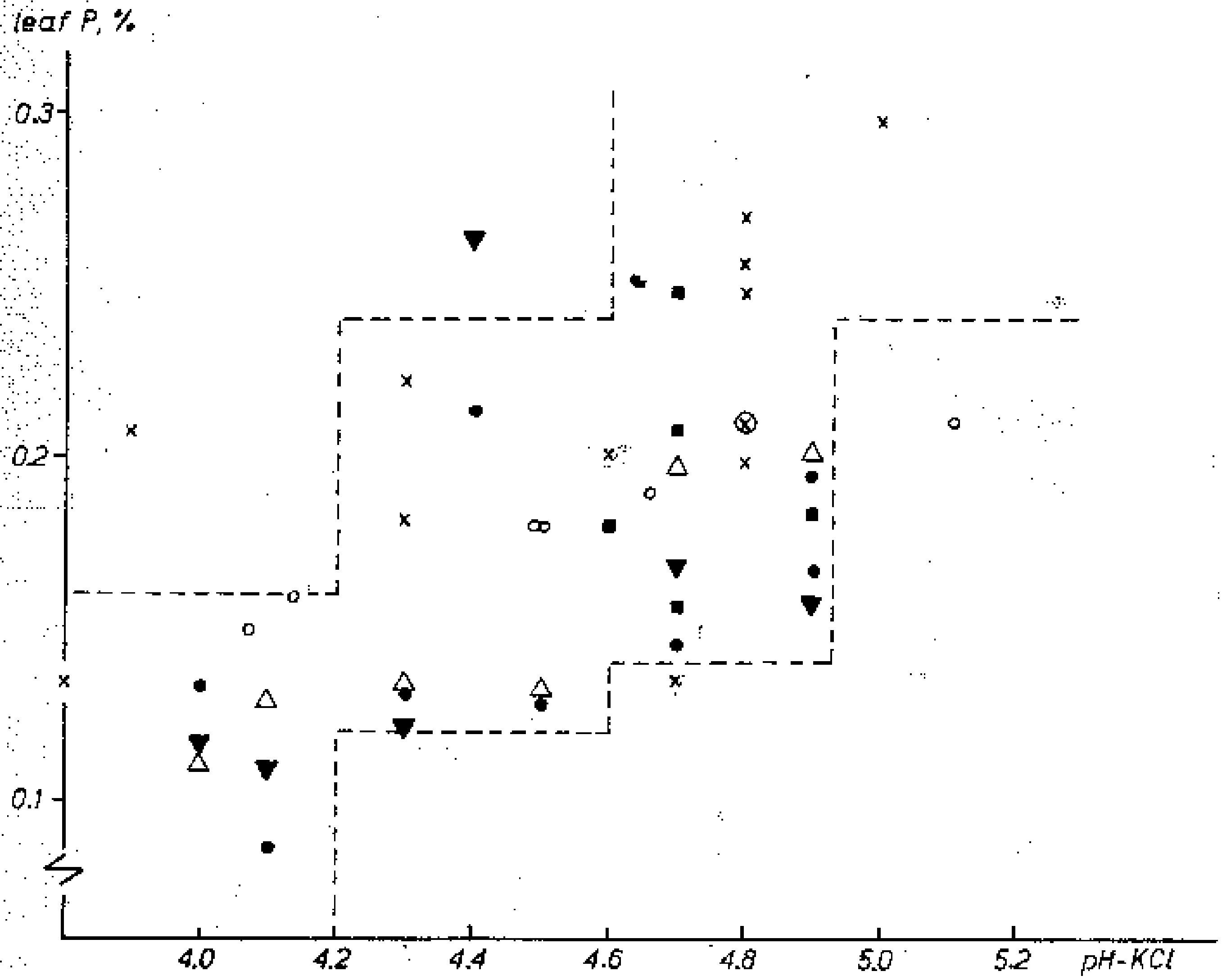
TRAINING PROJECT IN PEDOLOGY

KISII KENYA



Soil Fertility Aspects of the Kisii Soils

PRELIMINARY REPORT NO 6

…RICULTURAL UNIVERSITY
WAGENINGEN - THE NETHERLANDS

SOIL FERTILITY ASPECTS OF THE KISII SOILS

by

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TRAINING PROJECT IN PEDOLOGY, KISII KENYA

Agricultural University, Wageningen - The Netherlands

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Preface

This report of the Training Project in Pedology at Kisii of the section on Tropical Soil Science of the Agricultural University at Wageningen, the Netherlands is the sixth one of a series to be presented by Kenyan officials.
The project started in November 1973 after assent had been granted by the Office of the President of Kenya, and finished, as far as field work concerns, in April 1979.
It was meant for training of postgraduate students of the Agricultural University at Wageningen and for furnishing research opportunities to the staff. The activities of students and staff were directed to obtaining a better knowledge of the soils and the agricultural conditions of the project area to provide a basis for the further agricultural development of the area.
The project in Kisii was conducted by:
Ir. W.G. Wielemaker, teaching and research
Ing. H.W. Boxem, management.
Visiting specialists from the Agricultural University at Wageningen helped to resolve special problems.

This report is a contribution of the Department of Soils and Fertilizers. It consists of two parts. The first part originally was written as a paper for the Third Annual General Meeting of the Soil Science Society of East Africa, that was scheduled for November 1977, but had to be postponed till July 1979. The second part is the paper presented in July 1979.

We hope to pay back with these reports a small part of the great debt we owe to Kenya in general and to many Kenyans in particular for their valuable contributions to the good functioning of the project.

The supervisor of the project

J. Bennema, Professor of Tropical Soil Science

Part A

INTERIM REPORT ON SOIL FERTILITY STUDIES

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Abstract

Within the framework of the "Training project in Pedology", that is executed at Kisii under the leadership of the subdepartment of Tropical Soils of the Wageningen Agricultural University, soil fertility has been studied since October 1974. The work is being done by post graduate students and consists of

- multivariate analysis of the results of chemical analysis of samples of leaves of maize, coffee and tea, and the results of soil studies in the field and chemical and mineralogical analysis of soil samples,
- pot experiments in greenhouses at Wageningen,
- field trials in Kisii and South Nyanza.

Phosphorus was most often the yield limiting nutrient. Classical soil-P-tests had only a limited value in characterizing P availability. Factors of importance proved: soil parent material, pH, P-sorption, and climatic conditions during growth. In the field trials no response to P fertilizers was obtained if control yields and P-withdrawal were more than 2200 kg of grains and 6 kg P per ha, respectively. Probably the ease of phosphorus uptake between 7 weeks after planting and harvest was decisive for yield and P withdrawal.

Nitrogen supply was via soil organic matter related to altitude, parent material, rainfall and drought intensity.

Potassium supply was mostly sufficient; in soils containing volcanic ash it was abundant.

Zinc availability proved influenced by parent material; severe zinc deficiency was found in a soil from relatively young volcanic ash.

1. Introduction

In November 1973 the "Training Project in Pedology" at Kisii, Kenya, set to work. Its aims are:

- training postgraduate students of the Agricultural University at Wageningen, the Netherlands
- contributing to the soil survey of Kenya
- supplying information that is of value for the development of particularly the districts Kisii and South Nyanza, where the project is situated.

Dr. J. Bennema, professor in Tropical Soils, is supervisor of the project, while the leadership at Kisii is held by Ir. W.G. Wielemaker and Ing. H.W. Boxem.

In October 1974 after one year of soil survey by a number of students, enough knowledge of the soils had been collected to start soil fertility studies. The purposes of these studies are firstly to furnish general information on the relationships between mapped soil units and soil fertility and secondly to investigate more thoroughly phosphorus fixation, the main soil fertility problem in the project area. To coordinate the studies which were carried out by several students and to set up the phosphorus fixation research, staff members of the Department of Soils and Fertilizers of the Wageningen University visited the project (Janssen, 1974b, 1975; Van der Eijk, 1976).

The phosphorus fixation research by Ir. D. van der Eijk, that started in the field in 1977, is being left out of consideration here. This paper is to present a survey of the work of the students.

2. Soils and climate data

For detailed information on the soils occurring in the project the reader is referred to the series of "Preliminary reports" published (in a restricted number) by the Training Project. General information is given in Preliminary report no. 1 (Wielemaker (Ed.), 1974).

For the purpose of the present soil fertility studies, soils were distinguished primarily on base of parent material. Where necessary, subdivisions were made on the ground of soil texture and soil depth. The main parent materials are granite, rhyolite, basalt, quartzite, felsite, andesite and "volcanic ash".

The main climate factors to be taken into consideration are rainfall, drought intensity and temperature, which are strongly related to altitude. When useful, climatic data are given with the results.

3. Designs, methods and materials

3.1. Reconnaissance study

The research started with a soil fertility reconnaissance by ter Maat (1976). Leaf samples were taken from maize, coffee and tea, growing at sites representative for the most important parent materials and classes of soil texture and soil depth. Besides data on soils and on management were collected, e.g. altitude, topsoil depth, use of fertilizers, herbicides and insecticides, degree of weed cover, shade, intercrops, variety, planting time. All together 69, 29 and 34 sites were sampled for maize, coffee and tea, respectively. At 26 of these 132 sites one kg soil samples were taken for chemical analysis and pot trials.

The intention was to collect yield data as well. It proved however, impossible to obtain exact coffee and tea yield data of individual farmer fields. Because the study programme did not allow the students to be in Kisii at maize harvest time, neither yield data of maize could be obtained. Instead of it, growth rate was estimated; at two times plant height was measured on 56 fields. The results were arranged in four equally large classes, from class 1 (highest growth rate) towards class 4 (lowest growth rate).

A second series of leaf and soil samples was taken along an east-west transection through the project area in 1976, to study the influence of volcanic ash. Their results are not yet available.

Leaf samples were analyzed for nitrogen, phosphorus, potassium, calcium and magnesium, after digestion according to Lindner-Harley (1942). Soil samples were analyzed for pH, P-Bray I (1945), P-Olsen (1954), organic carbon according to Kurmies (1949) and to Walkley-Black (Walkley, 1947). The ratio Kurmies org. C/Walkley Black org. C proved 1,225. Organic matter was calculated as 1.75 * Kurmies org. C or as 2,11 * Walkley-Black org. C. In some samples CEC and exchangeable cations were determined (NH_4-acetate, pH 7). Sorption of phosphorus was determined as follows: 2 grams of soil were shaken with 40 ml solution of 0.01 M $CaCl_2$ and 75 ppm P. After 4 days the solution was centrifuged and phosphorus concentration was measured. The amount of phosphorus sorbed by the soil is expressed as percentage of the added phosphorus. The method was derived from Bache and Williams (1971).

It was tried to unravel graphically the relationships between the analytical data, soil units and climate.

3.2. Pot trials

Three types of pot trials were used, mostly with maize as test crop.

1. "Classic" pot trials in pots containing about one kg of soil. In these trials the response to phosphorus fertilizers was studied and the effects of special treatments:
   - placement and postponement of fertilizer application (Guiking, 1977b, Scholten, 1977)
   - influence of plant population on amount and speed of phosphorus uptake (Hwang, 1977)
   - influence of pH changes on phosphorus uptake (Duykers - van der Linden, 1978)
   - comparison of triplesuper- and rockphosphate (Laarman, 1978).

   On the average these experiments lasted seven weeks. After harvest shoots and roots were weighed and analyzed for phosphorus and other nutrients.

   For the purpose of these trials 50 - 100 kg samples had been shipped from Kenya to the Netherlands.
2. Double pot technique (Janssen, 1974a). The principle of the technique is that young plants can take up nutrients simultaneously from the soil to be investigated and from a nutrient solution. A pot with a gauze bottom and containing 200 g of soil is placed on another pot filled with a nutrient solution. The roots can pass the gauze and reach the nutrient solution below. When a nutrient is omitted from the solution, plants can take it up from the soil only. As availability index for that nutrient is used the so-called "sufficiency quotient", i.e. the ratio of the relative growth rates of plants growing on the deficient and the complete solution, respectively (and with the same soil in the upper pot). The relative growth rates are determined over a defined period, depending on climatic conditions; for maize this is about between the 15th and 25th day after sowing.

   Thus phosphorus availability was studied by ter Maat (1976) and zinc availability by Duykers (1978).

Table 1. General data on climate and soil and leaf analysis results for the most important soil parent materials (data from ter Maat, 1976 and Guiking, 1977a).

Parent material	Rhyolite	Granite fine textured		Bazalt	mixed with volcanic ash		
					Rhyolite	Rhyolite	Andesite
Location	Marongo W	Marongo W	Wanjare	Marongo E	Kebirigo	Tombe	Magombo
Rainfall (mm)[1]	<< 1400	<< 1400	1500	< 1400	1550	1750	1550
Drought[2]	0,2	0,2	0,3	0,25	0,35	0,35	0,35
Altitude (m)	1480	1500	1560	1680	1940	2000	1900
Soil samples							
Number	1	4	6	4	3	0	4
pH-KCl	4,98	4,31	4,83	4,80	4,80	-	4,41
org. matter[3] %	4,2	3,5	4,2	6,3	5,5	-	6,8
P-Bray I, ppm P	2,7	0,7	0,7	0,3	0,4	-	0,0
P-Olsen, ppm P	4	2	4,2	1,7	4,7	-	3,5
P-sorption[4]	54	79	80	92	73		91
Maize samples							
Number	5	11	8	12	8	-	5
%N	2,43	3,17	3,18	3,41	3,10	-	3,07
%P	0,23	0,20	0,18	0,22	0,19	-	0,17
%K	3,46	3,41	3,39	3,69	3,98	-	4,30
%Mg	0,23	0,22	0,22	0,25	0,19	-	0,23
growth class[5]	1,6	2,3	2,7	1,9	3,7	-	3,0
Coffee samples							
Number	0	5	7	5	0	0	0
%N	-	2,40	2,54	2,53	-	-	-
%P	-	0,14	0,21	0,14	-	-	-
%K	-	2,64	2,77	1,90	-	-	-
%Mg	-	0,28	0,29	0,46	-	-	-
Tea samples							
Number	0	0	0	0	5	8	15
%N	-	-	-	-	3,43	3,37	3,24
%P	-	-	-	-	0,17	0,18	0,16
%K	-	-	-	-	1,97	1,99	1,95
%Mg	-	-	-	-	0,24	0,19	0,18

1) probability of obtaining mentioned level once in four years (Van Mourik, 1974).

2) related to rainfall/potential evapotranspiration during driest three consecutive months: drought intensity index (ibid).

3) org. matter = 2,1 * uncorrected Walkley-Black org. C.

4) % sorption of added P after 4 days.

5) growth classes: 1 (good) → 4 (bad).

3. Verwey (1975) submitted soils to a potassium exhaustion pot experiment. 100 g of soil were placed in a pot, under and above which the pot was filled with quartzsand. The test crop was amaranth, which has high potassium demands. Uptake of potassium by amaranth and loss of exchangeable potassium were followed.

3.3. Field trials

Field trials, with maize as test crop, were performed between August 1975 and January 1976 (Guiking, 1977a). The design of the experiments discussed in chapter 4.3 included three treatments:

1. no phosphorus fertilizers
2. 50 kg P_2O_5, applied at planting as triple superphosphate
3. ibid, but split in 25 kg at planting and 25 kg 6 to 8 weeks after planting.

The trials were set up in triplicate and laid down on farmers' fields on basalt (2) and granite (3) soils.

After 7 weeks there was an intermediate harvest. Plants were analysed for phosphorus. Also grains of the final harvest were analyzed for phosphorus in order to be able to calculate phosphorus withdrawal. On base of literature data total phosphorus withdrawal was considered to be 100/70 * grain withdrawal.

4. Results and discussion

4.1. General data of the reconnaissance study

To come up to the purpose of the research to relate soil fertility to soil survey, data of soil and leaf analysis were grouped according to soil parent material and climatic indices. Only groups containing at least five leaf samples have been listed in Table 1.

At first glance attention is attracted towards the following:

1. Soil organic matter is higher in basalt soils and in the soils mixed up with volcanic ash (soils from basic parent materials) than in the granite and pure rhyolite soils (soils from acid parent materials). This might be due to the larger mineral reserve of the basic parent materials, as well to the higher altitude at which they occur. For soil organic matter is positively related to altitude and rainfall, as was found in Kenya by Birch and Friend (1956).

Table 2. Approximate optimal levels of leaf N, P, K and Mg for maize, coffee and tea as gathered and used by ter Maat (1976).

	maize	coffee	tea
N	3,5	2,5	3,0
P	0,20	0,15	0,20
K	3,0	2,5	1,0
Mg		0,3	0,22

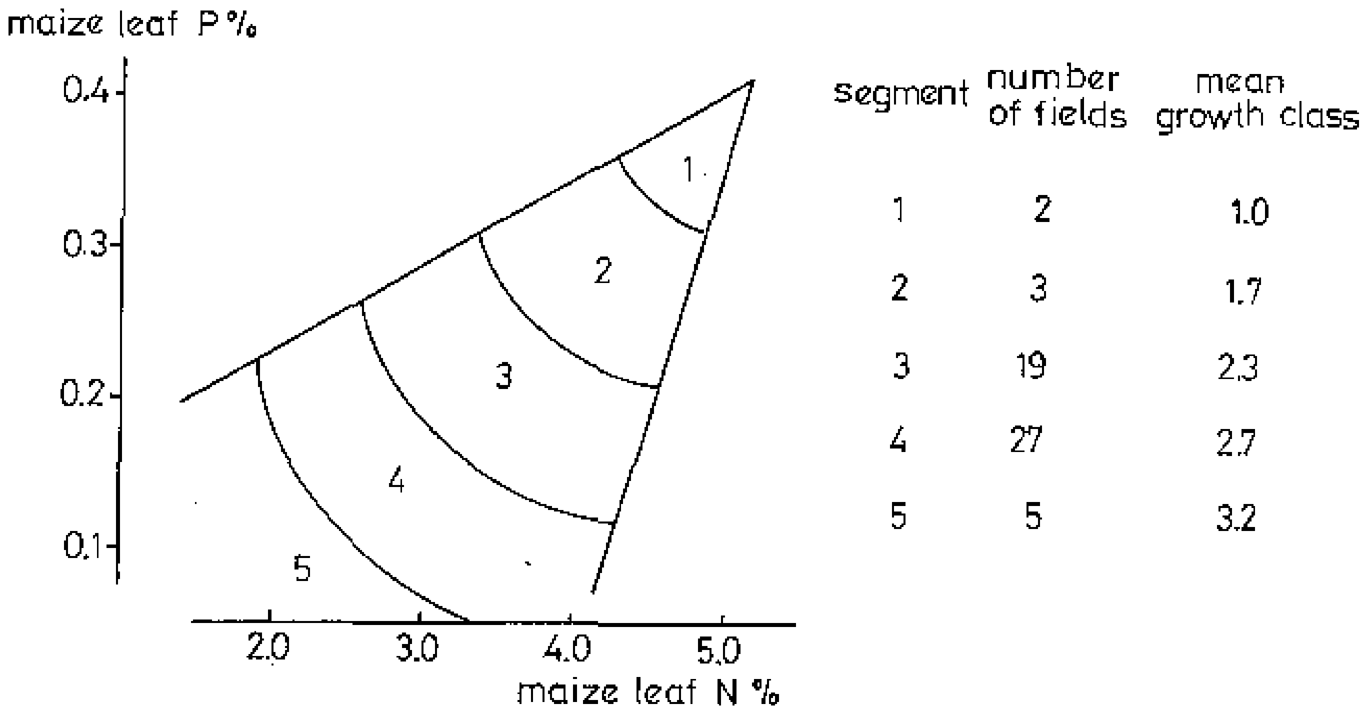

Fig. 1. Relation between maize leaf N and leaf P and growth class (from ter Maat, 1976).

2. There are no large differences in pH, only Magombo and Marongo West have a somewhat lower pH than the other groups. For Magombo this can be ascribed to the circumstance that most of the soils here are from tea fields. It is not (yet) possible to explain why the granite soils of Marongo West have a lower pH.
3. All soils are low in phosphorus. The differences between the groups, in soil phosphorus as well as in plant phosphorus, are small.
4. Comparison of Table 1 with Table 2 learns that nitrogen content is a little bit below optimal for coffee and maize, also there where tea leaf nitrogen content is sufficiently high. Phosphorus is too low for tea and often for maize and coffee, while potassium is abundantly present.

The use of leaf contents of single nutrients as a criterium to judge thenutritional status of a crop is not without risks. Dumenil (1961) and others have shown that often the balance between nutrients and not the level of a single nutrient is decisive for yield. Following Dumenil, ter Maat constructed Figure 1, showing how maize growth is related to leaf nitrogen and leaf phosphorus (the leaf samples had been taken three to four weeks before the first height measurement).

4.2. Nitrogen

The relation between leaf nitrogen and soil organic matter is not a distinct one, because also other factors including agricultural measures influence leaf nitrogen content. For coffee and tea and for maize on soils from acid parent materials there is a faint relation between leaf N and rainfall (Table 3). The table shows too that generally leaf N is higher for crops growing on soils from basic parent materials than for crops growing on soils from acid parent materials, which is in accordance with the organic matter contents of these soils. The same is reflected in Figure 2. Because soils from acid parent materials supply less nitrogen than soils from basic parent materials, leaf nitrogen is more sensitive for weeds on the former soils (Fig. 2).

In the Wanjare area finely and coursely textured granite soils are found. Maize leaf N content is 3.2 and 2.4% and coffee leaf N content is 2.5 and 2.1%, respectively on the fine and course soils. The cause of this difference is probably that soil organic matter content is lower in the sandy than in the clayey soils.

Table 3. Relations between leaf N content, rainfall, drought intensity index and soil parent material for maize, coffee and tea (data from ter Maat, 1976)

Rainfall[1)] mm	Drought[1)] int. ind.	% N in maize Acid	% N in maize Basic	% N in coffee Acid	% N in coffee Basic	% N in tea[2)] Basic
<< 1400	0,2	3,00	3,65	2,36		
< 1400	0,25	3,12	3,39		2,70	
1400	0,35					2,64
1500	0,35		3,11			3,24
1500	0,3	3,22		2,54		
1600	0,35		3,21			3,30
1600	0,3					3,51
1700	0,35				2,75	3,37

1) see notes 1 and 2 of Table 1

2) acid parent materials: granite, rhyolite, quartzite
basic parent materials: basalt, felsite, andesite, rhyolite mixed with volcanic ash.

4.3. Phosphorus

All soils are low in phosphorus, with exception of soils developed in volcanic material. (Table 5, Mbita Point and Mwongori).

Ter Maat (1976) determined phosphorus adsorption isotherms of eight soils. As the curves did not intersect, it was warranted to use the sorption percentage (chapter 3.1), which is actually one point of a phosphate adsorption isotherm, to characterize the phosphorus fixation or sorption capacity of the soils. To investigate whether this index can indicate the rate of response to phosphorus fertilizers, sufficiency quotients (chapter 3.2)were assessed for soils having received 0, 100 and 200 ppm P as superphosphate. Table 4 shows that there is not much agreement between sorption percentage and the other data. The SQ_p values suggest that particularly soils mixed up with volcanic ash from the eastern part of Kisii district (Keroka) do not set free easily fertilizer phosphorus for the plant: even when 200 ppm P was applied, SQ_p is lower than 0,9, indicating phosphorus deficiency.

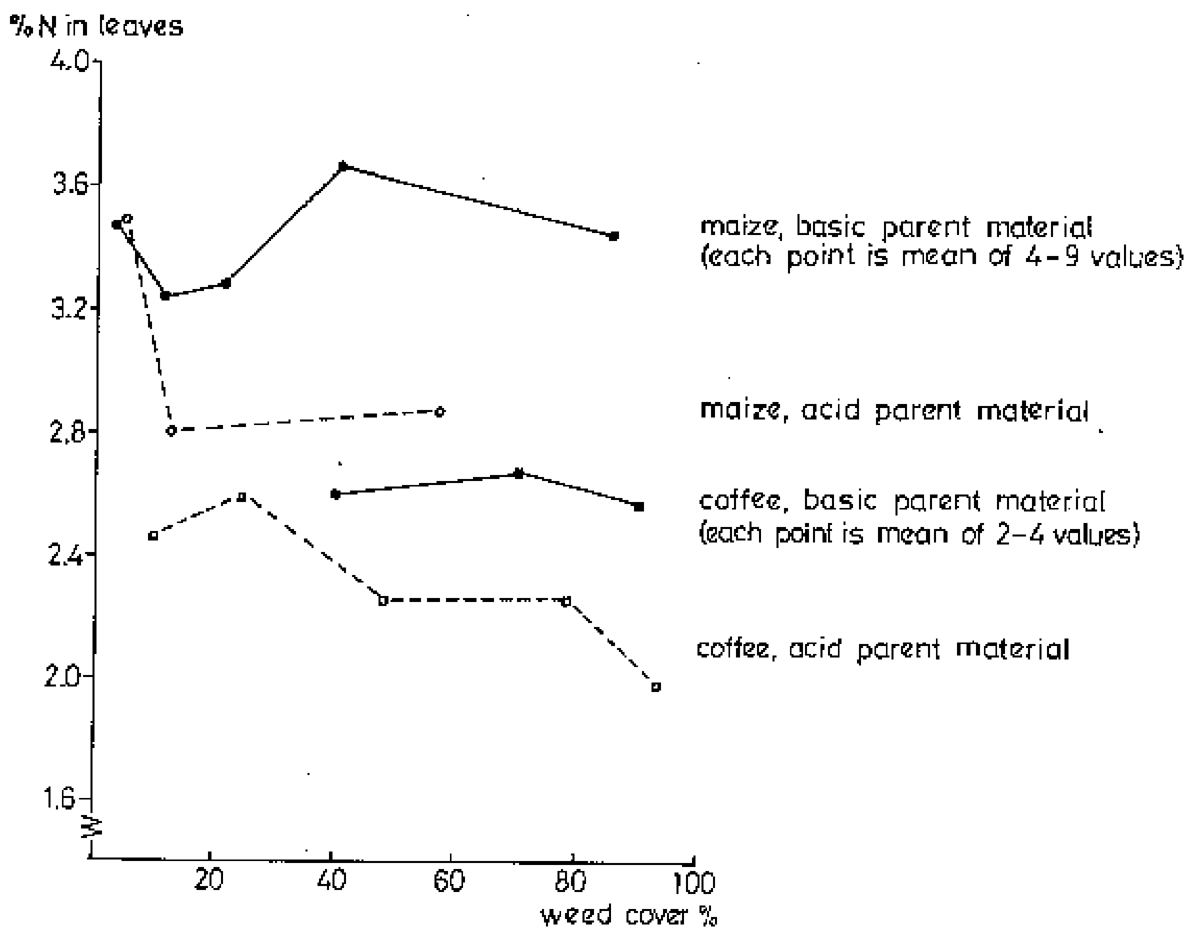

Fig. 2. Relation between soil parent material, weed cover and leaf nitrogen for maize and coffee (data from ter Maat, 1976).

The difference in phosphorus economics between these soils and the soils from Mbita Point and Mwongori can probably be explained by the fact that the latter are much younger and less weathered. In aging, volcanic soils get a higher phosphorus sorption capacity (Fox, 1974).

Table 4 further shows that all soils have a SQ_p lower than 0.9 when 100 ppm P is applied. Apparently phosphorus dressings should be higher than 100 ppm P to prevent phosphorus deficiency. This comes down to more than 250 kg P or 570 kg P_2O_5 per ha (broadcasting). The other pot trials suggest the same (Fig. 3 and Table 5). The response curves remain straights up to at least 80 ppm, and even beyond 100 ppm P there hardly exists a tendency

Table 4. P-Bray, sorption index and sufficiency quotients for phosphorus for some groups of soils (data from ter Maat, 1976).

Soil parent material	Location	Number of soils	P-Bray I ppm P	Sorption percentage	Sufficiency quotient (SQ_p) 0	100	200 ppm P added
granite	Marongo West	3	0,4	79	0,59	0,81	0,95
	Wanjare	2	0,4	80	0,61	0,86	0,96
basalt	Marongo East	3	0,0	92	0,56	0,81	0,94
rhyolite + ash	Keroka	3	0,4	73	0,50	0,76	0,87
andesite + ash	Keroka	2	0,0	87	0,54	0,68	0,81

Table 5. Data pertinent to soils and conditions of the experiments from which results are presented in Fig. 3.

Soil data

Number	Location	Parent material	pH-KCl	P-Bray I ppm	Org. matter %	CEC meq/100 g
1,5	Nyamarambe	basalt	4,7	0	4,5	18,6
2,4	Riosiri	granite	4,7	1,1	4,0	16,2
3,6	Mbita point	volcanic	6,0	51,1	2,8	32,5
7	Magombo	andesite (+ ash?)	4,3	0,4	7,0	22,9
8	Ranen	rhyolite	4,6	0,4	3,5	17,0
9	Koderopara	granite	4,2	1,6	3,6	11,4
10	Mwongori	volcanic	5,1	30,3	12,3	35,3

Experimental conditions

Number	Period		Duration	Temp.	Soil per pot (g)	Plants per pot	Reference
1, 2, 3	June-August	1976	8	hot	1300	1	Guiking 1977b
4	Oct.-Nov.	1976	8	warm*	800	3	Scholten 1977
5, 6	Sept.-Nov.	1976	7	cool	900	3	Hwang 1977
7, 8	June-August	1977	8	warm-hot	1000	3	Duykers-v.d.L.1978
9, 10	April-May	1977	6	warm	1000/800	2	Laarman 1978

* conditioned greenhouse; other experiments in non-conditioned greenhouses

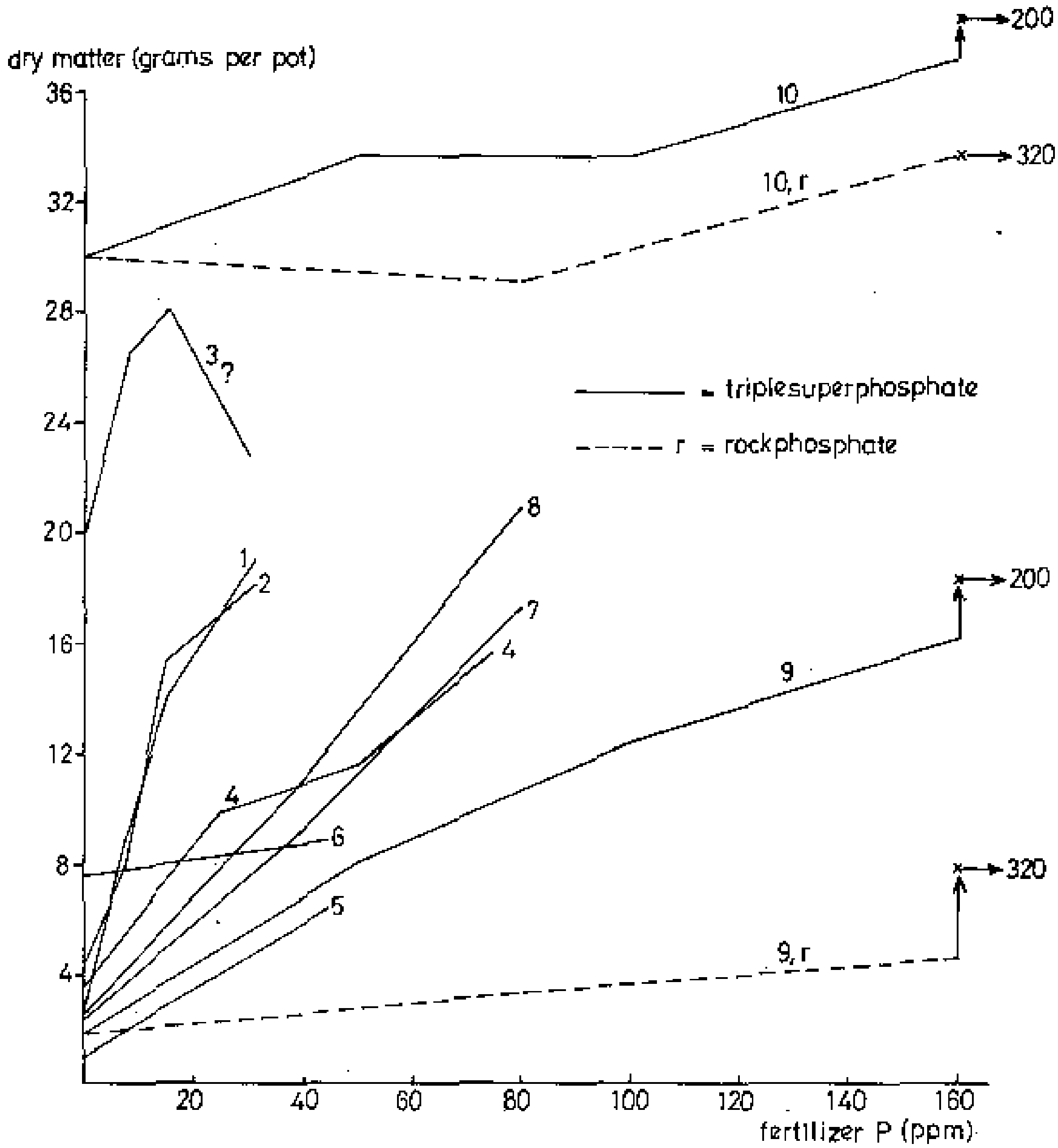

Fig. 3. Response of maize to triplesuper and rockphosphate in some pot trials. See for explanation Table 5.

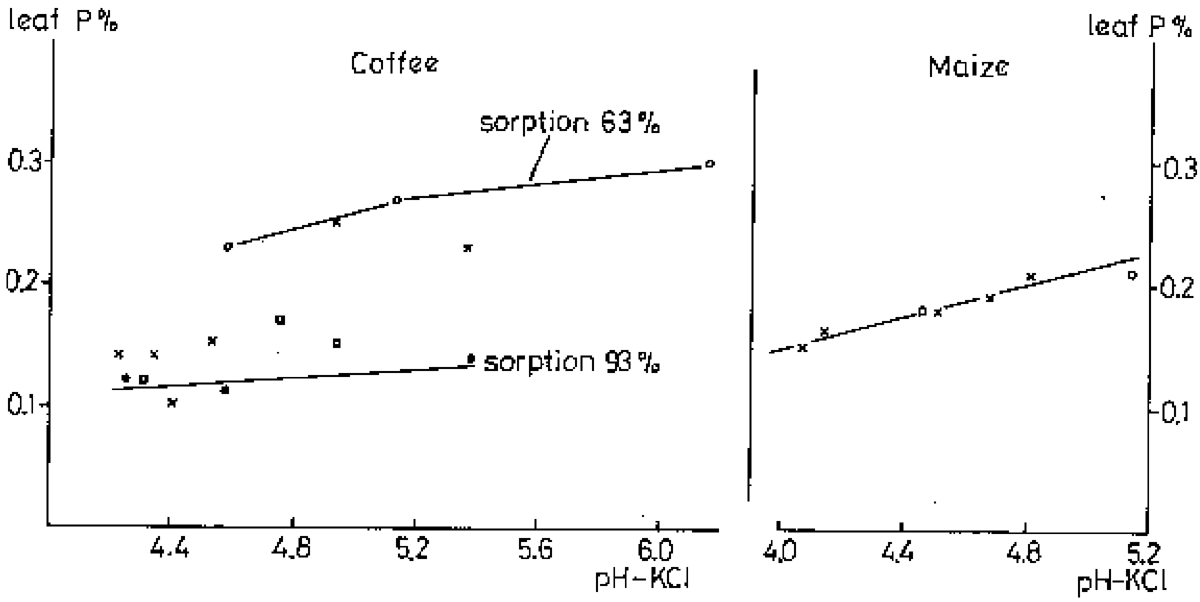

Fig. 4. Relation between phosphorus sorption and pH of the soil and leaf phosphorus for coffee and maize (data from ter Maat, 1976).

o ◻ x • 63, 74, 84 and 93% P-sorption, respectively

of diminishing returns. Not seen in this figure is that plants on all soils, except Mbita Point and Mwongori, had low to very low phosphorus levels, even if fertilized with 80 ppm P.
Striking are the high control yields and small responses to phosphorus for the mentioned volcanic soils (nrs. 3, 6, 10 and 10r).

Temperature has a strong positive effect on both control yield and the slopes of the response curves; compare nr. 2 versus 4, nr. 1 versus 5 and nr. 3 versus 6.

The response to rock phosphate, which was an apatite from Mali, containing 25 - 30% P_2O_5 as determined in concentrated acid, was poor in comparison with the response to triplesuperphosphate (9r versus 9, 10r versus 10) (Laarman, 1978).

Data from ter Maat lead to the conclusion that pH might be more informative on phosphorus availability than soil phosphorus tests (Fig. 4). The P sorption percentages influence the relation between pH and leaf P content for coffee, but not for maize. It is not clear why.

The results of a pot trial by Duykers - van der Linden (1978), however, seem to contradict the findings of ter Maat. By an increase in pH, brought about by $CaCO_3$ application, the availability of soil phosphorus was not, while the availability of triplesuperphosphate was negatively affected. It is hypothesized that $CaCO_3$ served as an extra source of phosphorus sorption. Anyhow, it seems not warranted to recommend liming as a mean to improve phosphorus availability in these soils.

Another question is whether maize leaf P content has a prognosticating value. Guiking (1977a) could not find a relation between leaf P and the response to phosphorus by maize in field trials. If control yields are higher than 2100 kg or control P withdrawal is more than 6 kg P per ha, there is none response (the yields of split-application and application at once have been averaged in Table 6). The amount of phosphorus that has

Table 6. Grain yields and phosphorus uptake of field trials.(Data from Guiking 1977a.)

Location Soil parent material	Ikoba basalt	Wanjare granite, fine	Kenyorora granite, coarse	Nyamarambe basalt	Riosiri granite
Grain yield (kg/ha), control	2642	2176	1154	836	n.d.
fertilized	2614	1964	1670	1608	n.d.
P uptake (kg P/ha)					
7 weeks, control	0,53	0,70	0,83	0,83	1,73
fertilized	0,80	0,68	1,10	0,90	1,90
harvest, control	8,90	6,43	2,71	2,61	n.d.
fertilized	8,26	5,50	5,76	5,60	n.d.
P uptake at 7 weeks as					
% of total, control	6,0	10,9	30,6	31,8	n.d.
fertilized	9,7	12,4	19,1	16,1	n.d.
P uptake between 7 weeks					
and harvest, control	8,37	5,73	1,88	1,78	n.d.
fertilized	7,46	4,82	4,66	4,70	n.d.

been taken up by the crop during the first seven weeks is not correlated with the final phosphorus uptake. Probably for yield and phosphorus uptake from the soil, the period before the seventh week is less critical than the period thereafter. How far soil properties rather than climatic conditions play a role here is not yet to say.

Also several other authors mention an unexplainable erratic pattern in responses to phosphorus in the field (e.g. Okalebo, 1976).

In this connection it is noticeable that fertlizer phosphorus could be taken up only during the first five weeks after application in a pot trial with basalt soil (Hwang, 1977). This means that postponement of fertilizer application might be successful, as then the plants have already a root system in the period that fertilizer phosphorus is available. However, the results of Guiking (1977b) and Scholten (1977) do not confirm this supposition. They found that postponement of four weeks resulted in a decrease of dry matter yield of 8 weeks old plants, while postponement of one or two weeks did not have a clear effect.

4.4. Potassium

Although the data of leaf analysis point to high potassium levels everywhere (with exception perhaps of coffee on basalt in Marongo East, see

Table 7. Potassium uptake by amaranth and loss of exchangeable and of non-exchangeable potassium in a potassium exhaustion pot experiment. Data from Verwey, 1975)

Location	Rongo	Kisii	Keroka
Parent material	granite	basalt	andesite + volcanic ash
CEC, meq per 100 g	9,7	12,8	16,0
Rel. K saturation, %	2,1	2,3	7,2
Exch. K, meq per 100 g	0,20	0,29	1,15
Loss of exchangeable K, meq per 100 g soil			
0 - 4 weeks	0,11	0,19	1,05
4 - 8 weeks	0,06	0,08	0,05
K uptake, meq per 100 g soil			
0 - 4 weeks	0,60	0,86	2,93
4 - 8 weeks	0,24	0,27	0,40
Calculated loss of non-exchangeable K, meq per 100 g soil			
0 - 4 weeks	0,49	0,67	1,88
4 - 8 weeks	0,18	0,19	0,35

Table 1), soils do differ in potassium supplying capacity. Verwey (1975) submitted soils from three locations to a potassium exhaustion pot trial. Table 7 shows that potassium uptake was much higher than the loss in exchangeable potassium. It means that also non-exchangeable potassium must have been withdrawn from potassium bearing minerals. The Keroka soil apparently has a much higher potassium reserve than the Kisii and Rongo soils. This can be ascribed to volcanic ash in the Keroka soil. It explains also why leaf K contents in maize and tea in this area are so high.

From this experiment might be concluded that if yields increase by nitrogen and phosphorus application, potassium deficiency might originate on soils like Rongo granite.

4.5. Magnesium

No special studies were made on magnesium. There are indications of K/Mg antagonisms. The K/Mg ratios are high enough to expect magnesium deficiency in tea, but this was not noticed in the field.

4.6. Zinc

Since in the field several times leaf discolourations were found, which could be diagnosed as zinc deficiency symptoms, a pot experiment according to the double pot technique was conducted with a number of soils to verify whether zinc deficiency could be indicated. The study has not yet been finished, but some data of Duykers (1978) are already available (Table 8).

Clear zinc deficiency is found in Kirundo volcanic soil and also, but less outspoken, in shallow, stony soils from Ranen and Wanjare.

5. Conclusions and outline for further research

Based on the studies carried out so far, some preliminary conclusions for the Kisii and South Nyanza districts can be drawn:

- nitrogen deficiency is most likely to occur on soils derived from granite, rhyolite and quartzite; weeds worsen the poor nitrogen situation
- phosphorus deficiency is to be expected everywhere, except on soils derived from relatively young volcanic material
- potassium deficiency is not likely to occur
- magnesium deficiency is not likely to occur, but if it appears it will be in tea in the eastern part of the project area
- zinc deficiency might be found on young volcanic soils and on shallow stony granite and rhyolite soils in the western part of the project area

- the response to phosphorus fertlizers depends perhaps for a main part on climatic conditions after the first two months of growth; with the present knowledge it is not possible to base phosphorus application recommendations on soil phosphorus tests.
- maize yields depend for a considerable part on the nitrogen-phosphorus balance.

Further research by Van der Eijk will be focussed on phosphorus, especially phosphorus fixation problems. He will try to find methods to mitigate the fixation. Further it is the intention to indicate more exactly where the problem areas are.

In the Netherlands efforts to find valuable analytical procedures for the determination of phosphorus availability in tropical soils are being joined in an co-operation between the Institute for Soil Fertility at Haren (Dr. Sissingh), the Soil Science subdepartment of the Royal Tropical Institute at Amsterdam (ir. Muller) and the Department of Soils and Fertilizers of the Agricultural University at Wageningen.

Table 8. Sufficiency quotients for zinc, calculated for the periods: day 14 - day 24 and day 19 - day 24 after sowing; test crop is maize (Data from Duykers, 1978).

Location	Parent material	sufficiency quotient for zinc	
		day 14 - 24	day 19 - 24
Keroka	rhyolite + volcanic ash	1,06	1,05
Keroka	rhyolite, shallow soil	0,94	1,02
Riakwaro	rhyolite + volcanic ash	0,97	0,97
Wanjare	granite	0,97	0,94
Ranen	rhyolite	0,85[1)]	0,90
Wilhelminapolder[2)]	marine clay	0,96	0,87
Ranen	rhyolite, shallow, stony	0,88	0,75
Wanjare	diorite/granite, shallow, stony	0,80	0,63
Kirundo	montmorillonite in volcanic ash	0,49	0,33

1) slow growth in the beginning

2) Dutch soil, whereon apples have zinc deficiency; this soil served as a reference

6. Acknowledgement

The authors are much indebted to the direction of the Training Project in Pedology, Prof.Dr. J. Bennema, Ir. W.G. Wielemaker and Ing. H.W. Boxem. We were happy with the contacts we had with scientists of Kenyan institutes of agricultural research, especially with Mr. Mbagaya, Mr. Ndjiba and Mr. Masyanga of the Nyanza Agricultural Research Station at Kisii and with Mr. Lubanga of the Kisii Coffee Research Substation. The help of the Kenyan workers in the field was highly appreciated.

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Part B

A TENTATIVE RATING SCHEME TO EVALUATE SOIL FERTILITY

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B.H. Janssen
D. van der Eijk

Abstract

Soil fertility studies in the Kisii area comprised analysis of soil and leaf samples and execution of field trials, especially to study the response to phosphorus fertilizers.
To calibrate the analytical and field results, a system was used of minimum requirements and guarantee values (to be explained in the paper).
The steps towards the fertility rating system were:
- determining yields in field trials on different soils.
- determining relationships between leaf nutrient contents and yields in field trials.
- construction of fertility classes based on yields and fertilizer needs.
- determining relationships between leaf nutrient contents and soil parameters in and outside field trials.
- determining relationships between soil parameters and soil fertility classes.

Finally a tentative soil fertility rating diagram is presented, based on combinations of soil organic matter, P-Olsen, pH-KCl and exchangeable potassium.

1. Introduction

Between 1973 and 1979, the Agricultural University of Wageningen, the Netherlands, carried out a soils project in Kisii, Kenya. The purpose of the project was to train post graduate students and at the same time to contribute to the soil survey and land evaluation of Kenya.

Soil fertility was one of the research subjects. It consisted of two main parts:

a) an evaluation of the fertility of the mapped soil units

b) a study of the behaviour of native and fertilizer phosphorus in soils and crops; this study was initiated because phosphorus deficiency and fixation proved the main soil fertility problems.

In this paper it will be discussed which steps were made to arrive at quantitative assessments of diagnostic soil characteristics to form the frame work of a soil fertility rating system. For the time being the system is restricted for maize, as for other crops like coffee and tea data couldnot yet be processed. We hope to finish the final report on soil fertility evaluation in 1980. The results of the phosphorus study will be published separately by Van der Eijk.

2. Soils

General information on soils in the project area was given bij Wielemaker (1974). Final maps and reports by Wielemaker and Boxem are in the process of publication at present.

The main geological formations underlying soils are felsite/andesite, basalt, granite, rhyolite and quartzite. However, relations between parent materials and soils often are obscured by admixtures of volcanic ashes, especially in the eastern part of the Kisii area (Wielemaker, 1979).

The present paper and the proposed rating system do not deal with soils that are either too shallow, too compact or too wet for undisturbed crop growth. This implies that the validity of the system is limited to well drained soils that are at least one meter deep and have no vertic properties. Wielemaker and Boxem classified these soils as mollic and humic Nitosols, haplic and luvic Phaeozems, humic Ferralsols and humic Acrisols.

3. Methods

Field trials form the ultimate test for the assessment of soil fertility. As it is not feasible to carry out field trials on all soil types, other methods were used as well, especially leaf and soil analysis. Because it is much easier to sample and analyse leaves than soils, much more leaf than soil samples were taken.

3.1. Sampling and analysis of soils and leaves

Leaf samples were taken from crops growing at sites being representative for the most important mapped soil units. In the case of maize it was the latest fully grown leaf (i.e. about the third youngest leaf) of plants having eight to twelve leaves, that was sampled.

In order to find the relationships between leaf nutrient contents and soil parameters, at some of the sites where leaves were sampled, also soil samples were taken (0-20 cm depth). For the purpose of calibrating leaf nutrient contents in terms of yield and yield responses to fertilizers, also in the field trials leaves were sampled.

Leaf samples were analysed for nitrogen, phosphorus, potassium, calcium and magnesium,after digestion by a H_2SO_4-H_2O_2-salicylic acid mixture (Van Schouwenburg and Walinga, 1978). Soils were analysed for pH-KCl and pH-H_2O, P-Bray I, P-Olsen, organic carbon, CEC and exchangeable cations (NH_4-acetate). The measured contents of organic carbon were multiplied by 1.03 when the method of Kurmies (1949) and by 1.26 when the method of Walkley-Black (Walkley, 1947) was used. The procedures of the other analyses are described in Houba, Van Schouwenburg and Novozamsky (1979).

3.2 Fertilizer trials

The main objective of the field trials was to learn the response of maize to phosphorus on different soils. Triple super phosphate was used. Methods of application were placement and broadcasting, the latter followed by incorporating of the fertilizers into the soil by means of a rotary cultivator. Rates of application were 12.5, 25, 50, 75, 100 and 300 kg P_2O_5 per ha with placement, and 75, 150, 300, 600, 1200, 2400 and 4800 kg P_2O_5 with broadcasting and incorporating. These rates were equivalent to the quantities of phosphorus sorbed by soils in laboratory experiments. In one trial also rockphosphate was used, and in some other trials cowdung and town market refuse were placed, alone or in combination with phosphorus fertilizers.

3.3 Interpretation and calibration

Common practice in calibration work is to express the relationship between two variables in a best fitting curve, and next to cut the curve into pieces, representing different categories of the variables. Such a procedure is described, for instance, by Sanchez (1976, pages 305 and 306). In this study, many relationships showed a large variation around the best fitting curve. Use of fitted values as diagnostic criteria, would introduce much inaccuracy. To avoid this, it was decided to indicate minimum requirements and guarantee values of x, needed to exceed particular values of y, in all cases where the relations between x and y showed a large variation. This method can be considered as an extension of the Cate-Nelson method (Sanchez, 1976).

To clarify the concept we use as an example the relationship between pH-KCl and phosphorus content in maize leaves (Fig. 6). The graph reveals that leaf P is always higher than 0.12%, if pH-KCl is more than 4.2. So, a pH-KCl value of 4.2 is a guarantee that leaf P exceeds 0.12%. Similarly are pH-KCl values of 4.6 and 4.9 guarantees for leaf P contents of more than 0.14 and 0.24%, respectively. Fig. 6 shows also that leaf P does not exceed 0.24%, if pH-KCl is lower than 4.6. So, pH-KCl 4.6 is a minimum requirement to obtain 0.24% leaf P. Further, pH-KCl 4.2 is a minimum requirement for 0.16% leaf P.

4. Results and discussion

4.1 Maize yields and responses to phosphorus fertilizers

In the Kisii area farmers seldom have yields of more than three tons of grains per ha. Guiking (1977) yielded about five to six tons per ha on basalt soils at the Nyanzian Agricultural Research Station at Kisii. Oenema (1978) and Van der Eijk (1978) obtained similar yields on basalt soils, when they applied about 50 - 100 kg P_2O_5 by placement or about 150 kg P_2O_5 by broadcasting and incorporating.

The difference between the yields of the farmers and of the trial fields (also situated at farmers fields), are to be attributed to differences in maize varieties, plant densities, weeding, fertilizer use etc.

Fig. 1 shows preliminary data of yields obtained by Van der Eijk in

March 1978. Apart from phosphorus all fields had received 60 kg N per ha. (Discussing the results of these trials, it should be kept in mind, that these fields were managed much better than the average farmers fields). Three yield levels can be distinguished:

a) Very high yields were obtained on volcanic ashes and on soils with volcanic ash admixtures. Without phosphorus fertilizer yields of 6 to 8 tons proved possible. The effect of phosphorus fertilizer here is mainly a starter effect.
b) The basalt and rhyolite soils take a middle positon. Without phosphorus about 4 tons of maize could be produced; maximum yield increases by phosphorus fertilizer were about two tons.
c) Granite soils gave the poorest yields, being less than one ton per ha when no phosphorus was applied. Yield levels did not flatten off until rates of 600 kg P_2O_5, while on the other soils about maximum yields were obtained already at 150 kg P_2O_5. This points out to a very poor phosphorus status of granite soils. At high phosphorus rates, however, yields hardly surpassed 4 tons. Apparently other factors than phosphorus were yield limiting then.

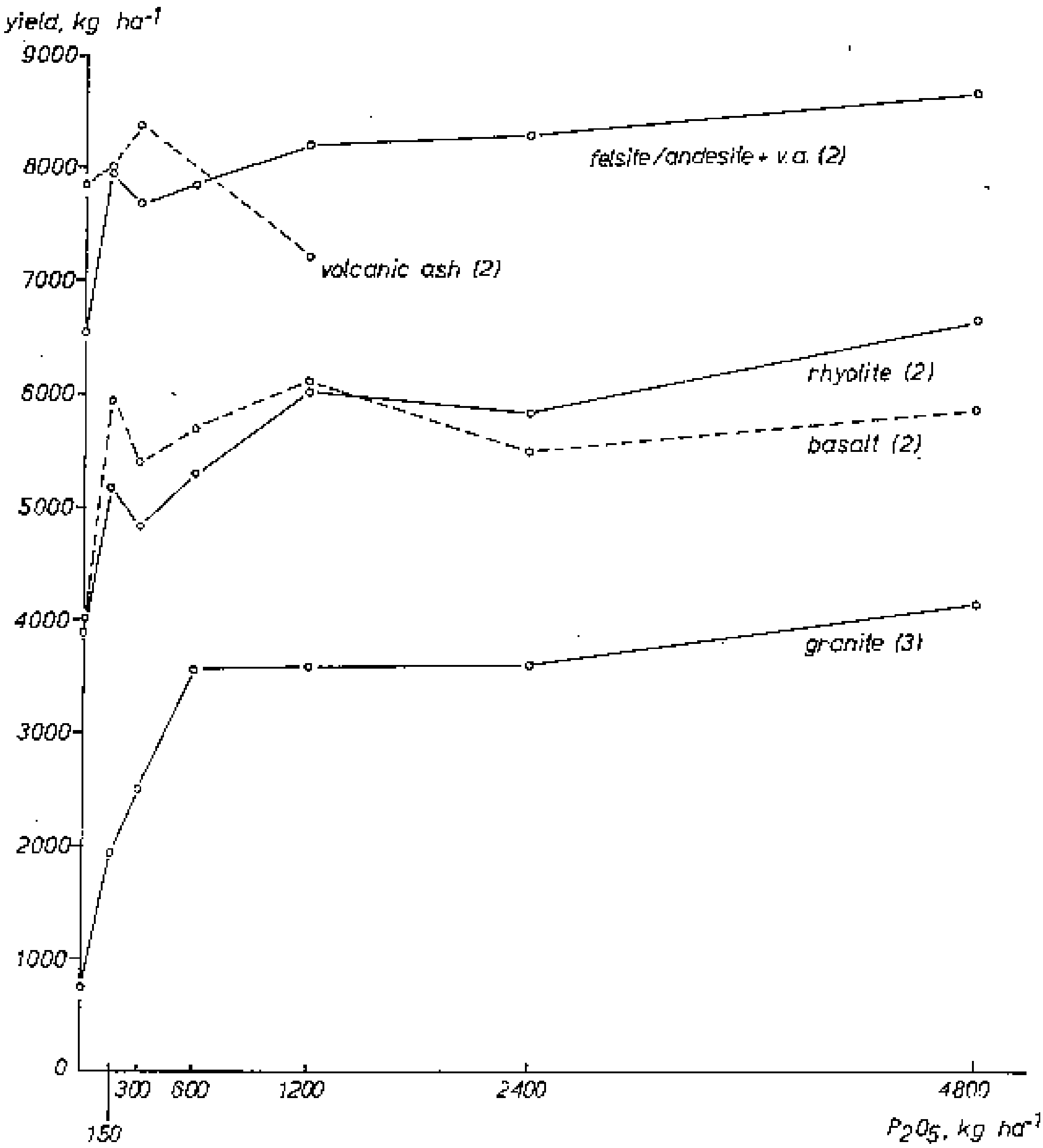

Fig.1 Effect of phosphorus application (broadcasting) on maize yield, averaged per parent material. Between brackets: number of fields. Preliminary data from Van der Eyk, 1978.

4.2 Relationships between leaf nutrient contents and yields

The relationship between leaf P and yield was more distinct than between leaf contents of other nutrients and yield. A schematic picture for N, P and K is shown in Fig. 2. The six curves represent leaf P - yield relationships for different combinations of leaf N and leaf K.

Curves 1 and 4 differ only in leaf N. Nitrogen becomes limiting for curve 4 at yield levels of 7 to 8 tons. To get higher yields extra nitrogen would have been necessary here.

Curves 1 and 2 differ in leaf K. Very high yields can be obtained in both cases, but at the lower K level this requires more phosphorus than at the higher K level. Similarly, the difference existing between curves 4 and 5 can be explained.

Curve 3 connects three points derived from plots on granite soils, that had received 4800 kg P_2O_5. Here other factors prevented yield increases by phosphorus application, so that nitrogen and phosphorus piled up in the plants. Perhaps potassium was deficient, but physical conditions might have been involved as well. The yields of curve 6 were higher than those of curve 3, probably because the imbalance between potassium on the one side and nitrogen and phosphorus on the other side was less severe.

By plotting all available yield data versus leaf N, leaf P and leaf K, respectively, it was tried to find minimum requirements and guarantee values of these leaf nutrient contents needed to yield 2, 4, 6 and 8 tons, respectively. (Extreme situations for P like those of curve 3 in Fig. 2 were disregarded).

A summary of the results is given in Table 1, showing that for leaf P both, minima and guarantees, could be given, but that for leaf N and leaf K only minimum requirements were found.

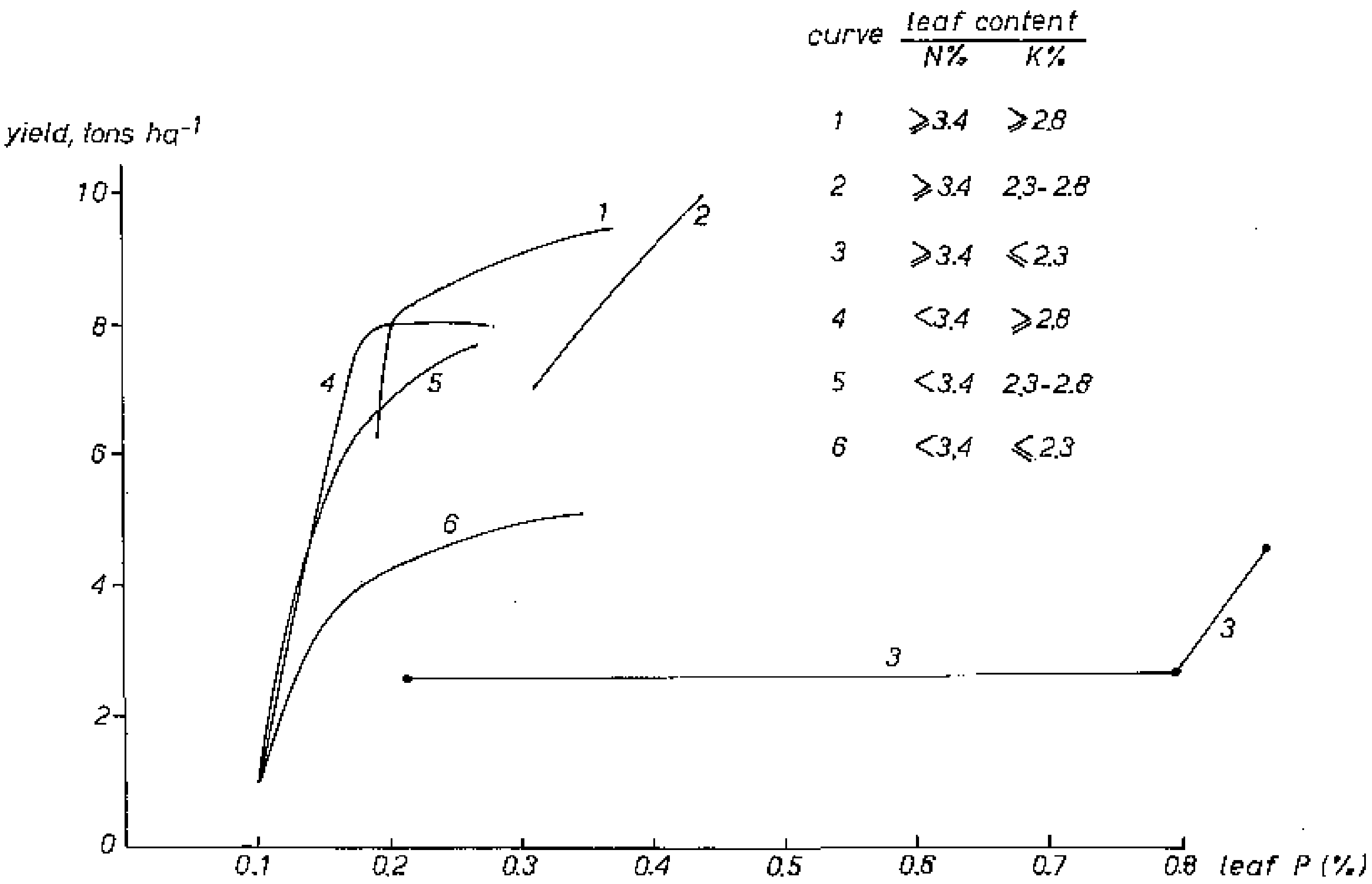

Fig. 2 Schematic relations between leaf P and maize yield for different concentrations of leaf N and leaf K.
Preliminary data from Van der Eyk and Oenema.

Table 1.

Tentative scheme of maize leaf concentrations (%) of N, P and K required as a minimum and as a guarantee, respectively, for different maize yield levels.

Yield levels	2	4	6	8 tons ha^{-1}
leaf N, minimum	2.0	2.5	2.5	3.4
guarantee	?	?	3.4	?
leaf P, minimum	0.12	0.14	0.16	0.24
guarantee	0.16	0.18	0.20	0.35 (?)
leaf K, minimum	2.0 (?)	2.2	2.2	2.8
guarantee	?	?	?	?

Fig. 3 presents the relationship between leaf P and the relative yield increase brought about by placement of 50 kg P_2O_5. If leaf P is more than 0.24%, yield increase is less than 20% of control yield. In such situations it is too hazardous to recommend to apply phosphorus fertilizers.
If leaf P is lower than 0.14%, yield increases are at least 20% of control yield and if leaf P is less thann0.12%, yields can be more than doubled by placement of 50 kg P_2O_5. If leaf P contents are between 0.14 and 0.24%, there is a big chance that considerable yield increases can be obtained, but this is not for sure.

Comparable data for nitrogen and potassium are not yet available.

4.3. Soil fertility classes

Combining the results of Fig. 1 and Fig. 2, four fertility classes were drafted, as mentioned in Table 2.

Class I soils produce 6 tons and class II soils yield 4 tons of maize without any fertilizer, while soils of class III and IV cannot even produce 2 tons of maize without phosphorus application. For all classes it holds that nitrogen and potassium might become limiting, sooner or later, when yields increase as a result of phosphorus application.

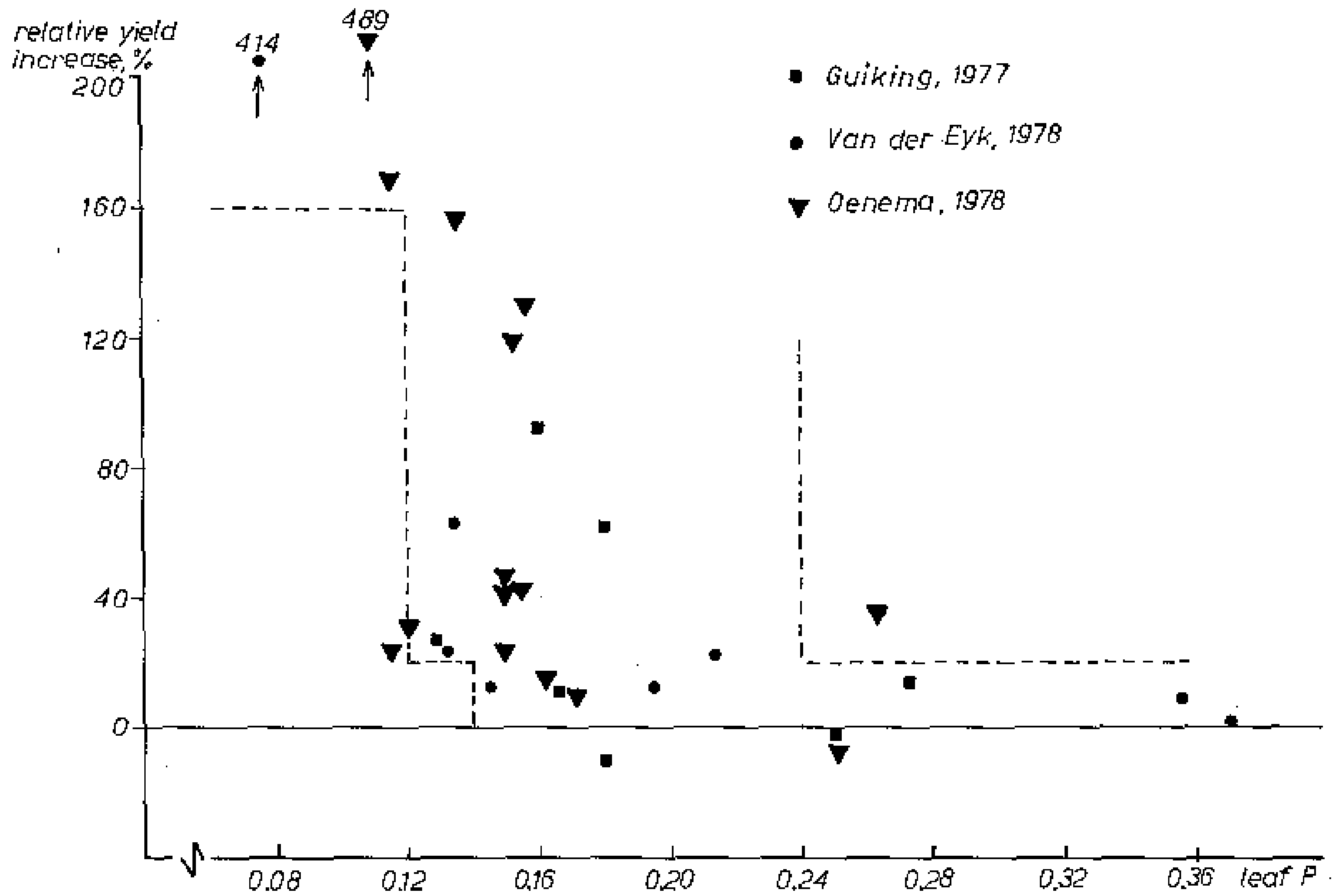

Fig. 3 Relations between yield increase by 50 kg P_2O_5 per ha (placement) and leaf P contents of control plants.

Table 2.

Tentative scheme of fertilizer needs for different maize yield levels and different soil fertility classes.

yield levels	2	4	6	8 tons ha^{-1}
fertility class				
I	-	-	-	N (P)
II	-	-	P	NP (K)
III	P	P	(N) P (K)	NPK
IV	P	NP (K)	N P K	1)

1) not possible because of drought and poor physical conditions

Table 2 shows further that class I and II differ mainly in phosphorus, class II and III in phosphorus, nitrogen and potassium, and class III and IV mainly in potassium and physical conditions.

Class I agrees with the upper curve of Fig. I, class II with the middle curve and class III with some soils of the lower curve. Class IV contains soils that are drought sensitive because of a rather sandy topsoil or because their subsoils are too compact to allow for root growth. It is still questionable whether classes III and IV should remain apart or should be combined.

4.4. Relationships between leaf nutrient contents and soil parameters

In Table 3 the minimum and guarantee values of some soil parameters are given, that are needed to reach certain leaf nutrient contents. The mentioned leaf nutrient contents are the values indicated in Table 1 as minima and guarantees. The soil criteria of Table 3 were derived from graphs like those of Figures 4, 5 and 6.

Fig. 4 shows the mutual relationships between leaf N, organic C, altitude and pH-KCl. A relation between altitude and organic C was already found by Birch and Friend (1956). Organic C certainly exceeds 1.8, 2.2 and 2.8% C, if the soils are located above 1500, 1700 and 1800 m respectively (guarantees). Minimum altitude requirements for organic C contents of 3.2 and 4.0% are 1700 and 1800 m. The graph further shows that pH-KCl values less than 4.2 hardly occur, where organic C is more than 2.6% C or where altitude is more than 1600 m. It should be kept in mind that this is found in maize fields. In coffee fields and especially in tea fields, pH-KCl is lower than in maize fields on comparable soils.

Table 3
Tentative scheme of values of soil parameters, required as a minimum and as a guarantee, respectively, for different maize leaf concentrations of N, P and K.

Leaf N, (%)		2.0	2.5	3.4				
org. C (%)	minimum	?	1.8	2.8				
	guarantee	1.5?	2.2	4.0				
altitude m	minimum	?	?	1800				
	guarantee	1400?	1700	?				
pH-KCl	minimum	?	?	4.3				
leaf P, (%)		0.12	0.14	0.16	0.18	0.20	0.24	0.28
P-Olsen mg P/kg^{-1}	minimum	?	?	?	?	?	?	4
	guarantee	2	4	5	5	6	7	7
pH-KCl	minimum	?	4.0	4.2	4.3	4.3	4.6	
	guarantee	4.2	4.6	5.0	5.0	5.0	5.0	
leaf K, (%)				2.2	2.8			
exch. K, meq per 100 g soil	minimum			0.4	0.4			
	guarantee			0.5	1.5			
$\frac{\text{exch.}}{\text{CEC}}$ x 100%, %	minimum			3	3			
	guarantee			4	8			
maximum yields without application of fertilizer K,		4	6	8 tons ha^{-1}				
exch. K, meq per 100 g soil	minimum	0.4	0.9	1.5				
	guarantee	0.6	1.2	1.8				

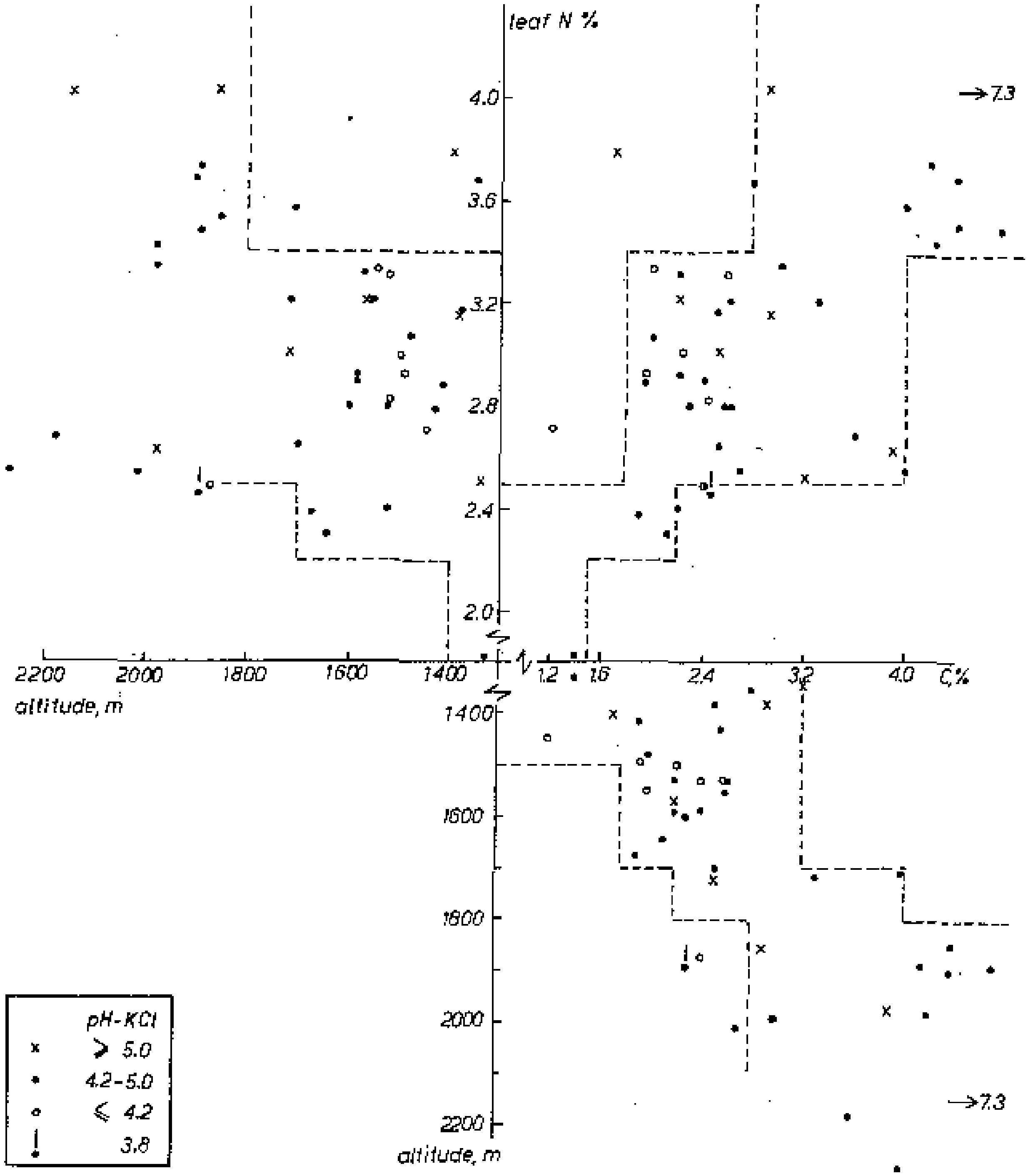

Fig. 4 Relations between altitude, org. C, pH-KCl and maize leaf N content Preliminary data from Duykers, Van der Eyk, Guiking and ter Maat.

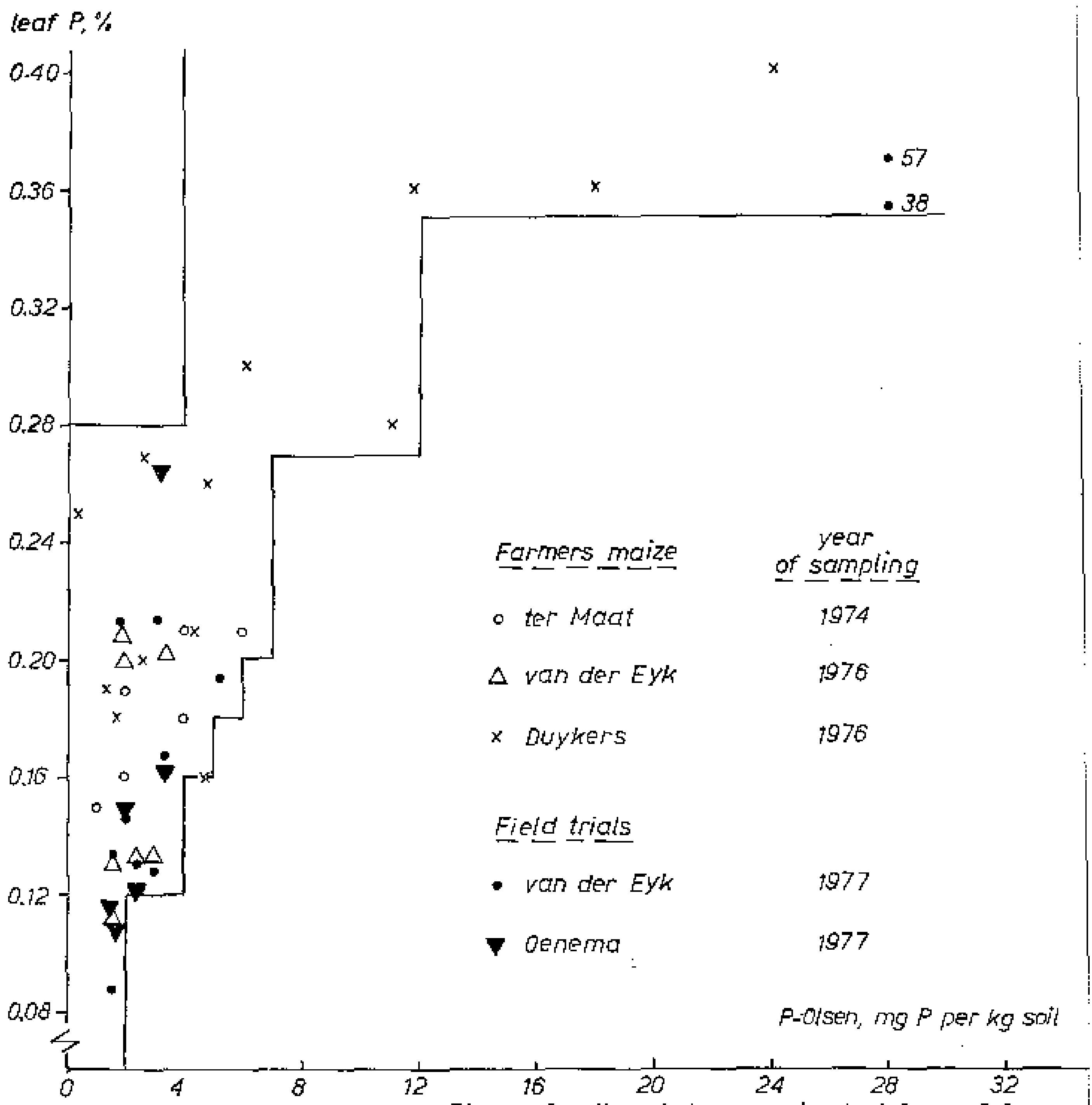

Fig. 5 · Relations between maize leaf P and P-Olsen

The relationship between leaf P and P-Olsen is rather poor (Fig. 5). Guarantee values, but no minimum requirements could be indicated. At very low P-Olsen values, e.g. 1 mg P per kg soil, leaf P might vary between 0.08 and 0.25 % P, which comes down to a range from very deficient to good. Apparently other factors are involved, e.g. pH-KCl. This is shown in Fig. 6, for which the interpretation is given in chapter 3.3.

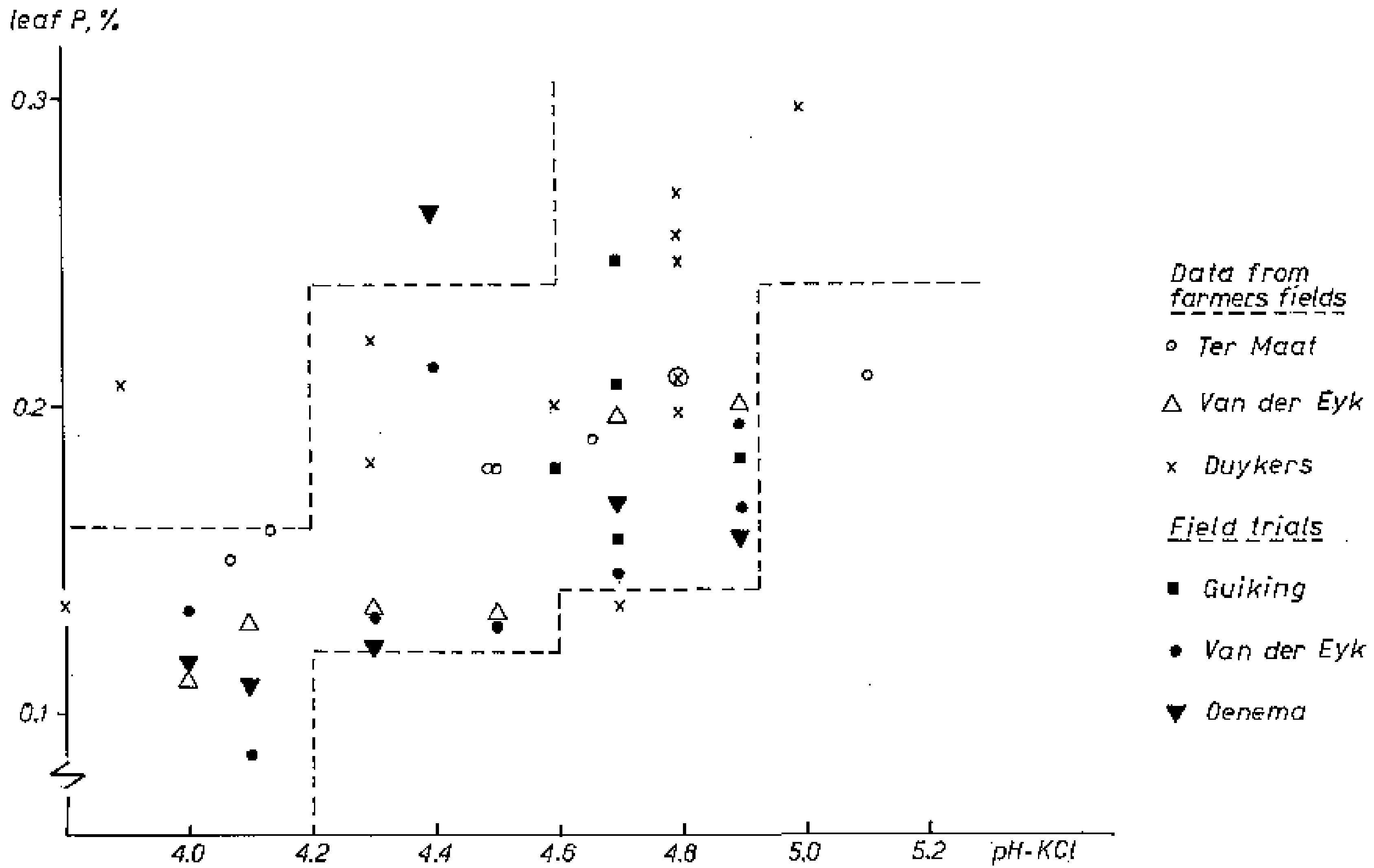

Fig. 6 Relations between maize leaf P content and pH-KCl, for soils having ⩽ 7 mg P per kg soil (Olsen).

There was no clear relation between exchangeable K and leaf K. However, a good relationship was found between maximum yields and exchangeable potassium (Fig. 7). Organic C had some influence on the level of the curves. It is still questionable whether the curves in Fig. 7 are indeed relations between yield and potassium, as it might well be possible that exchangeable potassium and poor physical conditions are confounded.

Inspection of all available data led to the conclusion that, for the time being, four soil parameters could serve as diagnostic characteristics for a soil fertility rating system: organic C, pH-KCl, P-Olsen and exchangeable K. Minimum requirements and guarantee values were found by combining the data of Tables 1, 2 and 3 (Table 4). Let organic carbon contents serve as an illustration of the followed procedure.

Table 4

Tentative scheme of values of soil parameters, required as a minimum (M) and as a guarantee (G), respectively, for soil fertility classes I, II and III

Soil fertility class	I		II		II	
	G	M	G	M	G	M
Org. C %	4.0	1.8	4.0	1.8	4.0	1.8
P-Olsen, mg P kg^{-1}	6	-	5			
pH-KCl	5.0	4.2	5.0	4.0		
exch. K, meq per 100 g	1.8	1.5	1.2	0.9	0.6	0.4

Table 2 tells that class I and class II soils can produce 6 tons of maize without N fertilizers. From Table 1 it is read that for yields of 6 tons, leaf N should be at least 2.5%, while 3.4% leaf N is guarantee. In Table 3 it is found that organic C should be at least 1.8% to get leaf N contents of 2.5%, while 4% organic C guarantees leaf N contents of 3.4%. So, minimum requirements and guarantee values of organic C for soils of class I and II are 1.8 and 4.0% C, respectively.

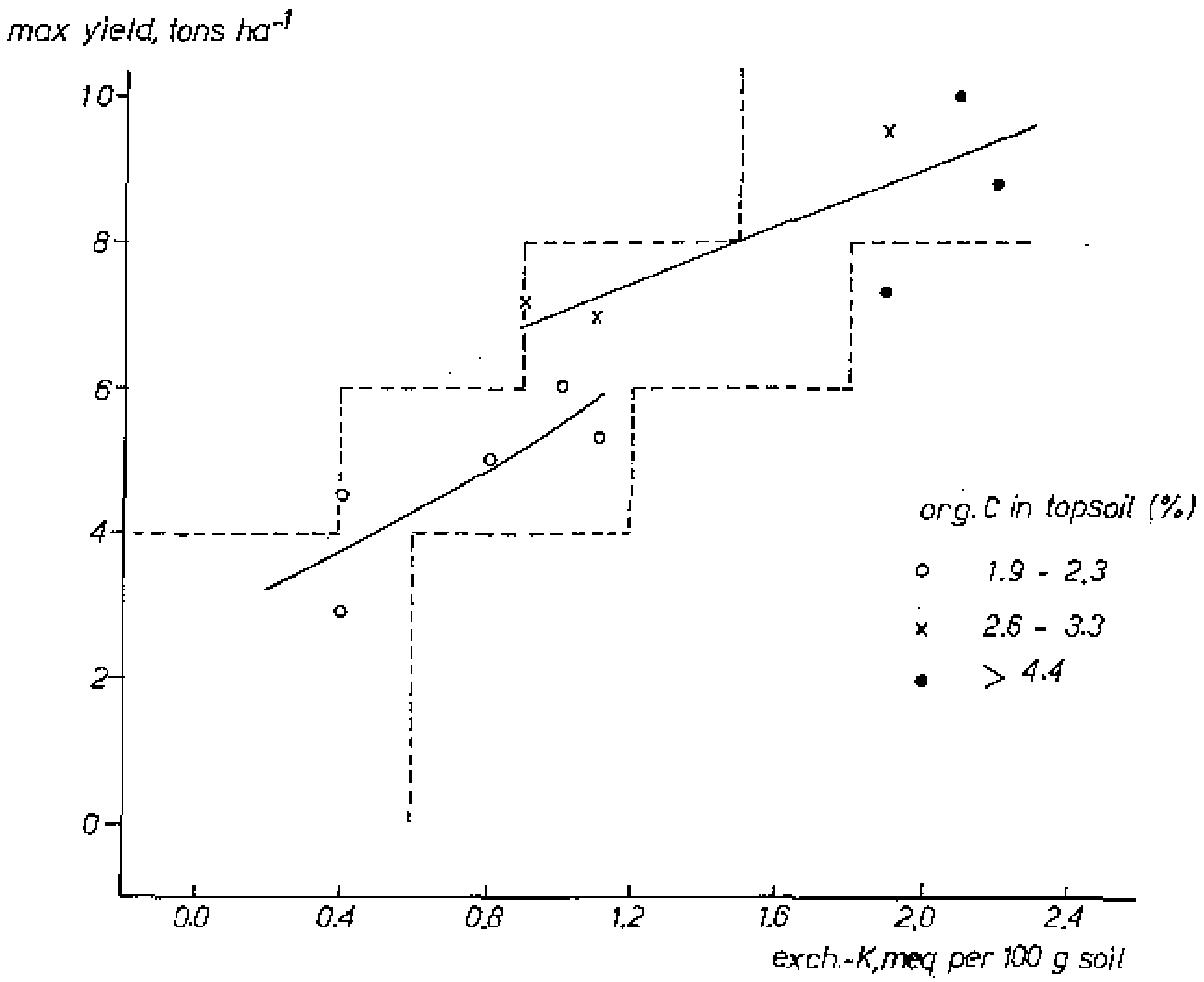

Fig. 7 Relations between maximum yield obtained by phosphorus application, exchangeable potassium and org. C in topsoil (0 - 20 cm).
Preliminary data from Van der Eyk.

Class III soils can yield 4 tons of maize without N fertilizers. This requires at least 2.5 % leaf N. A guarantee value was not (yet?) found, but it probably is less than 3.4% N (see Table 1). This means that the minimum organic C requirement for class III is the same as for class I and class II. A guarantee value cannot be given, but it likely has not to be as high as 4%.

5. Tentative soil fertility rating diagram

In Table 4 the following ranges can be distinguished:

organic C (%)	: < 1.8, 1.8 – 4.0, > 4.0
P-Olsen (mg P per kg)	: < 5 , 5 – 6 , > 6
pH-KCl	: < 4.0, 4.0 – 4.2, 4.2 – 5.0, >5.0
exchangeable K (meq/100 gr)	: < 0.4, 0.4 – 0.6, 0.6 – 0.9, 0.9 – 1.2 1.2 – 1.5, 1.5 – 1.8, >1.8

This means that 3 x 3 x 4 x 7 = 252 combinations of the four characteristics can be made. Fortunately, this number of combinations could strongly be reduced:

a) some combinations are illogical and do not really exist, e.g. low (high) values of pH and high (low) exchangeable K, high organic C and low pH (Histosols are excluded)

b) some combinations have no sense from the standpoint of soil fertility rating, e.g. all soils having less than 1.8% organic C fall in class IV, so that for these soils there is no need for a subdivision according to the other parameters.

It has been tried to combine the diagnostic criteria in one soil fertility rating diagram (Fig. 8). With the present knowledge it is not possible to rate unambiguously each compartment of the diagram. In some cases the present system cannot distinguish even between three soil fertility classes, e.g. legend units 3 and 6 in Fig. 8. This is a clear shortcoming. We have confidence however, that once all data of field trials and soil and crop analysis are available, this still tentative scheme can be refined considerably. This can be done by determining the minimum requirements and guarantee values that are still missing, and/or by introducing auxiliary diagnostic characteristics.

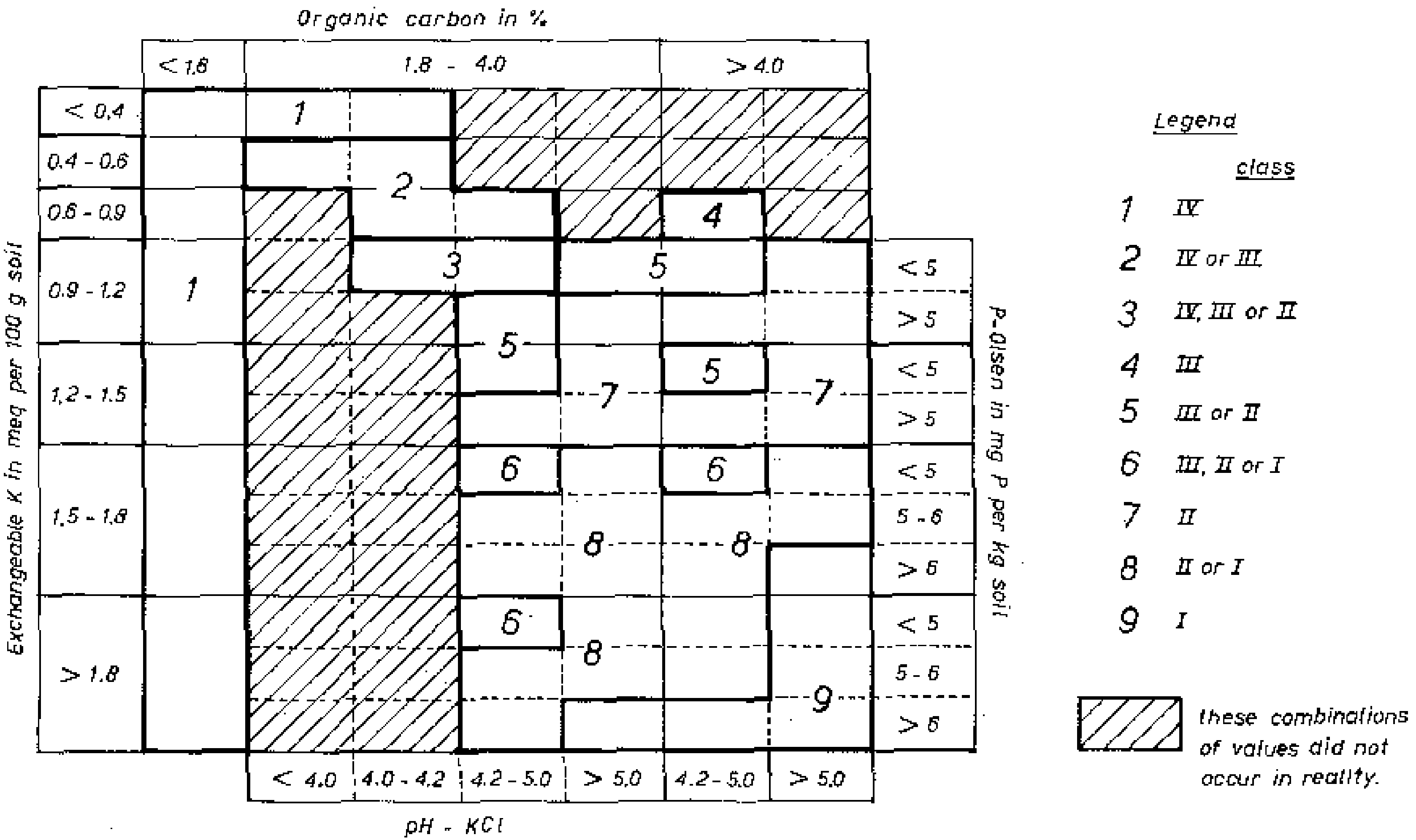

Fig.8 Tentative soil fertility rating diagram for maize.

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