	> 100	3	9.63	10.05	9.51	10.07
	95–100	6	9.66	9.47	8.96	9.57
	90– 95	2	11.49	11.36	11.20	11.37
	< 90	7	7.42	7.23	7.17	7.15
	mean	18	8.96	8.91	8.61	8.91
Loam	> 100	2	10.28	10.50	10.69	10.91
	95–100	6	10.52	10.57	10.12	10.40
	90– 95	5	8.78	8.51	8.48	8.41
	< 90	2	9.34	8.70	8.58	7.98
	mean	15	9.75	9.63	9.44	9.48

Fig. 3. Most extreme reacting trial DR; first crop, three months after planting on excavated sand.

with low soil fertility on an average show a lower potassium content than trials with a weak response of the crop. In the latter classes all soil fertility factors will be higher, and therefore, also the potassium content in the soil.

The increase in calcium content is caused by the calcium from the triple superphosphate.

Generally on sand and loam the phosphate dressings cause a small increase in the magnesium content of the crop. The rather high average magnesium percentage in the unfertilized plots of peat is attributed to a few extreme values.

The phosphate dressings do not influence sodium and chloride contents in the crop.

These results confirm those obtained in previous experiments (Roorda van Eysinga, 1961).

7 Total and nitrate nitrogen content in the crop

The 1957/1958 investigations showed a correlation between total nitrogen and phosphate in the crop. The present data confirms this: for mineral soils $r = 0.71^{**}$ ($n = 44$). From the analysis on NO_3-N of the lettuce heads from 29 trials on mineral soil and one on peat a high correlation of the nitrogen content with the P_2O_5 content of the crop is found (Fig. 4; $r = 0.80^{**}$). As the correlation between phosphate and organic nitrogen (calculated as the difference between total and nitrate nitrogen) is only 0.13, the variation in total nitrogen is mainly caused by the variation in nitrate content ($r = 0.87^{**}$).

Nitrogen fertilization experiments (Roorda van Eysinga, 1966) have shown that lettuce grown in winter has a high nitrate content due to poor light conditions. The high correlation between nitrate in the crop and harvest date in the present

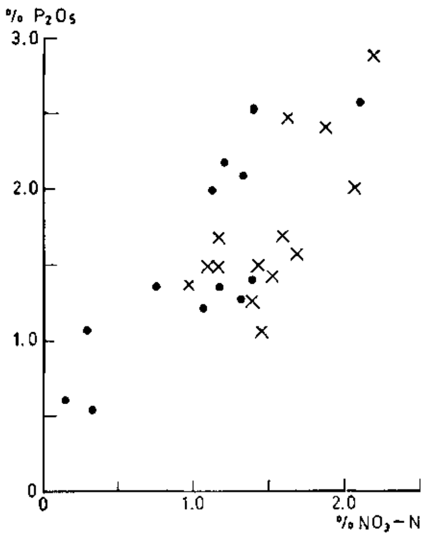

Fig. 4. Relation between nitrate and phosphate content (% on dry matter) of the crop of 0-treatments on sand and on loam.
• = sand × = loam

experiments confirms this.

It has been assumed that, if the lettuce is older when harvested, a decrease in nitrogen and phosphate is caused; but contrary to previous cases (Roorda van Eysinga, 1961) no adjustment has been made in the present investigation, as the cause of the correlation between total nitrogen or nitrate on the one side, and the phosphate content on the other side is not understood.

8 Relative yields and the threshold values for the phosphate in the soil or in the crop

Relative yield is logarithmically related to various parameters of phosphate status of soil and to phosphate content of crop. The regression equations were calculated first for each soil type, later for all mineral soils and for all soils together (Table 8). Especially for all soils together, it is difficult to harmonize the results.

From the remaining equations the threshold values, above which phosphate fertilizers should not be applied, have been calculated by putting relative yield at 100 (values over 100 indicate a decrease in yield due to phosphate dressing). These threshold values have been calculated for all soil types and the use of different threshold values for peat soils and mineral soils seems justified from the results, even to distinguish various mineral soils.

According to the experience obtained during the development of the Pw-value (van der Paauw, 1969; Sissingh, 1969) this characteristic varies in the soil less than other determinations of water extracts of mineral soils. This is confirmed by the correlation coefficients in Table 8: with sand and loam separately the correlations for Pw are slightly higher than those with other determinations, whereas for all mineral soils together they are distinctly higher. In the crop the same trend was found, though less clear (compare Table 4). This suggest that on mineral soils the Pw-value will be a more suitable index for recommendations on fertilizing. As different threshold values are found on sand and loam, Pw seems to depend to some extent on soil type (see also Figs 5, 6 and 7).

For the peat soils the outcome has been compared with the data obtained with Tepe's method. A correlation coefficient of 0.48 ($n = 10$) is found. The number of data for the other soil types separately is too small, but all mineral soils together yield $r = 0.44$ ($n = 14$). In both cases the threshold value turns to be 3.7, which is considerably higher than the optimal range mentioned by Tepe (0.4–2.0).

Crop analysis predicts most satisfactorily, the response of the lettuce crop to phosphate supply with all soil types, including peat, since similar threshold values are found.

Crops can only be analysed at the end of the growing season, to supply information on what should have been done before planting. To what degree the crop analysis figures predict a value for the next crop on the same fields is the question. No data are available to check this; those obtained with Tepe's method are interesting but are insufficient for an adequate comparison.

A comparison of the threshold values with those obtained in previous investiga-

Table 8. Correlation coefficients and regression equations for the relation between relative yield and phosphate content of the soil and of the crop; threshold values for phosphate contents with reliability intervals at $P = 0.05$.

	Correlation coefficients	Regression equations	Threshold values	Intervals
Sand (n = 18; all correlation coefficients highly significant)				
P-water	0.79	$y = 36.80 \log x + 73.2$	5	3 - 14
P-value	0.70	$y = 46.04 \log x + 48.2$	13	8 - 44
Pw-value	0.87	$y = 49.28 \log x + 43.0$	14	10 - 24
P-Morgan	0.89	$y = 40.98 \log x + 32.4$	45	31 - 76
P-AL	0.69	$y = 43.61 \log x + 6.1$	143	88 - 339
P-citr	0.78	$y = 43.15 \log x + 4.7$	162	99 - 390
P-total	0.70	$y = 48.48 \log x - 15.2$	237	145 - 746
P_2O_5 crop	0.92	$y = 124.09 \log x + 59.3$	2.13	1.81 - 2.74
Loam (n = 19; all correlation coefficients highly significant)				
P-water	0.70	$y = 8.17 \log x + 93.3$	7	3 - 71
P-value	0.72	$y = 13.94 \log x + 84.9$	12	7 - 44
Pw-value	0.76	$y = 15.33 \log x + 80.4$	19	12 - 49
P-Morgan	0.75	$y = 9.81 \log x + 82.4$	63	30 - 291
P-AL	0.69	$y = 14.32 \log x + 67.1$	200	114 - 864
P-citr	0.72	$y = 16.99 \log x + 60.0$	225	144 - 644
P-total	0.62	$y = 40.16 \log x - 4.0$	389	314 - 836
P_2O_5 crop	0.79	$y = 55.71 \log x + 79.3$	2.36	2.09 - 2.97
Mineral soils (n = 44; all correlation coefficients highly significant)				
P-water	0.55	$y = 15.99 \log x + 86.6$	7	3 - 34
P-value	0.53	$y = 23.63 \log x + 72.9$	14	8 - 45
Pw-value	0.74	$y = 33.06 \log x + 61.2$	15	11 - 22
P-Morgan	0.61	$y = 17.59 \log x + 68.3$	64	33 - 204
P-AL	0.69	$y = 30.38 \log x + 33.8$	151	81 - 255
P-citr	0.73	$y = 33.39 \log x + 25.5$	171	128 - 261
P-total	0.69	$y = 39.77 \log x + 0.4$	319	246 - 478
P_2O_5 crop	0.86	$y = 102.94 \log x + 65.6$	2.16	2.16 - 2.35
Peat (n = 11)				
P-water	0.43	$y = 2.48 \log x + 97.1$	15	not calculated because of the insignificant correlation coefficients
P-value	0.38	$y = 3.97 \log x + 94.1$	30	
Pw-value	0.54*	$y = 5.24 \log x + 91.9$	33	
P-Morgan	0.41	$y = 3.53 \log x + 93.7$	57	
P-AL	0.46	$y = 6.52 \log x + 83.1$	394	
P-citr	0.37	$y = 7.28 \log x + 79.2$	716	
P-total	0.12	$y = 5.35 \log x + 82.2$	2169	
P_2O_5 crop	0.50	$y = 16.55 \log x + 93.0$	2.64	
All soil types (n = 55; all correlation coefficients highly significant)				
P-water	0.51	$y = 13.35 \log x + 88.5$	7	3 - 36
P-value	0.52	$y = 21.32 \log x + 75.3$	14	9 - 38
Pw-value	0.71	$y = 28.33 \log x + 65.5$	17	12 - 25
P-Morgan	0.61	$y = 18.66 \log x + 68.9$	46	28 - 103
P-AL	0.68	$y = 26.85 \log x + 39.7$	176	139 - 232
P-citr	0.68	$y = 25.91 \log x + 38.2$	243	175 - 387
P-total	0.62	$y = 26.29 \log x + 28.8$	512	362 - 900
P_2O_5 crop	0.83	$y = 93.64 \log x + 68.5$	2.17	2.03 - 2.36

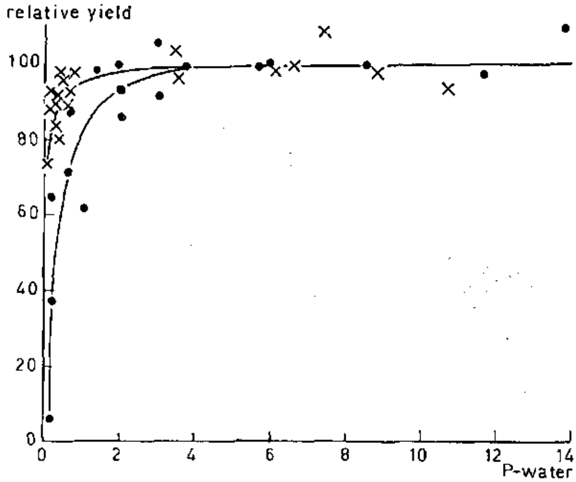

Fig. 5. Relation between P-water and relative yield on sand and on loam.
• = sand × = loam

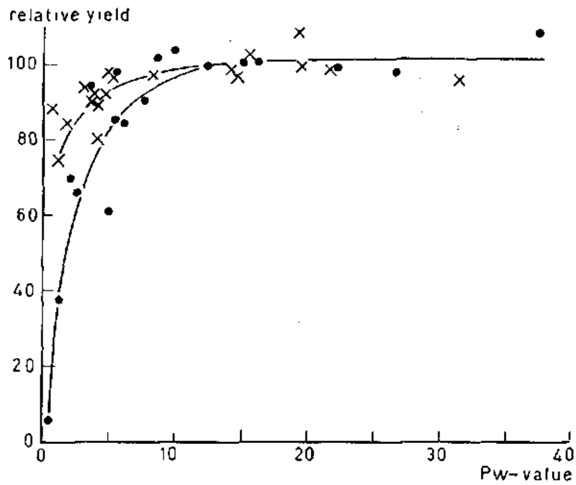

Fig. 6. Relation between Pw-value and relative yield on sand and on loam.
• = sand × = loam

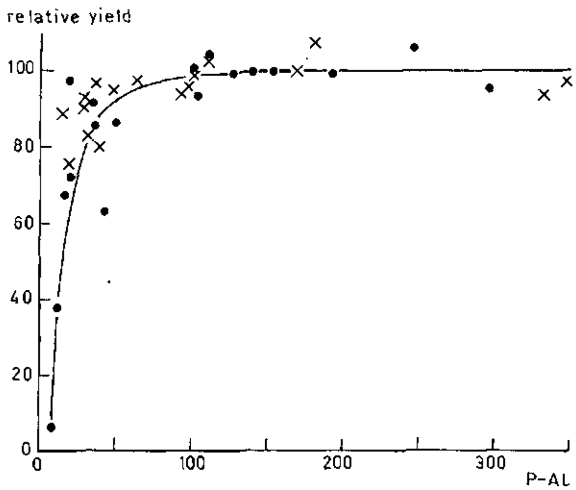

Fig. 7. Relation between P-AL and relative yield on sand and on loam.
• = sand × = loam

tions (1957–1958) shows a very good agreement for P-AL and P-citr. For the mineral soils in the Naaldwijk area they are 151 (81–255) and 171 (128–261), respectively; for pleistocene sand they amount to 151 (134–181) and 187 (165–226) (Roorda van Eysinga, 1961). This indicates that for P-AL and P-citr the same threshold value can be used for a greater variety of soil types than the P-water and Pw-value.

As far as available, the threshold values of other analysis methods show great differences.

9 Optimum phosphate application

By plotting the optimum phosphate applications (the dressing giving the highest yield in each trial) against the phosphate contents of the soil or of the crop the scheme of fertilizing for commercial lettuce growing might be improved. But the result was rather disappointing, due to the great variation in the data (Fig. 8). This follows also from the rather low correlation coefficients (Table 9 left). The calculated regression line giving the optimum application at a given phosphate content of the soil runs horizontal (broken line in Fig. 8 right); the 'true' line should run much steeper. In some trials the optimum application was over 20 kg triple superphosphate per 100 m², while in one case, even without phosphate application, too much was offered to the plant (both situations are indicated by dots with an arrow).

The age of the glasshouse may be considered a measure for soil fertility as phosphates hardly leach. Figure 9, in which the optimum application is plotted

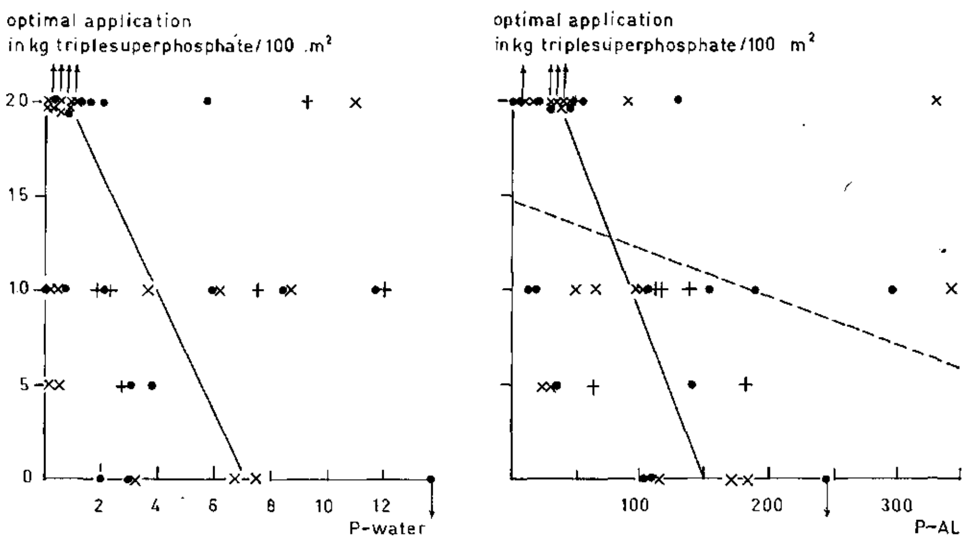

Fig. 8. Optimum application of triple superphosphate on mineral soils based on P-water (left) and on P-AL (right). • = sand × = loam + = loamy sand

Table 9. Correlation coefficients for the relation between phosphate in the soil or in the crop and optimum phosphate applications.

	Sand	Loam	Mineral soils	Peat
P-water	—0.43	—0.36	—0.36*	—0.42
P-value	—0.37	—0.48*	—0.33*	—0.55
Pw-value	—0.44	—0.40	—0.40**	—0.54
P-Morgan	—0.64**	—0.35	—0.46**	—0.42
P-AL	—0.48*	—0.24	—0.28	—0.49
P-citr	—0.47*	—0.28	—0.31*	—0.41
P-total	—0.42	—0.28	—0.23	—0.21
P_2O_5-crop	—0.57*	—0.52*	—0.51**	—0.60*

against the age of the glasshouse shows the relation between these two factors to be curvilinear (see also Table 10 right). It may be expected that the relation between phosphate content of the soil and optimum application is also curvilinear too, but unfortunately this cannot be established mathematically (see Fig. 8).

The regression equation corresponding with the broken line in Fig. 9 is $y = 1.84/x + 7.93$, in which y is the optimum application in kg triple superphosphate per 100 m² and x = the age of the glasshouse in years (for newly erected glasshouses the age has been considered to be 0.1 year). According to this regression equation even for old glasshouses the mean optimum application amounts to 8 kg triple superphosphate per 100 m². The explanation for this also gives a better insight into the problem. Previously the application of phosphate generally decreased the yield at a high phosphate status of the soil. In the present investigation

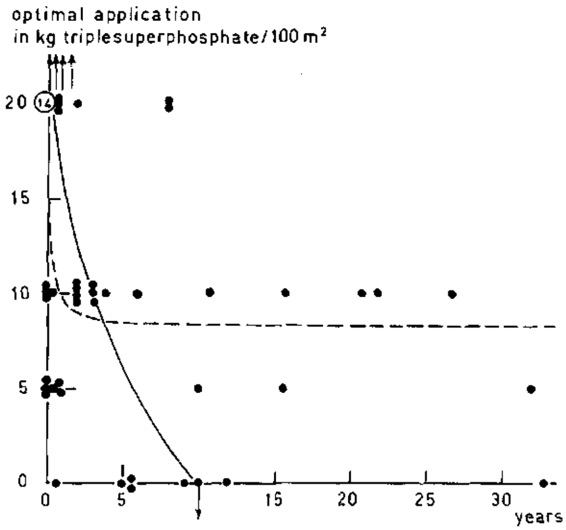

Fig. 9. Optimum application of triple superphosphate based on the age of the glasshouse (all soil types).

Table 10. Correlation coefficients for the relation between the age of the glasshouse and optimum phosphate application.

Adjustment	Sand	Loam	Mineral soils	Peat	All soil types
Rectilinear	—0.44	—0.53*	—0.45**	—0.47	—0.45**
Curvilinear	—0.43	—0.75**	—0.53**	—0.60*	—0.54**

a significant decrease in yield is found in only one trial. If at high phosphate content of the soil the crop is accepted as not reacting on a phosphate dressing, then, out of a series of trials in which the quantities 0, 5, 10 and 20 kg triple superphosphate are compared, due to variability 8.75 kg will be found as the mean optimum application.

This conclusion must also hold true in considering the relation between the phosphate content of the soil and the optimum application. The full lines drawn in Figs 8 and 9 are the best estimates for the evaluation of the optimum phosphate application.

In drawing these lines (the 'true' lines) it has been assumed, that the points of intersection with the abscissa correspond with the threshold value found in the previous section. Further, the slope of the line is mainly determined by the dots of an optimum application of 20 kg triple superphosphate and more at a low phosphate content of the soil. In Figure 9 the point of intersection with the abscissa (threshold value 10 years) has not been calculated but has been estimated by 'translating' the threshold values of phosphate content into the age of the glasshouse.

Treating the phosphate figures of peat according to Tepe, a correlation coefficient $r = 0.42$ is found. As too small a number of figures for other soil types is available, it is not possible to compare them with figures from other methods. But as, for the figures of mineral soils a low correlation coefficient is also found ($r = -0.24$), and Tepe's method does not give a better prediction of the optimum application than other soil analysis methods.

Summary

During the years 1962–1966 phosphate fertilization of lettuce in commercial glasshouses was investigated in the Naaldwijk area. Involved were 55 trials, partly taken at random, partly selected for low and high phosphate contents of the soil, on sand, loam and peat. Each trial included in quadruplicate the application of 0, 5, 10 and 20 kg triple superphosphate per 100 m².

In determining phosphate contents, all methods applied until now in the Netherlands, and a few still under investigation were included. The results were compared and their relation with crop growth (measured as 'relative yield') and phosphate content in the crop were studied.

The soil phosphate figures, with the exception of P-total, appeared to be highly correlated. For unfertilized plots the correlation with the phosphate content of the crop was reasonably high.

The threshold values (the limits above which a phosphate dressing should be omitted) were calculated for all phosphate analysis methods.

The correlations between the optimum phosphate application and the phosphate content of the soil, determined following various methods, were low. On the other hand, the correlation with the age of the glasshouses was strikingly higher.

A scheme to determine the optimum dressing with triple superphosphate based on P-water or P-AL was presented in diagrams.

Samenvatting

Beoordeling van de fosfaattoestand van gronden in het Zuidhollands Glasdistrict voor de teelt van kropsla onder glas

Gedurende de jaren 1962–1966 werden op 55 proefvelden in kasbedrijven proeven met fosfaatbemesting bij kropsla genomen. De kassen werden gedeeltelijk willekeurig, gedeeltelijk om de hoge of lage fosfaattoestand van de grond, uitgekozen, op zand, klei en veen. Elk proefveld omvatte in viervoud de fosfaattrappen 0, 5, 10 en 20 kg dubbelsuperfosfaat (43 % P_2O_5) per are.

De gronden werden op fosfaat onderzocht volgens de verschillende in Nederland gangbare of in beproeving zijnde methoden. De resultaten werden onderling vergeleken, en het verband met de reactie in de opbrengst en het fosfaatgehalte van het gewas werd bestudeerd.

Met uitzondering van P-totaal waren alle fosfaatbepalingen van de grond onderling sterk gecorreleerd, en er bleek een goed verband aanwezig te zijn met het fosfaatgehalte van het gewas van onbemeste veldjes.

Voor de verschillende fosfaatbepalingen werden grenswaarden vastgesteld, waarboven de bemesting met fosfaat geen zin meer heeft.

Het verband tussen de optimale fosfaatgift en de analyseresultaten volgens de verschillende bepalingsmethoden was matig; dat met de ouderdom van de kas was beter.

Een adviesbasis voor bemesting met dubbelsuperfosfaat op grond van P-AL of P-water werd in grafieken weergegeven.

Zusammenfassung

Auswertung des Phosphorsäuregehaltes der Böden im Naaldwijker Gebiet beim Anbau von Kopfsalat in Gewächshaüsern

In den Jahren 1962–1966 wurden im Naaldwijk Anbaugebiet 55 Parzellenversuche mit Phosphor zu Kopfsalat in Betriebsgewächshäusern durchgeführt. Die

Häuser wurden teilweise zufällig gewählt, teilweise auf Grund eines niedrigen bzw. hohen Phosphorsäuregehaltes des Boden, wobei Sand-, Ton- und Moorböden annährend gleich vertreten waren. Jeder Versuch umfasste in vierfacher Wiederholung die Mengen 0, 5, 10 und 20 kg Doppelsuperphosphat (43 % P_2O_5) pro Ar.

Die Bodenmuster wurden auf Phosphorsäure analysiert nach den in den Niederlanden bis jetzt angewendeten Methoden und nach einigen experimentellen Verfahrungsweisen.

Die Resultate wurden verglichen, und der Zusammenhang mit den Erträgen wurde studiert. Es ergab sich, dass Phosphorsäuregehaltzahlen, ausgenommen P-total (gesamt-P) unter einander stark korreliert waren und es zeigte sich ein guter Zusammenhang mit dem Phosphorsäuregehalt der Salatköpfe. Die Grenzzahlen wurden ermittelt für die verschiedenen Bestimmungsmethoden.

Die Korrelation zwischen Optimaldüngung und Analysezahlen der verschiedenen Methoden war niedrig; der Zusammenhang mit dem Alter der Gewächshäuser war besser.

Einige Graphike ermöglichen die Bestimmung der Optimaldüngung mit Doppelsuperphosphat auf Grund von P-water (P-wasser) und P-AL.

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Appendices

Appendix I. Results of soil analysis of the trials on loam.

Trial	pH-H_2O	$CaCO_3$ (%)	organic matter (%)	particles < 16 μ (%)	P-water	P-value	Pw-value	P-AL	P-citr	P-total	P-Morgan	P-TEPE	Fe (ppm in Morgan's extract)	Al (ppm in Morgan's extract)	Fe_2O_3-HCl (%)
KC	7.0	1.2	8.6	46	3.5	11.0	16.0	117	145	310	40	2.0	1.1	0.3	3.35
KF	7.3	5.1	4.3	36	6.2	8.3	14.4	103	120	270	43	1.0	0.6	0.0	2.97
KG	6.9	3.9	5.9	43	0.7	2.5	4.9	93	132	370	7	0.2	1.3	0.0	3.18
KI	7.1	1.6	6.7	48	3.5	10.0	14.7	100	146	280	43	1.3	1.4	1.1	3.49
KL	7.1	1.2	8.1	29	6.7	12.0	19.4	171	192	370	60	3.3	0.9	0.4	2.73
DA	7.2	2.2	8.7	38	0.7	4.0	5.0	41	64	230	8	—	3.0	1.3	2.91
DB	6.5	0.7	8.4	46	0.1	2.0	1.3	16	25	200	1	—	14.5	6.7	3.34
DC	7.3	2.2	7.8	38	0.1	1.0	1.6	19	26	190	1	—	7.3	2.1	3.07
DD	7.4	1.4	6.4	37	0.6	2.0	4.6	29	42	200	10	—	2.2	1.3	3.02
DF	7.1	2.5	6.7	55	0.5	1.7	5.3	49	83	240	7	—	4.4	1.9	4.48
DG	7.1	2.4	6.5	48	0.4	2.4	8.1	64	100	270	20	—	2.3	1.2	3.95
DN	7.1	0.9	5.5	40	0.1	1.6	3.4	31	42	220	7	—	4.7	2.4	3.35
DO	7.1	1.3	4.4	41	0.4	2.0	4.2	45	66	220	5	—	6.6	2.4	3.63
DP	7.0	1.2	5.7	45	0.3	1.6	2.4	33	54	200	3	—	14.0	3.8	3.67
DS	7.4	2.5	4.5	51	0.4	1.6	4.2	42	52	190	4	—	4.8	1.4	3.98
DT	7.1	3.9	2.4	39	0.4	2.6	4.1	39	50	200	7	—	2.4	1.3	2.96
GA	7.3	2.2	5.4	30	8.7	14.5	21.9	348	355	470	96	—	0.8	0.4	2.73
GC	7.4	0.6	5.4	25	7.5	15.0	19.3	186	220	320	59	—	1.6	1.1	1.07
GK	7.1	2.9	4.1	22	10.9	18.2	31.9	332	339	440	108	—	0.5	0.2	1.02

Appendix II. Results of soil analysis of the trials on sandy loam.

Trial	pH-H_2O	$CaCO_3$ (%)	organic matter (%)	particles < 16 μ (%)	P-water	P-value	Pw-value	P-AL	P-citr	P-total	P-Morgan	P-TEPE	Fe (ppm in Morgan's extract)	Al (ppm in Morgan's extract)	Fe_2O_3-HCl (%)
KE	7.4	2.9	6.1	20	7.4	13.0	16.3	135	148	260	70	2.0	0.8	0.0	1.67
ZA	7.5	1.4	1.7	16	1.9	3.8	8.4	110	126	200	35	2.7	0.6	0.3	1.50
ZD	7.7	0.8	1.1	16	3.0	6.3	9.8	65	88	140	27	0.9	0.9	0.9	1.52
ZH	7.5	2.6	1.3	14	2.3	4.5	9.3	105	126	190	30	2.0	1.2	0.6	1.25
DE	7.7	3.9	2.4	18	1.0	3.2	4.1	47	50	130	4	—	4.6	1.3	1.57
GE	7.3	0.3	5.4	16	12.0	22.2	23.9	182	212	260	51	—	1.0	1.4	1.27
GC	6.5	0.4	8.6	10	9.2	23.7	20.9	300	306	340	55	—	1.1	0.4	0.77

Appendix III. Results of soil analysis of the trials on sand.

Trial	pH-H_2O	$CaCO_3$ (%)	organic matter (%)	particles < 16 μ (%)	P-water	P-value	Pw-value	P-AL	P-citr	P-total	P-Morgan	P-TEPE	Fe (ppm in Morgan's extract)	Al (ppm in Morgan's extract)	Fe_2O_3-HCl (%)
ZB	7.7	1.8	1.8	2	3.1	6.0	10.2	116	123	180	52	2.7	1.1	0.4	0.43
ZC	7.5	0.2	1.9	3	2.1	6.3	8.3	104	124	160	38	2.9	1.1	0.7	0.41
ZE	7.1	0.9	2.5	4	3.8	7.0	12.3	144	169	210	64	3.7	1.1	0.2	0.50
ZG	7.5	2.9	1.1	4	6.0	12.0	15.4	156	170	220	67	2.4	1.5	0.6	0.55
ZI	6.0	0.4	4.9	3	5.6	13.0	16.4	130	177	240	42	4.0	4.2	2.4	0.53
DH	6.4	0.1	0.8	2	0.2	2.1	2.7	15	20	30	6	—	10.8	3.8	0.22
DK	7.6	2.6	1.9	8	2.1	4.7	3.6	104	106	170	25	—	1.8	0.8	0.77
DL	7.5	0.2	0.7	3	1.4	4.3	5.4	24	27	40	15	—	5.4	2.2	0.22
DM	5.8	0.0	1.0	2	0.3	2.1	1.6	12	13	30	2	—	12.5	4.9	0.19
DR	8.0	6.4	0.5	4	0.2	0.9	0.5	9	9	40	0	—	14.5	2.5	0.45
DV	7.4	2.2	3.7	3	2.0	3.3	6.0	35	40	60	16	—	3.9	1.4	0.33
DW	7.2	1.4	3.5	4	3.0	5.1	6.6	34	32	60	20	—	1.7	1.3	0.20
DX	5.5	0.2	1.3	8	1.0	3.9	5.0	42	50	100	5	—	13.0	10.0	0.79
DZ	7.3	0.9	1.5	8	0.7	3.1	5.5	49	50	100	14	—	2.9	2.2	0.82
DAA	7.5	0.2	0.5	1	0.6	4.8	2.3	18	22	40	3	—	10.0	2.9	0.24
GD	6.8	0.3	5.3	3	8.6	22.1	22.4	193	194	220	52	—	1.6	1.2	0.39
GE	6.6	0.5	3.9	6	13.8	29.4	38.0	247	299	350	99	—	0.6	0.7	0.49
GF	6.5	0.3	11.5	6	11.6	29.1	27.0	298	342	480	50	—	1.8	1.2	0.99

Appendix IV. Results of soil analysis of the trials on peat.

Trial	pH-H_2O	$CaCO_3$ (%)	organic matter (%)	particles < 16 μ (%)	P-water	P-value	Pw-value	P-AL	P-citr	P-total	P-Morgan	P-TEPE	Fe	Al	Fe_2O_3-HCl (%)
													ppm in Morgan's extract		
VA	5.7	0.2	23.5	16	4.0	16.0	18.9	219	407	780	15	1.5	6.4	3.0	1.95
VB	5.8	0.1	36.1	24	4.6	13.0	21.3	248	438	830	23	2.4	3.8	2.6	2.22
VC	5.8	0.2	43.9	19	1.1	6.0	12.7	165	286	690	10	1.0	6.5	4.9	2.30
VD	6.1	0.2	33.8	28	2.4	12.0	18.6	232	561	1290	14	2.0	6.2	3.6	3.86
VE	6.2	0.4	45.3	33	0.0	1.5	1.9	42	126	650	2	0.2	6.7	1.9	4.69
VF	6.7	0.6	30.8	31	0.9	3.8	8.4	185	370	790	11	1.5	6.6	4.5	3.28
VG	6.8	0.7	26.2	19	5.0	15.0	22.5	360	599	960	53	4.0	2.0	0.8	2.18
VH	5.5	0.3	28.5	35	1.2	5.5	12.3	148	286	650	7	0.5	15.0	7.2	3.02
VI	5.7	0.2	42.0	21	7.5	18.0	27.7	248	425	860	33	3.0	1.6	2.0	2.45
VK	6.4	0.7	42.3	32	0.2	3.5	3.3	77	218	810	4	0.2	11.0	2.9	4.63
GH	7.1	0.2	21.5	28	18.5	22.0	41.8	334	487	930	53	—	2.0	2.2	1.29