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AN EFFECTIVE WATER EXTRACTION METHOD FOR THE DETERMINATION OF PLANT-AVAILABLE SOIL PHOSPHORUS

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SUMMARY

A new variant of the water-extraction method for the assessment of soil phosphorus availability to the plant was recently developed by Van der Paauw and Sissingh. The correlation between the water-extractable soil phosphate (Pw value) and the response of the plant, measured in most cases by the P_2O_5 content of dry matter, was high on Dutch soil types and was not affected by differences in such soil factors as organic matter content, particle size content, $CaCO_3$ content, pH, phosphate-fixation capacity and other factors related to the origin of the soil. In other words, the relationship was the same for all soil types investigated.[7]

In order to investigate whether an equally good result would be obtained with soil types from widely diverging origin and properties, the method was evaluated in a pot experiment with potato (tops) and spring wheat grown successively on different soil types of European, American and Australian origin.

A high correlation between Pw value and the P_2O_5 content of spring wheat was found, which explained 88% of the variance. All soil types of different origin could be represented by one regression line.

The dry-matter yield of wheat was also closely correlated with Pw value, although the yield was also influenced by the pH of the soil.

With potatoes a high correlation between water-extractable P and P_2O_5 content of the tops was found in the series of European soils, but on part of the American and Australian soils the P_2O_5 contents of plants were higher than those on European soils with corresponding Pw values. This difference could not be explained.

In general it may be stated that the Pw value provides a reliable estimate of the availability of soil phosphorus to the plant in a wide variety of soil types.

INTRODUCTION

The laboratory methods which have been developed to provide a satisfactory estimation of available soil phosphorus are particularly characterized – in so far as these methods are performed by means of an extraction – by the kind of extractant used. It may be assumed that simplified ideas concerning the mechanism of dissolution of soil phosphates and their absorption by the plant have guided the choice of these solvents.

Less attention has been paid to the question whether optimum use is made of the selected extractant. It seems that the procedure followed (with respect to factors such as ratio soil/solvent, duration of extraction, temperature) has often been dictated by arguments which emphasize the ease of analytical procedure. Hence it follows that the selected extraction conditions are not necessarily the most efficient.

Generally, any estimation of the effectiviness of a solvent and its comparison with others as measured by the relationship with crop response is limited to the use of a single procedure for each solvent. In some cases it might have been logical to test the same extractant under a range of conditions.

However, such a laborious task can only be justified when there are clear indications that the extractant as such is a promising one and that variations in the extraction technique might give rise to results that require modifications in interpretation of the results obtained. Such a justification appears to be present in the case of the solvent water.

Its effectiveness as an extractant of soil phosphorus was demonstrated in various field and pot experiments with arable soils. This effectiveness was partly obscured by the circumstance that critical values found in earlier experiments with a water-extraction method in use in the Netherlands varied among different soil types. Furthermore, the results obtained on some soil types were poor and only slightly differentiated. It appeared, however, that crop response on diluvial sandy and alluvial loamy soils, which was different according to the water-extraction method mentioned, was similar when the rather closely related method of Kawe [4] was used *.

It is clear that the results of an extraction of soil with water depend upon the conditions under which the extraction is performed. Varying the conditions of the extraction systematically and studying the correlation, taking the response of the crop as the criterion, a variant of the water-extraction method could be selected which is

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* Thanks are due to the late dr. A. Kawe who kindly investigated a series of representative Dutch soils of which the crop response to phosphorus was known.

probably better suited to the purpose than any other water-extraction method (Van der Paauw, Sissingh and Ris [7])

Laboratory investigations in combinations with pot experiments likewise have pointed to water as the most promising solvent of plant-available soil phosphorus (Sissingh [8 9]). Values of isotopically exchangeable soil phosphate, determined under laboratory conditions in soil–water systems (E-value) and in pot experiments (L-value), appear to be of the same order of magnitude (Sissingh [8], Baert [1]). It may therefore be concluded that in laboratory experiments water mobilizes the same components of soil phosphate as are in a mobile state (adsorbed or in solution) in soil in contact with soil solution.

DEVELOPMENT OF THE METHOD

The investigation was based on the response obtained of young potato plants to the phosphorus status of 88 Dutch soils in a pot experiment performed earlier (1960). Large samples of the soils tested were stored for subsequent use. The conditions under which the water extraction was executed were varied systematically.

The variant of the extraction method which showed the best relationship with crop response in the standard pot experiment was then tested independently in a number of field trials and additional pot experiments which were all performed in the past and of which soil samples were still available.

Motivation of the method

It was found, that using a wide ratio between water and soil the interpretation of the P-values was the same for the soil types mentioned before. A further improvement was attained by premoistening the soil. Dried soils are artifacts. Better results following premoistening may be due to restoration of the original properties of the soils. The improvement is of special importance for soils relatively high in organic matter. Volume basis instead of the more usual weight basis was chosen for practical reasons related to routine analysis. Furthermore, it was indicated that results obtained in this way correlate slightly better with crop response than those obtained on a weight basis at approximately the same ratio of soil and water.

A more extensive description of the features of the method will be given elsewhere (Sissingh and Van der Paauw [11]).

Description of the method

The final form of the method is as follows. Demineralized water is used at a water–soil ratio of 60:1, both water and soil on volume basis. The extraction is preceded by moistening the soil sample, during 22 hours. The premoistened soil is stored, extracted and filtered at a constant temperature of 20°C. The duration of the extraction under intensive shaking is 1 hour. The concentration of phosphate in the extract is determined following the colorimetric method of Murphy and Riley [5]: a molybdenum-blue method with ascorbic acid as the reducing agent and antimony added to give a stable Mo-P-Sb blue-coloured compound. The results are expressed in arbitrary units (Pw-value = mg P_2O_5 per liter of dry soil, passed through a 2-mm sieve). A more detailed description is given elsewhere in this issue by Sissingh [10].

Evaluation of the method

The conclusions from the evaluation of the Pw value for Dutch soil types (Van der Paauw, Sissingh and Ris [7], Van der Paauw [6]) were as follows:

1. The evaluation is not affected by differences in some important soil factors, such as organic matter content, particle size distribution, calcium carbonate content, and phosphate-fixing capacity. It may sometimes be affected, but only slightly, by differences in pH. Pw values were found to be too low in soils with high Fe_2O_3 contents.
2. The high correlations found indicate that other factors (not determined in these experiments) cannot have affected the relationship Pw value/crop response materially.
3. Changes of Pw value effected by dressings of different kinds of fertilizer (*e.g.* phosphate rock or water-soluble phosphate), liming and mixing the soil with peat correspond strictly to the response of the plant to these treatments.
4. As a consequence, *the correlation between Pw value and crop response is high and essentially non-specific for all soil types.*
5. Critical Pw values may vary for different crops.

Conclusion

On account of the effectiveness of the water-extraction method it may be assumed that the amount of soil phosphorus dissolved in water under the conditions mentioned gives an expression of, or is closely related to the supply of phosphorus to the roots. If this assumption is true, the method involved ought also to be effective for a much wider variety of soils than is available in the restricted area of the Netherlands.

To test this hypothesis, a pot experiment was conducted with soils collected from different parts of the world.

POT EXPERIMENTS WITH SOILS FROM EUROPE, NORTH-AMERICA AND AUSTRALIA

Materials and methods

A series of 74 soils was collected, including 23 soils from the U.S.A., 5 soils from Australia, 11 soils from Great Britain and 15 soils from a series of field experiments conducted by an European working group for soil fertility studies, which included 7 soils from West Germany, 3 soils from Yugoslavia and 1 soil each from France, Belgium, Switzerland, Austria and The Netherlands. For comparison with earlier results 20 other Dutch soils were added.

Origin and chemical characteristics of these soils are given in the Appendix.

Pots of the Mitscherlich type (diameter 20 cm) were filled with the soils and brought to near-optimum moisture level. In most cases one pot for each soil was used, but 28 soils were present in duplicate, *viz* 20 Dutch, 7 American and 1 Austrian.

Potato (var. Bintje) and spring wheat (var. Peko) were grown in succession. Young sprouts of potato (9 per pot) were planted on May 20 and harvested as green shoots on June 13.

Wheat was sown on August 21. The above-ground portions of the plants, about 60 cm high and in heading stage, were harvested on October 3.

For both crops, dry-matter yield and P_2O_5-content of the dry matter were determined.

Amounts of 0.6 g N, 0.8 g K_2O and 0.3 g MgO per pot in the form of NH_4NO_3, K_2SO_4 and $MgSO_4.7\,H_2O$ were applied to the potatoes; after the harvest of this crop the soils were leached with water to remove the remaining nitrates, dried (slightly) and replaced into the pots. Amounts of 0.5 g N and 0.67 g K_2O in the form of a mixture of NH_4NO_3 and KNO_3 were applied to the wheat. Phosphate was not included in any treatment.

Pw values and other soil indices were determined in soil samples taken before the pots were filled. The determination of the Pw value was repeated at the end of the experiment.

The yield of dry matter per pot and P_2O_5 content of dry matter were used as measure of the response of the crop. Quantities of P_2O_5 absorbed were computed, but these will not be reported here because they gave no additional information.

Anticipating the results it may be mentioned that the highest correlations were found when the P_2O_5 content of the crop was used as a plant index. Apparently the relation between P contents of soil and plant is a direct one and influenced only slightly by other factors. On the other hand, the growth of the plant is also affected by other soil factors. Attempts have been made to identify some of these factors so that corrections for their effects can be made.

Experiment with wheat

The Pw value and the P_2O_5 content of the plant are highly correlated (Fig. 1). The correlation was slightly lower when the Pw value determined at the start of the experiment was used instead of the Pw value determined after harvest of the wheat.

It is evident that the relationship is the same for all soils of different origin. Similarly no influence of any other soil factor (including Fe_2O_3 content) on this relationship could be found. It is interesting to note that soils with a high content of $CaCO_3$ see Appendix Soils 1, 2, 37, 57, and 58) behaved in the same manner as did other soils.

Making use of the 28 duplicate determinations it could be estimated that 88 per cent of the variance of the P_2O_5 content of the plants was accounted for by the Pw value. Two additional percentage points could be ascribed to the errors of the estimations of the P_2O_5 content and of the Pw value, which shows that only 10 per cent of the variance is left unexplained. This result is still better than that obtained earlier in the experiment with Dutch soils (1960), which formed the basis for development of the Pw method. In that experiment 82 per cent of the variance was explained.

The superiority of the water-extraction method relative to the P-AL method (Egnér, Riehm, and Domingo [3] is clearly demonstrated by a comparison of Fig. 1 with Fig. 2. The P-AL method (Egnér, Riehm, and Domingo [3]), until recently in use in the Netherlands for arable soils, is rather closely related to the DL method of Egnér and Riehm, in use in many European countries.

The correlation of Pw value with dry-matter yield is somewhat lower (Fig. 3). Certainly this is due to the effect of other factors also affecting growth. It could be shown that the effect of pH on crop yield is represented by a curve having its optimum at pH = 6.0. Compared with other experiments on pH-crop yield relationships this result seems rather plausible, though pH stands for a complex of possible yield-controlling factors, which may not be the same for all soils.

It also appeared that yield depended slightly on the content of particles $< 16\ \mu$. A flat optimum was found at a content of 35 per cent. While the latter was neglected the yield data were corrected for the effect of pH. The correlation of Pw value with these corrected yield data is high (Fig. 4). Apparently the extent of plant growth was also determined by the Pw value. No marked influences of the origin

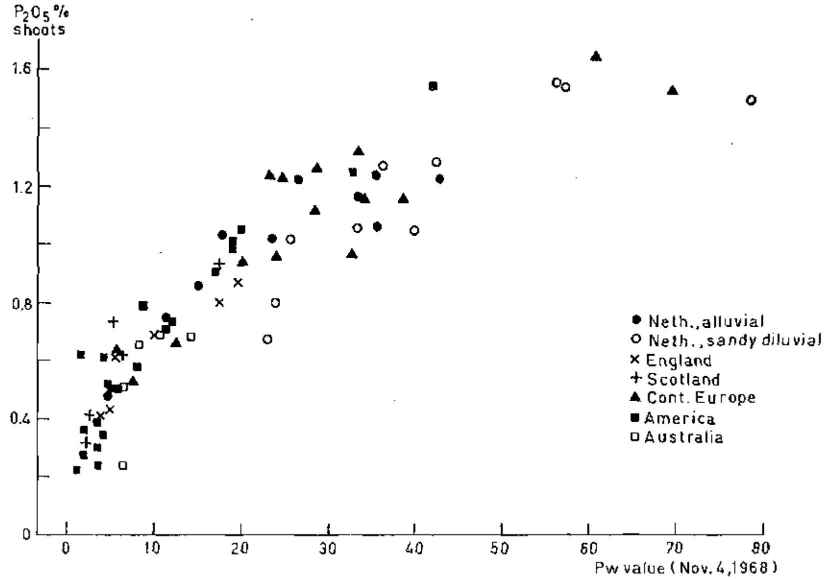

Fig. 1. Relation between Pw value and P_2O_5 content of green wheat (dry matter) grown on soils of different origin.

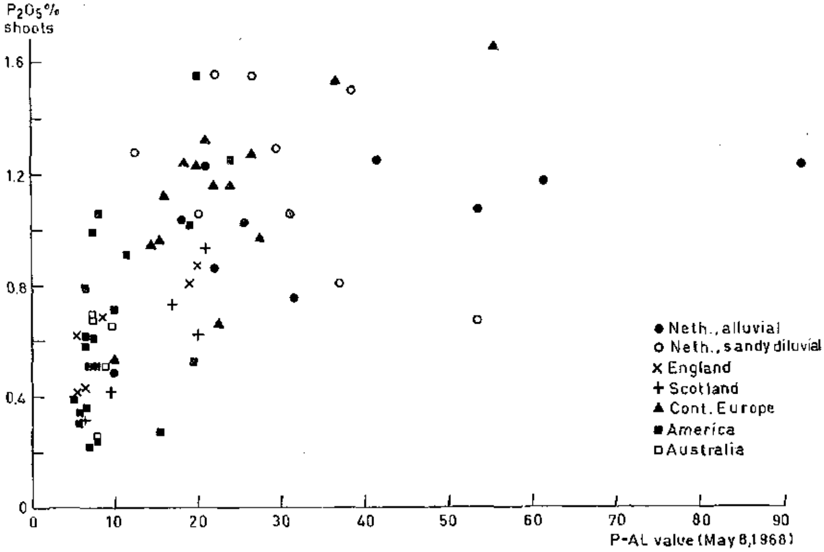

Fig. 2. Same as Fig. 1 for P-AL number.

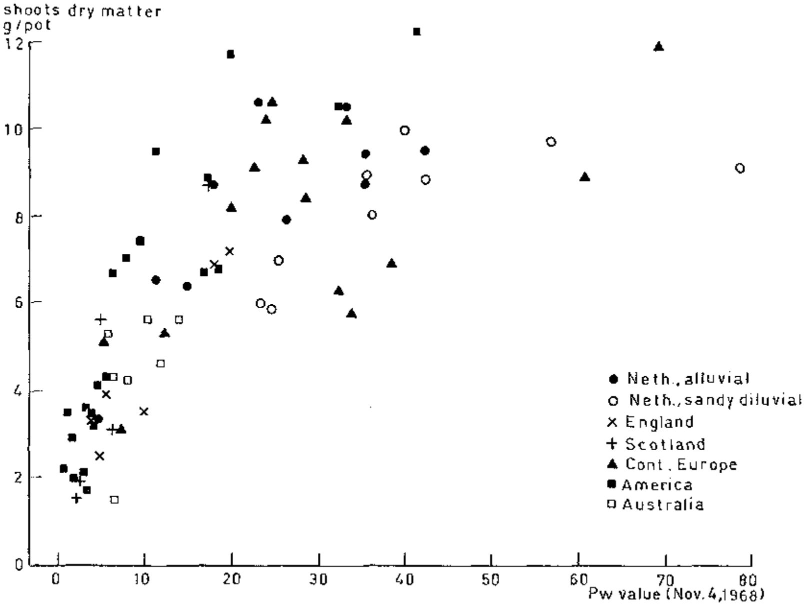

Fig. 3. Relation between Pw value and yield of dry matter of wheat plants.

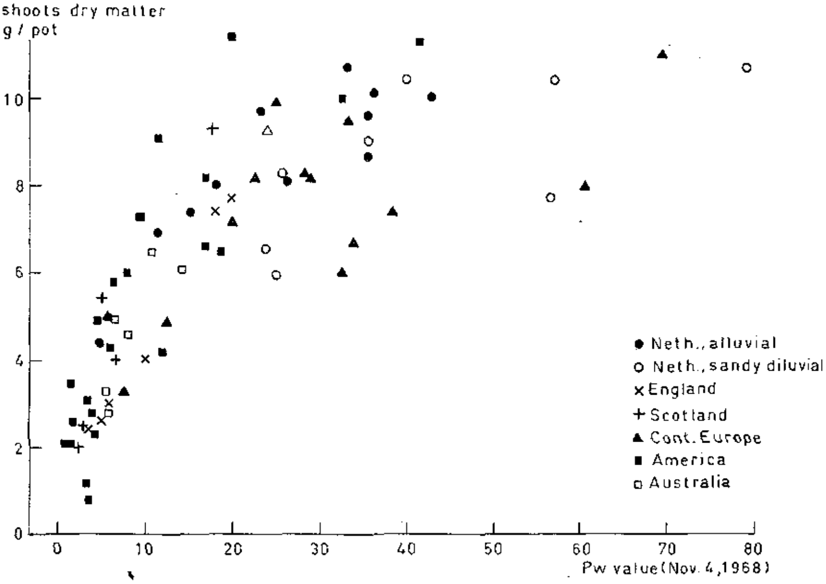

Fig. 4. Same as Fig. 3 after elimination of the effect of pH on the yield.

of the soils are evident. No difference was found in the relationship between plant growth and Pw value when Dutch soils were compared with soils from abroad.

Experiment with potato

With this crop, a certain difference in behaviour of European and some of the American and Australian soils was found. With European soils the correlation between Pw value and P_2O_5 content of the shoots is high (Fig. 5). The curve is clearly S-shaped. Obviously, potato is more sensitive to P-deficiency than is wheat. No deviations due to the different origin of these soils have been found and no influence of other factors on P_2O_5 content other than Pw value could be detected.

On the average P_2O_5 contents of potato shoots grown on American and Australian soils are higher (Fig. 6). Within this group the correlation is also satisfactory.

The deviations were found for the soils from Iowa and New York, for one soil from Washington (66), and for the Australian Soils 72, 73 and 75 (Appendix). The Iowa soils are characterized by high contents of exchangeable Mg, one New York soil (70) and the deviating Washington soil by a high content of exchangeable K. A rather high content of Mg was also found for Australian Soil 73 and a high content of K for Soil 72, but both contents are low in the case of Soil 75. It is, however, uncertain whether a causal relation exists between these factors and the higher P_2O_5 contents observed. For the European soils no such relation was evident.

The data on Soil no. 50 (Iowa) could not be used because the potato plants succumbed to an unknown disease at the end of the experiment. Early growth on this soil was as expected on the basis of the Pw value.

Pw value and dry-matter yield are rather weakly correlated (Fig. 7). Differences between American and European soils are less pronounced than in the case of the P_2O_5 content. Australian soils do not deviate from the average. The large scatter found may be due to other factors which also affect growth. When the vertical deviations from the yield curve (not shown in Fig. 7) were plotted against pH a clear negative correlation between this factor and yield could be demonstrated. This result agrees with knowledge of the pH–yield relationship of this crop. The effect is considerable, adjusted yields at pH 4.5 on the average being 1.8 g higher (about 35 percent) than at pH 7.3. Thus, a considerable part of the scatter could be explained by this factor.

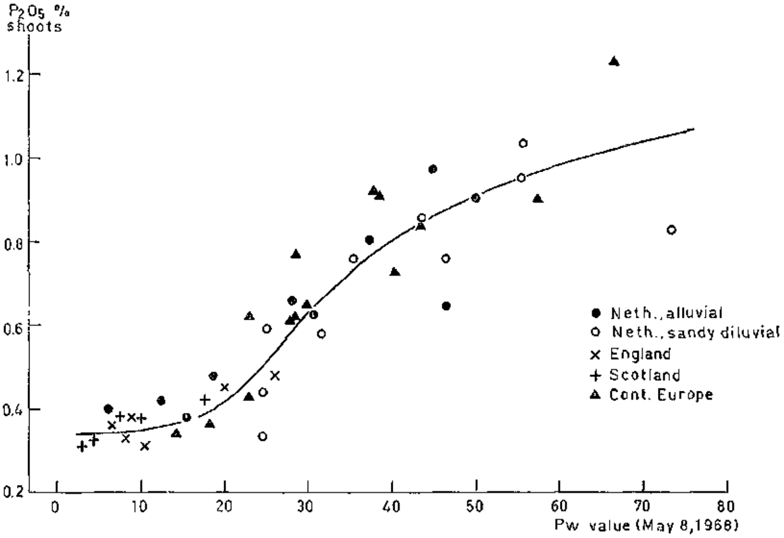

Fig. 5. Relation between Pw value and P_2O_5 content of dry matter of potato shoots grown on European soils only.

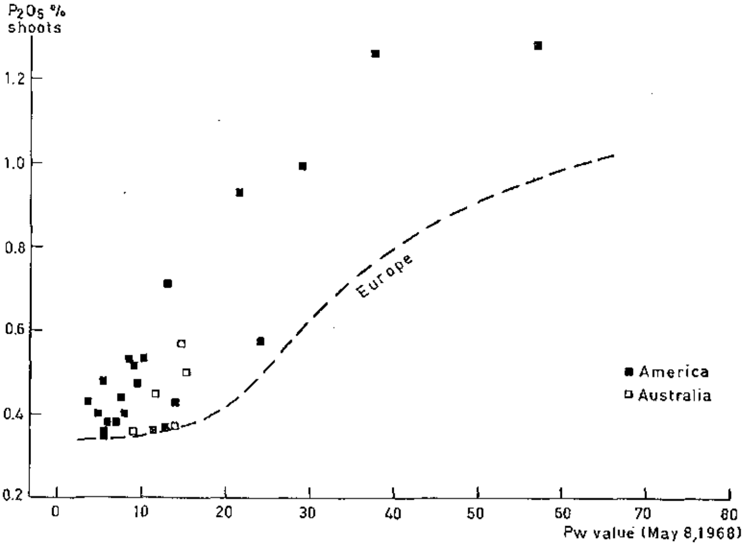

Fig. 6. Same as Fig. 5 for soils of American and Australian origin. Comparison with the average relation found with European soils.

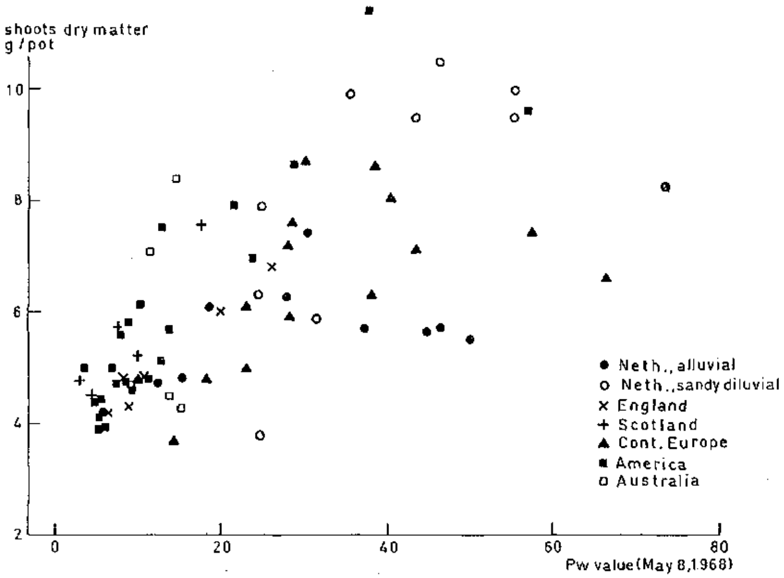

Fig. 7. Relation between Pw value and dry-matter yield of potato shoots grown on all soils.

DISCUSSION

The method of extraction of plant-available phosphorus described in this paper seems to meet to a considerable extent the requirement of 'the most satisfactory laboratory method', as posed by Black*. Its high effectiveness demonstrated for Dutch soils by Van der Paauw, Sissingh, and Ris[7] was confirmed by the experiment with soils of different origin and composition. This makes it very probable that a determining factor in the process of phosphorus supply is expressed by this index. This method shows promise for its suitability with a wide variety of soils.

Some restrictions must be attached to this statement. It was already mentioned before that deviations were found on Dutch soils with a content of Fe_2O_3 exceeding 10 per cent. Differences in pH

* 'The most satisfactory laboratory method for providing an index of soil phosphorus would evidently be one for which the relationship between yield of phosphorus in the plant and the soil phosphorus measured by the method is the same for all soils under similar conditions, as when plants are grown on quantities of the different soils in a greenhouse. Indications are however, that no such method has been developed or in fact is likely to be developed' (Black[2]).

among soils affected the results slightly in a few cases only. It may also be doubtful wether this statement is valid for other climatological conditions.

It is rather surprising that the excellent result obtained with wheat in the present experiment was not completely confirmed with potatoes. No satisfactory explanation could be given for the higher absorption of phosphorus from some of the American and Australian soils compared with the soils of European origin.

It is not quite certain that the method will be equally useful with all kinds of crops. It can only be said that so far no important deviations have been found with single crops, including some grass species. However, the method proved to be rather poorly applicable to grassland. Results obtained with the P–AL method (Egnér, Riehm and Domingo [3]) were decidedly better [6 7]. An attempt will be made to find the reason for the conflicting results.

The fact that equal significance is given to the same Pw value, irrespective of the kind and the properties of the soil, needs not to imply that equal amounts of fertilizer have to be applied to obtain a similar yield response in all cases. However, recent field trials (Ris, yet unpublished) showed that under Dutch conditions practically identical fertilizer recommendations should be made for all soils at equal P_w values.

The method was adopted by the Agricultural Extension Service in The Netherlands on August 1, 1968 for sandy and peaty soils, and on September 1, 1970 for all arable soils (permanent grassland excluded).

From the high correlations found it may be concluded that the process of phosphorus supply to the plant must be closely related to the dissolution process of soil phosphate in an excess of water. From a theoretical point of view the fact that no equilibrium is obtained in the one hour extraction period implies that a rate process is involved. A longer duration of the extraction (18 hours) resulted in higher values which clearly proved to be less well correlated with the response of the crop (Sissingh and Van der Paauw [11]).

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(*For Appendix see pages* 480 *and* 481)

APPENDIX

Properties of soils used in the pot experiment. (For decimal points commas have been used)

No.	Country	Origin or soil type	Textural class-name	Granular composition							Phosphorus			K_2O-HCl	MgO-NaCl
				Weight kg/pot (dry)	> 100 μ	16–100 μ	< 16 μ	Org. matter %	$CaCO_3$ %	pH-KCl	Pw ***	†	P–AL	exch. (parts per 10^3)	exch. (parts per 10^5) ††
1	Netherlands	N.E.-polder-Zuiderzee	loam-silt loam*	6,8	1	55	32	2,5	9,9	7,7	6	5	10	16	14
2	Netherlands	Wieringermeer-Zuiderzee	sandy loam**	7,1	34	32	21	2,2	12,3	7,7	16	15	22	15	6
3	Netherlands	Warffum-Groningen	silt loam	7,5	6	75	17	2,0	0,2	7,2	31	26	21	11	30
5	Netherlands†††	Hedel-Gelderland	loam	7,0	24	43	26	2,4	5,0	7,5	47	43	93	24	16
6	Netherlands	Horssen-Gelderland	sandy loam	7,0	53	8	32	2,9	0,1	6,6	19	18	18	13	13
7	Netherlands	Ferwerd-Friesland	silt loam	6,7	4	57	34	2,5	2,4	7,3	50	36	54	35	21
8	Netherlands	Ferwerd-Friesland	silt loam	6,6	4	66	25	2,4	2,8	7,4	13	11	32	16	15
9	Netherlands	Ferwerd-Friesland	silt loam	7,0	5	76	16	2,3	0,8	7,2	45	33	62	31	26
10	Netherlands	Engwierum-Friesland	silt loam	6,55	3	77	17	2,2	0,4	7,1	38	35	42	15	19
11	Netherlands	Anjum-Friesland	silt loam	6,85	2	63	32	2,7	0,1	6,4	28	23	26	23	39
12	Netherlands	Zeyen-Drenthe	loamy sand-sandy loam	6,4	37	48	6	8,9	0,0	4,0	47	36	13	14	12
13	Netherlands	Nuil-Drenthe	sandy loam	5,7	29	58	5	8,1	0,0	4,3	25	26	22	4	12
14	Netherlands	Assen-Drenthe	loamy sand	6,55	65	24	5	5,8	0,0	4,7	25	24	54	8	6
15	Netherlands	Gasselte-Drenthe	loamy sand	6,8	46	44	5	5,0	0,0	4,9	25	25	37	10	7
16	Netherlands	Gasselte-Drenthe	sand	6,6	87	4	3	5,7	0,0	4,7	44	40	20	6	6
17	Netherlands	Meppen-Drenthe	sand	6,15	82	9	3	5,9	0,0	4,9	32	35	31	19	12
18	Netherlands	Zuidvelde-Drenthe	sand-loamy sand	6,7	74	29	3	4,2	0,0	4,5	36	42	30	8	7
19	Netherlands	Zevenbergen-Drenthe	loamy sand	6,6	64	26	5	5,5	0,0	4,2	56	57	22	6	6
20	Netherlands	Steenbergen-Drenthe	loamy sand	6,95	70	21	4	5,4	0,0	4,2	74	79	39	19	6
21	Netherlands	Steenbergen-Drenthe	loamy sand	6,7	68	23	4	5,3	0,0	4,6	56	57	27	14	5
22	Netherlands	Ottersum-Limburg	sandy loam	7,9	62	20	16	1,7	0,0	5,2	40	33	28	13	11
23	Germany	Rauisch-Holzhausen (Hessen)	loam	7,75	5	60	33	1,9	0,0	5,5	38	33	21	15	21
24	Germany	Bookhorn-Oldenburg	loamy sand	6,95	67	24	7	1,8	0,1	5,8	58	61	56	12	11
25	Germany	Puch-Bavaria	loam	6,65	7	55	35	2,6	0,0	6,1	28	28	16	14	12
26	Germany	Dülmen-Westphalia	sand-loamy sand	6,75	77	15	6	2,1	0,0	5,1	30	29	27	8	4
27	Germany	Gross-Gerau (Hessen)	loamy sand	7,45	72	20	7	0,8	0,0	4,5	39	34	24	13	2
28	Germany	Braunschweig-Völkenrode	sandy loam	7,3	35	47	16	1,8	0,1	6,0	67	69	37	18	6
29	Germany	Oberer Lindenhof (Wttbg)	loam-silt loam	5,95	3	41	49	6,6	0,1	5,3	18	13	22	53	10
30	Belgien	Leuven-Lubbeek	loam	6,5	16	60	22	2,2	0,0	5,5	29	25	20	13	13
31	France	Versailles	loam	6,4	3	65	30	2,4	0,1	6,2	28	23	19	12	8
32	Switzerland	Bern-Liebefeld	sandy loam	6,9	39	32	26	2,9	0,1	5,7	23	24	16	11	4
33	Yugoslavia	Bilje	loam	6,0	26	34	34	2,4	3,3	7,3	14	8	10	15	8
34	Yugoslavia	Domzale	clay loam	6,3	8	31	56	5,3	0,1	5,0	10	6	7	10	32
35	Yugoslavia	Rakičan	sandy loam	6,9	34	41	23	2,1	0,0	4,6	44	39	22	23	10

36	Austria	Linz-Hart	loam silt loam	6,9	2	57	39	2,4	0,1	6,1	23	20	15	12	30
37	England	Bridget-Berkshire	silty clay loam	6,7	11	27	29	5,5	27,6	7,4	11	10	9	20	5
38	England	Boxworth-Cambridge	clay loam	6,0	22	23	51	3,3	0,5	7,2	8	5	8	20	16
39	England**	Terrington-Cambridge	silty loam	6,5	1	59	35	3,2	1,6	7,4	20	18	19	28	31
40	England**	Terrington-Cambridge	silty loam	6,5	1	64	31	3,1	1,4	7,4	26	20	20	25	32
74	England**	Rosemaund, Herefordshire	silty loam	6,8	2	39	56	2,9	0,0	5,7	7	4	6	14	26
75	England**	Rosemaund, Herefordshire	silty loam	6,9	2	40	55	2,6	0,0	5,7	9	6	6	13	24
41	Scotland	Scotston	sandy loam-loam	6,3	36	28	26	10,2	0,2	4,6	5	3	10	21	23
42	Scotland	Tillymorgan	sandy loam-loam	6,6	29	34	31	6,4	0,1	5,1	8	5	17	14	6
43	Scotland	Westside	sandy loam	6,15	39	33	21	6,8	0,1	4,5	10	6	20	15	6
44	Scotland	Uras	loam	6,25	30	28	36	5,6	0,1	4,6	18	18	21	22	43
45	Scotland	Catcraig	sandy loam	6,2	38	30	24	8,4	0,1	4,6	3	2	6	12	7
46	Iowa (USA)	Edina no. 1	silt loam	6,3	1	44	51	3,8	0,0	5,3	6	4	5	11	51
47	Iowa (USA)	Edina no. 8	silt loam	6,2	1	38	57	4,3	0,0	5,2	13	12	10	13	48
48	Iowa (USA)	Edina no. 10	loam-silt loam	6,3	2	51	42	4,5	0,2	5,0	15	17	12	18	53
49	Iowa (USA)	Nicollet no. 1	clay-loam	6,65	36	32	29	3,4	0,0	5,7	7	2	7	12	60
50	Iowa (USA)	Nicollet no. 2	clay-loam	6,4	36	29	31	3,5	0,1	5,5	22	17	8	14	58
51	Webster (USA)	Webster no. 1	silty clay loam	6,05	28	27	39	5,8	0,0	5,0	10	8	7	29	70
52	Iowa (USA)	Webster no. 9	silty clay loam	6,1	28	32	34	5,6	0,0	5,7	9	6	7	14	80
53	Iowa (USA)	Webster no. 26	silty clay loam	5,8	26	26	42	6,4	0,1	6,0	57	42	20	18	83
54	Iowa (USA)	Webster no. 32	silty clay loam	6,5	34	31	30	5,1	0,0	5,1	29	20	8	12	65
55	Iowa (USA)	Ida no. 1	loam-silt loam	6,4	0,4	59	29	1,4	11,0	7,5	6	2	16	20	39
56	Iowa (USA)	Ida no. 2	loam-silt loam	5,9	0,3	55	32	1,9	11,6	7,6	5	5	20	22	37
57	Iowa (USA)	Grundy no. 1	clay loam-silty clay loam	6,15	3	38	54	4,8	0,1	6,0	8	6	7	18	71
58	Iowa (USA)	Grundy no. 20	silt loam-silty clay loam	6,2	3	46	46	4,6	0,1	6,1	10	8	7	15	71
59	Iowa (USA)	Grundy no. 21	silt loam-silty clay loam	6,15	3	47	45	5,0	0,1	5,7	6	4	6	14	63
60	Iowa (USA)	Pershing	loam-silt loam	5,9	5	45	46	4,4	0,1	6,0	8	6	8	25	53
61	Florida (USA)**	Lakeland no. 1	sand	7,55	92	5	2	1,3	0,2	6,8	14	12	17	3	12
62	Florida (USA)**	Lakeland no. 2	sand	7,45	95	1	2	1,4	0,2	6,9	24	19	19	3	11
63	Washington (USA)	Cinebar no. 1	loam	4,9	12	33	45	9,5	0,2	5,0	6	1	7	25	10
64	Washington (USA)	Cinebar no. 2	loam	4,8	9	46	29	16,2	0,2	4,9	4	2	7	53	15
65	Virginia (USA)	Davidson no. 1	clay loam	6,5	9	28	60	2,9	0,2	5,7	12	4	8	10	15
66	Virginia (USA)	Davidson no. 2	clay loam-silty clay loam	6,5	6	24	67	3,2	0,2	5,8	13	3	6	18	14
67	New York (USA)	Mardin A	loam-silt loam	6,7	17	39	40	3,5	0,1	5,5	9	4	6	13	12
68	New York (USA)	Mardin D	loam	6,6	23	31	42	4,1	0,1	5,3	38	33	24	53	15
69	Victoria (Austr.)	Kyabram, Lemnos loam	loam-silt loam	6,45	5	38	53	4,3	0,1	4,5	14	6	9	15	37
70	Victoria (Austr.)	Tresco	loamy sand-sandy loam	7,2	66	14	16	2,3	2,2	7,4	15	14	8	63	26
71	Victoria (Austr.)	Romsey	loam	6,1	9	44	40	6,7	0,1	4,7	12	8	10	26	39
72	Victoria (Austr.)	Ruffy	sandy loam	6,45	47	29	20	4,2	0,1	4,3	9	6	8	14	7
73	Victoria (Austr.)	Bairnsdale	loamy sand	6,2	67	20	10	2,7	0,0	4,5	15	11	8	8	11

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* The soils 1–3 and 7–11 are marine alluvial soils, 5 and 6 are fluviatile alluvial soils, 12–22 are diluvial soils.

** The couples 39–40, 74–75 and 61–62, were each taken from experimental fields. For each couple, the former represents the control, the latter the plot treated for a series of years with a phosphorus dressing. The samples 57–58–59 were all taken from one field; 59 represents the control, 57 the plot dressed moderately and 58 that with a double annual dressing for a 3-year period.

*** Pw value determined of May 8.

† Pw value determined on November 4.

†† 10 g soil extracted with 50 ml 0.5 n NaCl at 20°C during 1 h.

††† Soil 4 was not used.