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ASSISTANCE FOR THE PRODUCTION OF PEAT-BASED FERTILIZERS

SI/BDI/78/801

Burundi

Terminal Report

Physical and chemical investigations and evaluation of Burundian peats and soils for the production of peat-based fertilizers

Prepared for the Government of Burundi
by the United Nations Industrial Development Organization
executing agency for the United National Development Programme

Based on the work of F. Gáti
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United Nations Industrial Development Organization
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SUMMARY

The Republic of Burundi is known to be poor in mineral raw materials, the economical and rational utilization of the peat resources and deposits available in the country /about 500 million tons/ are therefore of primary importance.

Peat is currently used in air-dry state and in 2 kg blocks either to produce energy or simply as fuel in households.

Since there are also limestone and phosphate deposits in the country, the idea arose to use these raw materials to turn natural peat into peat-based fertilizers for agricultural application. Most of the country's soils are ferralithic, with low nutrient levels and adverse physical properties. This was also a reason for suggesting the use of peat-based fertilizers as soil amendments.

Several technologies are available to manufacture peat-based fertilizers, but before their introduction in Burundi it had to be determined if the Burundian peats are suitable for the production of peat-based fertilizers and soil amendments or for any agricultural utilization, to what extent and under what limits.

In view of these considerations, pursuant to a proposal by l'Office National de la Tourbe /ONATOUR/, by l'Institut des Sciences Agronomiques de Burundi /ISABU/ and by le Ministere des Travaux Publics, de l'Energie et des Mines, UNIDO invited the specialist to take peat samples in the major peat areas in Burundi /Buyongwe, Gishubi, Gitanga, Kashiru, Kuruyange and Nyamuswaga/ and soil samples from the areas around the peat locations in order to establish the chemical and physical properties of these peats and soils. The specialist performed this task between August 20 and September 19, 1985, and in addition to the peat and

soil sampling, he collected limestone samples from the Mosso area and rock phosphate samples at Matongo.

To analyse the above sample material, UNIDO contracted the Research Institute for Soil Science and Agricultural Chemistry of the Hungarian Academy of Sciences, Budapest, and the Soil Science Department of the Horticultural University, Budapest /Hungary/ with the additional requirement that beyond these analyses, a technical report should be prepared on whether the Burundian peats are appropriate for the production of peat-based fertilizers and soil amendments and on whether improvement may be expected in the adverse physical and chemical properties of the soils and increase the nutrient supply of plants.

The specialist's report has been prepared on the basis of the analytical findings by the Research Institute for Soil Science and Agricultural Chemistry, where the analyses were carried out with the specialist's active participation.

It occurred from the analyses that peats in Burundi are acidic /the pH-value is below 5/ and have high total nitrogen and medium phosphorus and potassium contents /e.g. total N = 1.5-2.15%; P_2O_5 = 0.18-0.27%; K_2O = 0.04-0.25% - See Tables 6, 7, 8, 9/. Burundian peats have satisfactory physical properties and 150-300% water retention capacity in powdered form, under 2 mm particle size. Their hygroscopicity values are 2-5 times higher than those of the soils /hy = 13.67-19.55/.

The soils surrounding the peat areas were also investigated on the assumption that the produced peat-based fertilizers would be applied primarily on soils around the peat locations. These soils were found to be acidic /pH is below 6/, have low nutrient content and low cation exchange capacity /CEC/ /T value = 10-25 meq/ but to possess rather high humus content /2.7-12.9%/ /Tables 3, 4 and 5/. Due to their high humus level, they have a good buffering capacity, which involves that no appreciable reduction in the pH-level occurs even if 100 t/ha peat rates are applied to these soils in case of soil amelioration /Table 15/.

As both soils and peats are acidic, it was of great importance to decide what composition can be ensured for the peat-based fertilizers from the available components of peat, stable manure, limestone powder and rock phosphate and to what extent the pH-value of the mixtures can be adjusted towards the higher pH-levels /Tables 10, 11, 12, 13 and 14/. It has been established that in mixtures of peat and stable manure at variable proportions /2:1, 1:1, 1:2 and 3:1, 1:1, 1:3/, both the nutrient content and pH-level of the mixture rise if the amount of manure component is increased. For example, in case of the peat + manure compost with Serial number 9 in Table 11, if 50 t/ha amendments are applied, 760 kg N, 605 P_2O_5 and 774 kg K_2O can be introduced into the soil and in this case the pH of the mixture is 6.69, i.e. it is close to the neutral 7. Farmyard manure plays an important role in adjusting the pH-level, since its original pH is 8.04, which is very high. As the buffer capacity of peats is low, the pH-level can easily be raised to the desired value by means of manure and limestone powder /e.g.: Table 13 indicates that every 1% limestone added to the peat raises the pH of the mixture by almost one unit/. A similar rise in pH was observed for peat and manure mixtures if limestone powder was added to them /Table 14/.

Another requirement in the manufacture of peat-based fertilizers is that they should not reduce the pH-value of the soil. It was found in the course of analyses that the good buffer capacity of Burundian soils /which is mostly due to their high humus content/ resulted in no appreciable reduction in the soil pH-value if peat and peat + + limestone powder mixtures are applied /Table 15/.

The examination of the pF curves shows that the peat added to the soil improved the moisture regime of the soil, increased the moisture available to plants and influenced the hydraulic conductivity of the soil advantageously /Table 17 and 18, Fig. 1a-1h/.

According to the examination of the buffer effect, it has been shown that the buffer capacity of the soil has a good feature in acid and alkaline medium as well and the peat + stable manure added to the soil improves its buffer properties /Table 19, Fig. 2/.

The results of the experiments conducted with Burundian soils and peats lead to the conclusion that with the application of stable manure, limestone powder and rock phosphate, such peat-based fertilizers can be made from the different peats that can be efficiently used in agriculture, partly as soil amendments and partly as fertilizing medium providing plant nutrients. It may be expected that a part of the imported fertilizers can be replaced by these peat-based fertilizers. A conclusive answer, however, can only be obtained if prior pot experiments and small field plot tests can establish and determine the extent to which the nutrient stock /N, P, K, Ca, Mg and trace elements/ of peat-based fertilizers are available to the plants and to find out if they can reach the same fertilization effect as inorganic fertilizers.

The other important, but open question, is if the profitability of peat-based fertilizers is comparable, and if so, to what extent, to the cost and price factors of inorganic fertilizers. It is substantial that one should be able to demonstrate by way of a cost-benefit analysis what is more economical or less expensive: to produce peat-based fertilizers from local raw materials for the Burundian agriculture or to purchase fertilizers abroad for costly currency. I believe that the truth lies somewhere halfway; on a part of Burundian soils, peat-based fertilizers should in any way be used for amelioration and in areas where this procedure is not imperative and where crops require only low levels of nutrients, one may have recourse to artificial fertilizers.

Pot experiments and small plot field trials will make it possible to work out a kind of low-cost technology by adopting certain parts of the technologies reviewed by the specialist in his earlier reports. The physical and chemical analyses and tests conducted on Burundian soils and peats by the Research Institute for Soil Science and Agricultural Chemistry of the Hungarian Academy of Sciences will provide useful indications in working out this plan.

The specialist takes this opportunity to declare his readiness in providing assistance for both related research and pot and field experimental work and for designing the most profitable technological variant.

I. INTRODUCTION

1. Objective of the investigations

The peats in Burundi, which are generally strongly carbonified, currently are used almost exclusively for heating purposes or to obtain energy. However, the demand has presented itself to use these peats - as peat-based fertilizers - to ameliorate and increase the nutrient supply of these soils.

In order to determine to what extent the Burundian peats are appropriate for soil amelioration and to increase nutrient supply, physical and chemical test and analyses have been conducted on soils typical of extensive areas in Burundi and at major peat locations.

In practice, peats are not used in pure form but are mixed with manure /where there is a shortage of stable manure, fertilizer supplements are applied/. In our experiments the peats were mixed with stable manure in different proportions and we observed the changes occurring in the chemical composition of the mixtures. These investigations help to adjust the mixtures to the desired pH-value and to the required nutrient composition.

We also investigated how the pH-value of the acidic Burundian peats can be enhanced by adding limestone powder. There are large limestone quarries in the country; the use of limestone for this aim seems therefore justified.

The results of our analyses indicate that most of the Burundian soils are acidic. Therefore, it is advisable to produce mixtures containing peat, stable manure, limestone powder and rock phosphate, which increase, or at least do not reduce further the pH of soils and ensure the optimum pH range for crops under the given farming conditions. We carried out tests of this kind and determined the changes in the pH-value of the soils. The role of rock-phosphate was also taken into consideration because the country has large phosphate deposits that could probably be used as substitutes for the imported phosphate fertilizers.

The hygroscopicity and water holding capacity of peats were also determined. From there properties one can infer the changes in the moisture regime of soils if peat or peat-mixtures have been added. The pF-curves of the soils and soil-peat mixtures provide equally valuable data; this examination allows one to determine the amount of moisture available to plants and bound to the soil by osmotic pressure.

The buffer capacity of peat and peat-based mixtures indicates the degree to which soils are capable of counterbalancing the effect of different soil amendments, with particular emphasis on changes in the pH-value.

Based on the experimental results conclusions can be drawn on the possibilities and limiting factors of utilizing Burundian peats for soil amelioration, nutrient supply and thus enhancing crop production.

2. Place of origin of the soil- and peat samples, and method of sampling

According to the specialist's information, samples were taken from the areas adjacent to the peat locations, acting on the assumption that, to avoid excessive transport costs, the peats and amendments made therefrom will primarily be used on these areas. As there was no time to perform the description of the soil profiles and their analysis by genetic horizons and to classify soils accordingly, the soils were named by the specialist according to the place of origin, e.g. Buyongwe, Gishubi, Gisozi /Kuruyange/, Gitanga, Kajondi and Kashiru.

The peat samples were taken from different sites within the major peat locations /Kashiru, Kuruyange, Gishubi, Gitanga, Buyongwe and Nyamuswaga/. The samples were taken from the 0-50 cm and 50-100 cm layers of the five profiles - mutually spaced 20 meters apart on the specified locations, Perimeters A, B, etc. - had been homogenized in order to obtain good average samples from the various sampling points. This allowed us to establish the quality variations of peats in the function of depth and location for the entire area. The location and marking of peat samples are given in Table 1. In addition, average samples were also taken from peat heaps dried to air-dry state in the open.

II. RESULTS

1. Physical and chemical properties of the soils

Table 3 shows the physical properties - specific weight, hygroscopicity /hy/ and particle size distribution - of the soils. There are no significant variations in specific weight from soil to soil /2.6-2.7/. However, their hygroscopicity varies widely /1.94-7.60/, which may be related to their texture and humus content /See Table 4/. The highest hygroscopicity, humus level and NH_4 content were measured in the samples from Gisozi-Kuruyange/ /Ta_3: hy = 7.60; humus = 12.92%; NH_4 = 19.6 ppm/ and from Kashiru at the 0-30 sampling depth /cm/ /Ta_6: hy. = 7.10; humus = 9.76%; NH_4 = 39 ppm/. The obtained results are characteristic of tropical ferralithic soils: The particle size distribution is varied: particles $>$ 0.05 mm and clay fractions $>$ 0.002 mm are present in high proportion, whereas the 0.05-0.02 mm fractions have a lower /2.8-16.1%/ ratio. Their friability in dry state is due to the high sand fraction, while in wet state their heavy texture is the consequence of the medium clay content /0.002$>$ 14-40%/. The soil of Gitanga /Ta_4/ is an exception because this has the highest sand /$>$ 0.05 = 64.9%/ and the lowest clay fraction /0.002$>$ = 14.2%/.

The chemical properties of the soils are given in Table 4 /pH; hydrolytic acidity /y_1/; humus; KCl soluble: ammonia, magnesium, nitrate-nitrite, sulphate; Ammonium-lactate /AL/ soluble: phosphorus, potassium, sodium; EDTA soluble trace elements: zinc, copper, manganese/. It should be noted that all the tested soils are acidic /pH is below 6/, with significant hydrolytic acidity /y_1 above 20/. The soils have a high or in some cases very high humus content, e.g. Gisozi-Kuruyange soil /Ta_3/ /12.92%/, except for the Buyongwe soil /Ta_1, Ta_9/ /3.48% and 2.76%/. The Kashiru soil /Ta_6, 0-30 cm/ has the highest NH_4 /39 ppm/, while the Gisozi-

-Kuruyange /Ta$_3$/ soil has the highest NO_3+NO_2 ion content /66 ppm/. The P_2O_5 content, as determined by the AL-method /ammonium-lactate/, is very low /even the soil with the highest value can only be considered as being poorly supplied according to the Central European standards/. The available K content is also low, with the exception of Buyongwe /Ta$_1$, 0-30 cm/, Gisozi-Kuruyange /Ta$_3$/ and Gitanga /Ta$_4$/ soils /K_2O = 358, 184 and 206 ppm, respectively/. The soils at Buyongwe /Ta$_1$, 0-30 cm and Ta$_9$, 30-60 cm/ and Kajondi are well supplied with magnesium /Mg = 164, 186 and 126 ppm, respectively/. The soils have a medium sodium content /17-41 ppm/. As regards the trace elements, Zn and Cu contents are well balanced, with the exception of Buyongwe /Ta$_1$, 0--30 cm; Zn = 10 ppm/ and Gishubi No. 1 soil /Cu = 17.4 ppm/. The manganese content is exceptionally high in the Buyongwe soils /Ta$_1$, 0-30 cm and Ta$_9$, 30-60 cm/ /Mn = 294.6 and 246.8 ppm, resp./. The sulphate content in the Kashiru /Ta$_6$, 0-30 cm/ and Gitanga virgin /Ta$_7$/ soils /SO_4^{2-} = 6.2 and 7.6 ppm, resp./ is higher by an order of magnitude than in the others.

The low basic saturation /Table 5/ is characteristic of the adsorption relations of soils. The S-value - ranging between 2.94 and 6.03 meq/100 g - reflects the low level of metallic cations. Among the S-values, the Ca cation is dominant /2.1-4.35 meq/100 g/. The T-value, which expresses the adsorption capacity, shows a typical value /10-25 meq/ for ferralithic soils. However, in the case of Buyongwe /Ta$_1$, 0-30 cm/ and Kajondi No 1 /Ta$_5$/ soils lower values /7.03 and 7.07 meq/, while in the Kashiru /Ta$_{10}$; 30-60 cm/ soil higher T-values /44.56 meq/ were measured. The latter very high T-value can be explained by the high clay content of the soil /See Table 3, 0.002> = 51.2%/. The basic saturation coincides well with the hydrolytic acidity value /Table 4/, because the lower the basic saturation of soils /or the higher their level of unsaturation/, the higher the y_1 value is in the soils and conversely.

2. Physical and chemical characteristics of the air-dry average peat samples

Currently, the most extensive exploitation is being carried out at peat areas in Buyongwe, Gishubi, Gitanga, Kashiru and Kuruyange. At these locations, the specialist took 5-10 kg average samples from the extracted and air-dried peat blocks. These air-dry peat samples were used later on /Points 4, 5, 6, 7 and 8/ to prepare peat mixtures.

The physical properties of peats /Table 6/ are characterized by volume weight, water holding capacity and hygroscopicity /hy/. The volume weight does not vary appreciably from peat to peat /0.55-0.68 g/cm^3/. The differences are due to the fact that certain peats are light textured, which is caused by the presence of larger or smaller amounts of papyrus, leaf, reed and root residues. The water holding capacity is not high /217-312%/; this may be explained by the high degree of carbonification. These values are appreciably lower than those typical of peats under the temperate zone /Hungary, Ireland, Finland, etc./, where water retention is higher than 500%, particularly in the case of sphagnum peats.

On the other hand, the hygroscopicity /hy/ of the peats is very good and increases depending on the particle sizes. The hygroscopicity values of the soils /Table 3/ are much lower /1.94-7.10, the average is about 5/. Peat hygroscopicity values are 2-5-times higher than those of soils /13.67-19.55/.

Table 7 comprises the chemical properties of the peats: pH-values, hydrolytic acidity /y_1/, exchange acidity /y_2/, ignition losses /expressing combustible organic matter/, readily available nutrients, trace elements, total sulphur /S/ and sulphates. The data indicate that the peats are acidic /pH is below 5/, their hydrolytic acidity value is very high /above 100/ and exchange acidity is also considerably high /7-23/. This is due to the following: when the exchange acidity is determined, the KCl solution exchanges only the loosely bound H^+ ions of the colloidal part, while in the case of hydrolytic acidity, where Ca-acetate is used for determination - due to alkaline hydrolysis, the more strongly bound hydrolyzable H^+ ions are also exchanged. In tropical soils the hydrolytic acidity is generally /sometimes 10-times/ greater than the exchange acidity, /especially in soils with a high organic matter content/ because the former value includes nonexchangeable hydrogen associated with carboxyl groups and aluminium hydrated oxides as well. When admixing the additives like stable manure, limestone powder, etc., this "hidden" acidity of the peat should be neutralized. The high ignition losses /70-90%/ point to the high organic matter content of peats. Thus, Burundian peats constitute a fuel with high calorific value /3500 Kcal/ for household and industrial usage. The humic acid content of the peat samples is above 30% on the average, showing a strong carbonification. The bound ammonia content of the peats is high /above 164 ppm/; the highest value was observed in the Buyongwe peat /TT_1/ /918 ppm/. The NO_3+NO_2 content was the highest in the Kuruyange peat /TT_5/ /87.8 ppm/. The available phosphorus content of the peats, although still not excessive, may be 10-50 times more than the level of the soil /P_2O_5 = 69-225 ppm/. This component is only 3-6 ppm on the average in soils. The same applies to potassium, e.g. in the Kashiru peat /TT_4/ the K_2O level is 422 ppm, while for the Kashiru soil /Ta_6/ this value is only 57 ppm. In peats the Mg content may be 5-10 times as much as in the soil.

The highest nutrient values /NH_4, NO_3+NO_2, P_2O_5, K_2O, Mg/ were found for the Buyongwe soil /Ta_1/ and peat /TT_1/, which means that the soil near to or under the peat layer and rich in N, P, K and Mg interacts with the chemical composition of the peat located over a depressed terrain.

The trace element composition of the peats and soils is roughly the same, apart from the exceptions mentioned previously in soils /Table 4/. The Gishubi peat /TT_2/ has a very high Mn content /156.2 ppm/, while in case of the other peat samples, this value ranges between 36.8 and 61.2 ppm. The total sulphur content varies between 0.3 to 0.8%, which is a relatively high value in comparison to peats in the temperate zone. However, the readily available sulphate sulphur content is considerably lower than the total S level; e.g. in the Gishubi peat /TT_2/ the total S is 0.8%, SO_4^{2-} content is 83.4 ppm, which is only 1% of the total S content. The sulphate content of peats may exceed that of soils by 1-2 orders of magnitude /e.g.: Buyongwe peat /TT_1/ SO_4^{2-} = 258 ppm, while for Buyongwe soil /Ta_1, 0-30 cm/ SO_4^{2-} = 0.4 ppm. /

3. Chemical properties of peat samples taken in situ

In Tables 8 and 9 we indicate the chemical characteristics of the peat samples T_1 to T_{99}.

Table 8 shows the total nitrogen /N/, phosphorus /P_2O_5/, potassium /K_2O/, calcium /Ca/ and magnesium /Mg/ contents of the peat samples. The total N content of all peat samples is very high, about equal to the total N content of the studied stable manure /See Table 11/, while their phosphorus, potassium, calcium and magnesium contents are well below the levels found in the manure. Mixing Burundian peats with stable manure is justified partially by the differences in their nutrient contents and by the need to adjust the pH level adequately for soil amendments containing peat and manure /see Tables 11 and 14/, besides the biological effect, which is not subject to this report.

Table 9 gives the chemical characteristics of 49 peat samples /pH, ignition losses - combustible organic matter -, easily available nutrient-, trace element-. and sulphate content/. The pH-values of the freshly taken peat samples are lower than in case of the air-dry average samples /Table 7/. The ignition losses were determined after drying the samples at 105 °C. /It should be noted that the other elements are also expressed in percentage of the dry matter/. The ignition losses of peats from all the six areas, irrespective of the sampling depth, are extremely high /70-93%/, which indicates a high organic matter content. In the peat samples from Gitanga, Buyongwe and Nyamuswaga /T 57 - T 99/ the NH_4 content is higher in the 50-100 cm, than in the 0-50 cm layer. No such tendency could be observed in either layer for the NO_3+NO_2 content. It was found that the phosphorus content was the highest in samples from the Kashiru peat area /T 1 - T 11/ /reaching even 633 ppm/. This value is much lower for other samples, with the exception of the 50-100 cm layer of the Gishubi Perimeter A /T 39/ sample, where the P_2O_5 content is by far the highest /1320 ppm/. The potassium content is also the highest in the latter /2740 ppm/, while the Mg-, sodium- and zinc content is 798, 236 and 16.2 ppm, respectively. Magnesium reaches its highest level in samples originating from Kashiru and Buyongwe /T 77 - T 87/. As for trace elements, copper and zinc are present in about the same levels as in the air-dry average peat samples /Table 7/. The very high value of Mn /above 100 ppm/ was obtained for the Buyongwe peat area /T 77 - T 87/. The SO_4^{2-}-sulphur is slightly more abundant in freshly taken peat samples than in the air-dry average peat samples /Table 7/.

4. Chemical properties of mixtures containing peat, stable manure and limestone powder

Mixtures containing different proportions of peat, manure and limestone powder were prepared to study their chemical composition. Table 10 gives the components of these mixtures and their ratios.

Table 11 shows the total nitrogen, phosphorus, potassium, calcium, magnesium and readily available nitrogen contents for the air-dry average peat samples /TT 1 - TT 5/, the stable manure /I/ and the peat and manure mixtures /K 1 -

- K 15/, as well as for mixtures of Kashiru peat with limestone powder and manure /KL 1 - KL 3/. It can be noted that the total nitrogen content of the stable manure /I/ is slightly lower than that of the peats /TT 1 - TT 5/, but stable manure has higher levels of P, K, Ca, Mg and readily available N. The Buyongwe peat /TT 1/ has an outstandingly high total N content /2.83%/ and its readily available N content is also the highest /575 ppm/. The N content of the mixtures decreases with the increase in the rate of added stable manure, which is due to the high N content of peats. As regards the other elements, their proportion increases as more and more stable manure is admixed /1:1, 1:2 ratios/.

For mixtures containing limestone powder /KL 1, 2 and 3/, as it was expected, there is a proportional increase in the calcium content.

In Table 12 the general chemical properties of the stable manure, the mixtures of peat and stable manure and the mixtures containing limestone powder are shown. Stable manure has the highest pH /8.04/, therefore the pH level of the mixtures rises with higher admixture rates of manure. The stable manure was produced on a Hungarian dairy farm, from straw bedding; it was a ripe, slightly soily stable manure.

The organic matter content of the stable manure is 50.86%, while in peats it is 70-90% /Table 7/. Therefore, the mixtures reflect the decreasing quantity of organic matter as more and more manure is added. The drop of the ammonia /NH_4/ level in mixtures also appears to be logical, since the NH_4 content of peats is higher /164-198 ppm/ than that of the stable manure /134 ppm/ /Table 7/. The high NH_4 content /918 ppm/ of the Buyongwe peat /TT1/ is reflected in the NH_4-values of the mixtures K 1, K 2 and K 3. As regards the other elements and compounds /P_2O_5, K_2O, Mg, Na, Zn, Cu, Mn and SO_4^{2-}/, they are found in larger amounts in stable manure than in peats, consequently, their levels are also higher in mixtures if the manure admixture rates are increased.

This tendency suggests that, in order to increase the nutrient supply of Burundian peats, it is worthwhile to mix peats with stable manure. The level of manure admixture rates are, of course, adjusted to the available quantity of stable manure. The higher the proportion of stable manure is in the mixture, the more advantageous it is. The peat-stable manure ratio should be at least 1:1 in the mixture.

5. Changes in the pH-values of mixtures containing peat, manure and limestone powder

When producing peat-based fertilizers and soil amendments, it is imperative to know what changes take place in the pH-value of the mixture containing peat and limestone powder, i.e. to what extent does the limestone powder increase the overall pH-value.

For that purpose, we prepared mixtures of different compositions /Table 13/ by using the air-dry average peat samples from the five major peat areas /Buyongwe, Gishubi, Gitanga, Kishuru and Kuruyange: TT 1 - TT 5/. Finely powdered /$<$ 1 mm/ limestone - from the Mosso site in Burundi - was used for the experiment.

Table 13 indicates that with the increase in the applied quantity of limestone powder, the pH of the mixture increases, that is, pH-values of peats can be raised. By adding 4 weight units of limestone powder to 100 weight units of peat, the pH-value increases from the original 4 to 6.5--7.5. If 8 units of limestone are added, the pH-level can even reach about pH 11.

According to the data of Table 14, stable manure alone can increase the pH of the mixture, but if limestone powder is also added, a pH-value higher by a unit can be reached. Its value can even be raised above 8, like in case of the Buyongwe /TT 1/ No. 10 mixture.

Based on our results the conclusion can be drawn that the pH level of peat-based mixtures can be substantially increased by the admixture of stable manure or limestone powder and of stable manure + limestone powder. The appropriate level of pH can be adjusted by producing a mixture that does not reduce soil pH and, in addition, ensures an optimum pH-level for the crops.

6. Changes in the pH-values of mixtures composed of soil, peat, limestone powder and rock phosphate

As peat-based fertilizers are primarily utilized in soil amelioration, it is imperative to investigate the effect of peat, limestone powder, peat + limestone powder and peat + + limestone powder + rock phosphate on the pH of soils. To conduct this experiment 5 peats /Buyongwe - TT_1, Gishubi - TT_2, Gitanga - TT_3, Kashiru - TT_4 and Muruyange - TT_5/ and soils adjacent to the peat areas /Buyongwe - Ta_1, Gishubi - Ta_2, Gisozi-Muruyange - Ta_3, Gitanga - Ta_4, Kajondi - Ta_5 and Kashiru - Ta_6/ were selected and amendment mixtures were added at rates usually adopted in practice.

In practice the applied rates and quantitites of amendments are generally referred to the upper 15-30 cm soil layer. In terms of one hectare, a 20 cm soil layer is calculated to weigh 3 million kg. In practice, the following peat, limestone powder and rock phosphate quantities are generally added to this amount of soil:

Soil kg	Peat	Limestone powder	Rock phosphate
		t/ha	
3 000 000	10	0.1	1
	25	0.25	
	50	0.5	
	75	0.75	
	100	1	

Our model experiment /based on the above mentioned/ was performed with 30 g soil, and the amendment rates were adjusted accordingly /Table 15/. The amount of applied peat reached the maximum 100 t/ha level. We were rather careful with limestone powder, we set the upper limit at 1 t/ha. The limestone rates, which were 1% as compared to the peat, seemed to be low for soils, while the limestone powder applied at 1-8% levels in our former experiments /Table 13/ resulted in considerable pH changes, reaching even pH 11. This phenomenon might be explained by the poor buffering capacity of Burundian peats as opposed to the high buffering capacity of the soils. The pH of the peats increased by one unit as a response to a limestone admixture as low as 1% /Table 13/. On the other hand, as it is shown in <u>Table 15</u>, there was almost no change in pH when 1% limestone powder was added to the soil directly or after mixing with peat. The pH change induced by the application of rock phosphate was also negligible. It should be noted that in determining the 1/ha rock phosphate rate, our starting point was that the P_2O_5 content of the Matongo phosphate is 11.24% /Table 21/; thus one ton contains 112.4 kg P_2O_5, which is a medium phosphate fertilizer level in practical soil fertilization.

According to the data we may conclude that even large amounts /50-100 t/ha/ of peats can be applied for amelioration purposes without any risk, because, due to the high buffer capacity of the soils, there is no danger of the soils turning acidic.

Occasionally it might be necessary to raise soil pH by adding limestone powder, particularly if plants require a higher pH level /above 6/. <u>Table 16</u> shows how the pH-values of soils change if 1-20 t/ha limestone rates are applied. The well established practice of liming temperate region soils to neutrality is not effective in most of the highly weathered soils of the tropics. More often than not, liming to pH 7 causes more harm than good. Many tropical crops are well adopted to acid soil conditions; frequently, they do not respond to lime as better known crops do.

7. Hydrophysical properties /water retention /pF/ curves; saturated hydraulic conductivity/ of soils and soil-peat mixtures

For the characterization of hydrophysical properties of Burundi soils water retention /pF/ curves and saturated hydraulic conductivity values /K = cm/day/ were determined in 6 soil samples /Ta_1, Ta_2, Ta_3, Ta_6, Ta_7, Ta_8 - See Table 1/. The influence of various Burundi peats on the above mentioned hydrophysical characteristics were studied in the following soil-peat mixture combinations:

Serial number	Soil	%	Peat	%
1	Ta_8	100	TT_2	-
2	Ta_8	90	TT_2	10
3	Ta_8	80	TT_2	20
4	Ta_8	60	TT_2	40
5	Ta_7	100		-
6	Ta_7	90	TT_4	10
7	Ta_7	80	TT_4	20
8	Ta_7	60	TT_4	40
9	Ta_2	100		-
10	Ta_2	90	TT_1	10
11	Ta_2	80	TT_1	20
12	Ta_2	60	TT_1	40

The measured numerical data of water-retention /pF/ curves of 6 soils and 9 soil-peat mixtures were summarized in Table 17, and their characteristic saturated hydraulic conductivity ranges are given in Table 18. The determined pF-curves are illustrated in Figures 1a - 1 h. Water retention data were determined at pF 0; 0.4; 1.0; 1.5; 2.0; 2.3; 2.7; 3.4; 4.2 and 6.2. In Table 17 measured particle density and bulk density values were also tabulated, as well as the total porosity /Pr: calculated from particle density and bulk density/. The available moisture range /AMR/ values were calculated as the difference between the moisture content /in volume percentage/ at pF 2.5 /1/3 atmosphere percentage: taken from the graphically illustrated pF-curves /Figure 1a-1h// and pF 4.2 /wilting point, 15 atmosphère percentage/. These AMR values are also given in Table 17. for the soils and soil-peat mixtures studied.

The following conclusions can be drawn on the basis of our measurements:

a/ Soils.

- The bulk density of the studied soils is very low /with the exception of Ta_1, it remains below 1 g/cm^3/, and shows a strong negative correlation with the organic matter content. The lowest bulk density /0.7-0.8 g/cm^3/ was measured in Ta_3 and Ta_6 soils with a high organic matter content /10--13%/. The "highest" bulk density /1.18 g/cm^3/ was determined in the Ta_1 soil with low /3.5%/ organic matter content. Because there are no significant differences in the particle density of various soils /Table 3/, the calculated total porosity increases with decreasing bulk density /Table 17/.

- The volumetric moisture content at pF 0 /full saturation/ is similar to total porosity in most cases. There is no indication of swelling /pF $0 > P_T$/ and the saturation was imperfect only in a few cases /pF $0 < P_T$/, e.g. in Ta_2 and Ta_1 soil samples. In these cases the moistening of soil is a slow process and limited by entrapped air.

- The pF curve is determined by the total porosity /~ bulk density/ in the low suction range. With increasing suction the influence of the specific surface /determined by particle size ← texture, clay content, organic matter content/ becomes more and more significant, and finally dominant. Within the high suction range /pF ≧ 2.3/ the retained moisture content shows a strong positive correlation with the organic matter content /e.g. Ta_3/ and/or clay content /e.g. Ta_2/.

- The AMR /calculated as the difference between pF 2.5 and pF 4.2/ is highest in Ta_6 and Ta_3 soils with a high organic matter content, due to their very high field capacity. The AMR is somewhat lower in the Ta_1 and Ta_7 soils - due to their lower field capacity /← lower organic matter content/, and in the Ta_2 soil - due to its higher wilting percentage /← higher clay content/.

- The saturated hydraulic conductivity is high in the studied soils because of their low bulk density, high porosity, and particularly due to their considerable gravitational porosity /large pores/. K values are within the range of 120-140 cm/day in Ta_2, Ta_6, Ta_7 and Ta_8 soils. This is unfavourably high from the viewpoint of water storage and water retention. A considerable amount of water, falling to the soil surface, percolates very rapidly down to the deeper horizons through the large pores existing among the slowly and imperfectly moistened soil particles. These "filtration losses" decrease water-use efficiency and limit the adequate moisture supply of plants and crops. In the Ta_3 soil the saturated hydraulic conductivity is lower due to high water retention /← high organic matter content/, in the Ta_1 soil due to lower gravitational porosity. K-values in both cases are within the range of 10-25 cm/day /Table 18/.

b/ Soil-peat mixtures

Different amounts of peats were mixed to the soils and the changes in their hydrophysical properties were registered as follows:

- The increasing amounts of peats decreased the average particle density and bulk density of the mixture; there was no significant change in total porosity; and increased the water retention in the high suction range /pF = 3.4/ /Table 17/.

- 10% peat was the most efficient dosage in all cases. It considerably increased field capacity /+5-15%/, only moderately increased the wilting percentage, and as a consequence the AWR also increased /+4-12%/.

- Under the influence of increasing peat dosages these favourable effects do not increase. Just in the contrary: the high amounts of peats /which are not acceptable in practice/ result in an increase in wilting percentage, which leads to - in several cases - a decrease in AWR /Table 17/.

- Increasing amounts of peats decrease gravitational pore-space and consequently the saturated hydraulic conductivity /Table 18/. But the moistening of peat particles is very slow. Therefore, in the first period of wetting a considerable quantity of water percolates very rapidly to the deeper layers through the large gravitational pores /: filtration losses/.

8. Examination of the buffer effect of mixtures containing peat and manure

Titration curves characterize the effect of the acid and base on the sample. Addition of acid and base changes the pH-value of the total sample, depending on the properties of its constituents. Thus the buffering property and buffering mechanism can slo be evaluated using the titration curves /Table 19 and Figure 2/.

The behaviour of the Kajondi soil /Ta$_5$/ shows that the increase in the applied amount of acid/base results in smaller and smaller pH-decrease/increase, the slope of the curve decreases monotonously. From the viewpoint of amelioration, the righ side of the curve is more important, which shows how much base of lime is necessary to reach a preselected pH-value. The most favourable feature of the soil is that the smallest amount of base results in the highest pH-increase.

The behaviour of the peat is quite different. The peat is strongly acidic, its original pH is below 4.5. The acid/ /base treatment does not lead to considerable changes, the pH-decrease/increase is slight, the curve is almost linear in the wide concentration range. The reason is that the organic matter content is very high and it contains different components which are able to hydrolyze and as a consequence of this, they are able to neutralize the acid/base. This means that amelioration with this peat only is practically impossible because too much lime would have to be used and at the same time it would result in a slight pH-increase only.

The behaviour of the stable manure is very favourable. It also shows very slight pH-changes in the wide concentration range, but its most important feature is that it is situated in the pH-range above 7.0. The pH-decrease/increase is slight, the curve is almost linear. The slope of the line is smaller than that of the peat, which means that the buffer capacity of the stable manure is stronger than that of the peat. If the stable manure is considered to be an amendment of acid soils, its behaviour caused by the acid treatment has particular importance. It has been found that the stable manure can neutralize the acid very well, meanwhile its pH hardly decreases. For this reason stable manure can be used for amelioration.

The titration curve of the mixture of 0.165 g stable manure and 0.165 g peat and 10 g Kajondi soil /Ta$_5$/ was also determined. This is equivalent to the application of 50 t stable manure and 50 t peat per hectare. The curve demonstrates that amelioration is very effective. The pH of the original soil is increased by 0.9 pH-unit, which is remarkable. By this increase the pH of the soil reaches 6.0. The advantage of this pH-value is that the release of aluminium from soils and aluminium toxicity problems cannot be expected; this limiting factor of soil fertility is eliminated. The addition of base to the mixture gives slightly smaller pH-increases than in case of the original soil, nevertheless, the application of lime for further amelioration of the mixture is easier.

It can be concluded that the application of 50 t stable manure and 50 t peat per hectare for amelioration proved to be very effective and it may be suggested for practical use.

9. The quality of the limestone powder and rock phosphate and the possibilities of their utilization in peat-based fertilizers

Limestone powder and rock phosphate constitute essential components of the peat-based fertilizers, their chemical composition was therefore analysed and is presented in Tables 20 and 21.

The analytical data indicate that the limestone powder at Mosso, besides $CaCO_3$, contains CaO and MgO as well, mainly in hydroxide form. This property explains the high level of alkalinity of the limestone powder. The addition of 1-8% limestone powder increases the pH levels of acidic peats considerably /Table 13/. When added in small rates to mixtures containing peat and stable manure /1-2%/ the pH of the composition rises above 7 /Table 14/. Admixing this mixture to the soil, the pH of the latter is only slightly enhanced, which is due to the strong buffer effect of the soil /Table

15/. We also observed the changes in the pH when limestone powder was added to the soil at a rate of 1-20 t/ha /Table 16/. Considering these experimental data, an optimum limestone powder dosage can be selected that may be utilized in peat-based fertilizers without leading to the acidification of soils.

The most typical feature of rock phosphate at Matongo is its low P_2O_5 /11.24%/ and high $CaCO_3$ contents /7.42%/. Phosphate is suitable for being used as a component in peat-based fertilizers. In this way phosphorus is introduced into the soil on the one hand, while on the other, due to its $CaCO_3$ content, one can raise the Ca-level of the acidic soils poor in Ca and with a ferralythic character. If added to peat, the acidic peat is capable of dissolving the phosphorus content of the rock phosphate, whereby phosphorus becomes readily available to plants.

III. EVALUATION

A great number of physical and chemical analyses have been carried out in order to verify the suitability of Burundian peats to ameliorate and increase the nutrient supply of the soils. Based on the results of our investigations, the following conclusions may be drawn:

1. Burundian peats are strongly carbonified /near the lignification stage/. They are therefore used as fuels to obtain energy. In addition, these peats are rather acidic /pH-value = below 5/ and have a high sulphur content /total S = 0.4-0.8%/.

Previously suggestions and proposals had been made to produce peat-based fertilizers for soil amelioration purposes. In fact, the specialist was informed that the Institut des Sciences Agronomiques de Burundi /ISABU/ had already conducted small plot field experiments with peat and stable manure compost. On certain extracted areas of the peat fields reclamation experiments were also performed, with a view to recover these areas for farming.

The data of our investigations confirm the possibility that Burundian peats may be utilized under certain limited conditions, it seems advisable for the Office National de la Tourbe /ONATOUR/ and ISABU to go on with their previous experiments.

2. The physical and chemical properties of the Burundian soils /Tables 3, 4 and 5/ are typical of tropical ferralithic soils. The soils have an acidic character /with pH below 6/, high hydrolytic acidity /y_1 = between 20 and 90/ and medium humus content /3-6%/. In certain soils, like Gisozi-Kuruyange /Ta_3/ and Kashiru soil /Ta_6, 0-30 cm/ the organic matter content can reach and even exceed 10%. These soils are very poorly supplied with potassium and phosphorus, their

trace element content is on an average level /Zn, Cu and Mn/, the sum of their exchangeable metallic cations /S-value/ is low /below 6 meq/ and, except for the Kashiru soil /30-60 cm/, their adsorption capacity is below 25 meq. Their basic saturation is low.

These data clearly show that a partof the soils studied require amelioration and that it is necessary to implement a nutrient supply system that meets with the requirements and conditions of "soil-improving" fertilization. This involves that the application of peat-based fertilizers on Burundian soils is justified if it is possible to produce mixtures and composts of such composition and quality that, in addition to physically improving soils, ensure an adequate pH and quality and quantity of nutrients required by the plants.

3. Burundian peats are characterized well by the average samples we have collected at the major peat areas /Buyongwe - TT_1, Gishubi - TT_2, Gitanga - TT_3, Kashiru - TT_4 and Kuruyange - TT_5/ and dried to air-dry stage in peat heeps /Tables 6, 7 and 11/. According to the analyses the peats are very acidic /pH below 5/, have a high hydrolytic /y_1/ and exchange acidity /y_2/. They are abundant in organic matters /70-90%/. They are conspicuously relatively well supplied with nutrient elements /total N, P, K and available N, P, K and Mg/, and their trace element content is on the average level. The total sulphur /S/ content of the peat is high /0.3-0.8%/ and their sulphate content is higher by 1-2 orders of magnitude than that of the soils. The water holding capacity was established to be sufficient, but not high. It was 2-3 times higher in terms of dry peat weight, particularly if the peat was in a powdered state /$<$ 2 mm/.

Peat hygroscopicity values /hy/ are 3-5 times higher than those of the soils. These fairly good physical features indicate that peats, as soil amendments, are capable of ameliorating the physical properties of soils and of enhancing their moisture regime.

In addition, large quantities of nutrients /nitrogen, phosphorus and potassium/ can also be introduced into the soils by means of peat, which is an important aspect too. If an average rate of peat /50 t/ha/ is added to the soil, this involves the supply of the following nutrient rates to the soil, calculated on the basis of Table 11.

	Nitrogen N, kg	Phosphorus P_2O_5, kg	Potassium K_2O, kg
Buyongwe peat /TT_1/	1 415	183	139
Gishubi peat /TT_2/	815	126	73
Gitanga peat /TT_3/	885	149	79
Kashiru peat /TT_4/	950	92	36
Kuruyange peat /TT_5/	970	114	36

Burundian soils can thus become well supplied with nitrogen if peats are added. Peats, however, contain less phosphorus and potassium; provisions can be made for these elements by making /e.g. peat + stable manure compost/ a mixture to supply the soil with 605 kg P_2O_5 and 774 kg K_2O at an application rate of 50 t/ha compost, if the mixture specified in Table 11 /Serial number 9/ is used. Phosphorus may also be supplied through the rock phosphate of Matongo, which has a low P_2O_5 content /11.24%/ but represents a local phosphate source at least /Table 21/.

It is not advisable to use peats in their original wet state. The moisture content of the freshly extracted peat might even exceed 80%, which makes it uneconomical to transport it over large distances. In addition, if the freshly mined peat turns dry in the field, it does not become friable even under atmospheric effect; but keeps its shape as stone hard clog with such a low hygroscopicity and water holding capacity that it is unable to exercise its ameliorative property. The hygroscopicity and water retention data given in

Table 6 apply only particle sizes smaller than 2 mm. It is recommended therefore to chop up peats dried to air-dry stage and to comminute them to particles < 2-3 mm. Peats with such particle size /or powdered/ may be applied alone in certain exceptional cases as amendments, however, the most viable alternative is to prepare mixtures containing stable manure, limestone powder and rock phosphate as well.

4. The samples /T 1 - T 99/ of the six largest peat areas /Kashiru, Kuruyange, Gishubi, Gitanga, Buyongwe and Nyamuswaga, Table 2/ were taken from the 0-50 cm and 50-100 cm layer. These samples provide a fairly good average picture on the chemical composition of Burundian peats. Table 8 shows the total N, P, K, Ca and Mg contents, while Table 9 illustrates the pH, organic matter content, readily available nutrients, trace elements and sulphate content. It appears from the tables that there are no essential differences among peats from the various areas. There is a scatter in values of certain elements /e.g. pH, ignition losses, NH_4^+, P_2O_5, K_2O, trace elements, etc./ of peats originating from the same area. However, one should not infer from this that, e.g. the upper or lower 50 cm layer is better, or that a peat on a certain area is better than one on another. It may be concluded that peats from all areas can be used to produce peat-based fertilizers, even those peats in which the fibrous structure of the papyrus fibres are recognizable. The layers composed uniquely of papyrus fibres are, of course, not recommended for soil amelioration.

5. Particular emphasis should be laid on the investigations carried out with mixtures containing stable manure, limestone powder and rock phosphate /Tables 10, 11, 12, 13, 14, 15 and 16/. In these tests the following peat-stable manure mixtures were used: 2:1, 1:1, 1:2 /Tables 10, 11 and 12/ as well as 3:1, 1:1, 1:3 /Table 14/. Since the nutrient levels

in the stable manure /P, K, Ca, Mg, with the exception of N/ are higher than in the peats, the increasing amount of stable manure raises the overall nutrient content of the mixture /apart from N of course/. In our view however, a ratio of at least 1:1 should be ensured for the peat - stable manure mixture because the higher ratio of manure can contribute to the development of microbiological activity in the soil. To detect this effect, it would be suitable to carry out the relevant microbiological testing as well. Data from Tables 11 and 12 might provide a basis for the production of peat-based fertilizers, which in turn might help to select the desired quality and quantity, as well as type of mixtures.

Limestone powder was added to the peat in 1-8% rates and the changes in the pH of the mixture were observed /Table 13/. It could be clearly established that even a low admixture /3-4%/ of limestone powder resulted in a considerable pH rise, which is due to the poor buffer capacity of the Burundian peats. The same was experienced when stable manure and peat were mixed. It could, however, be proved that by applying low rates of limestone powder /1-2%/, the pH level of the peat + organic manure mixtures can be significantly increased /to above 7/ /Table 14/.

6. By adding mixtures of peat, limestone powder and rock phosphate to the soil, unexpected results are obtained. It follows from the data in Table 15 that the soils have such a high buffer capacity that their pH value is not appreciably raised even if 100 t/ha peat are applied; the same is valid in case 1 t/ha limestone powder is applied. The same holds for the application of peat + limestone powder mixture. These findings suggest that the physical and chemical analysis of peat, stable manure and other components /e.g. rock phosphate/ can only be used to estimate the optimum composition of peat-based fertilizers and about the rates and ratios /t/ha/ of the mixtures produced to be applied in crop production. Since

Burundian peats possess a substantial amount of plant nutrients, the composition of the peat-based fertilizers can be chosen to satisfy the nutrient requirements of the plants.

It is likely that the admixture of the Matongo phosphate to the Burundian acidic peats promotes the solubility of phosphorus; the use of rock phosphate in peat-based fertilizers is justified. The other advantage of Matongo phosphate is that it contains about 7.42% $CaCO_3$, which seems to favour the improvement of Ca level in the soil, and in consequence, it promotes the supply of Ca for the plants. In case the soils are limed, the rate of limestone powder application may be reduced because a part of the limestone powder can be replaced by the $CaCO_3$ in the rock phosphate. The only disadvantage of the Matongo phosphate is its low P content /P_2O_5 = 11.24%/, i.e. 1 t of Matongo phosphate contains only 112.4 kg P_2O_5. In view of this, it should be applied in great amounts to the soil in order to attain a medium phosphorus level.

7. Mixing 10% peat to the soils results in favourable changes in their hydrophysical properties: the field capacity /pF 2.5/ was increased by 5-15%: the available moisture range /AMR/ /pF 2.5 - pF 4.2/ by 4-12% /Table 17/; the original very high saturated hydraulic conductivity was moderated /Table 18/. In these variants a greater part of water filtrates into, and is stored within the soil and becomes available to plants. The evaporation and/or filtration losses are reduced, which lead to increasing water-use efficiency, more stabilized soil moisture regime, with much less probability of extreme situations /surface runoff, water-logging, over-wetting — drought sensitivity/.

Higher rates of peat application are not recommended. Not only because of economical considerations /high costs/, but because of their unfavourable consequences. In these cases the AMR decreases, due to the increase of wilting percentage, and, a considerable amount of water filtrates to the deeper horizons through the large pores formed among the very slowly moistened peat particles / filtration losses/.

8. On the basis of the buffer titration curves it can be concluded that the application of the peat- stable manure mixture for amelioration of the Kajondi soil /Ta_5/ proved to be effective and it can be recommended in practice.

Our investigations, performed with the specialist's active participation, converge to the conclusion that it is possible to produce peat-based fertilizers from Burundian peats and that these products affect the chemical and physical properties of the soils fayourably. For the numerical assessment of these effects, pot culture and small plot experiments and tests should be carried out, in addition to the considerations of our results and findings. The usual routine experiments are insufficient since Burundian peats have special properties. A specific experimental procedure should thus be developed. Now that our Institute has an active part in the physical and chemical investigation of Burundian peat and soil samples, we offer our continued cooperation in both preparing the experimental procedure and plan and in the analyses that might become necessary. Since the specialist has taken part in the Burundian project from its start and has given permanent technical reports on the work, with which we are in agreement, we propose the specialist to carry out the pot cultural and field small plot experiments in Burundi.

Table 1. Place of origin of soils

Serial number	Sample	Place of origin
1	Ta_1	Buyongwe 0-30 cm /under avogado tree/
2	Ta_2	Gishubi No. 1
3	Ta_3	Gisozi-Kuruyange /soil cultivated/
4	Ta_4	Gitanga /soil cultivated/
5	Ta_5	Kajondi No. 1 /champ de blé/
6	Ta_6	Kashiru 0-30 cm
7	Ta_7	Gitanga /soil virgin/
8	Ta_8	Kajondi /soil virgin/
9	Ta_9	Buyongwe 30-60 cm /under avogado tree/
10	Ta_{10}	Kashiru 30-60 cm

Table 2. List of peat samples

Serial number	Sample	Place of origin	Site	Depth /cm/
			of sampling	
1	T_{1}	Kashiru	Perimetre B	0-50
2	T_{3}	"	Perimetre B	50-100
3	T_{5}	"	Perimetre D	0-50
4	T_{7}	"	Perimetre D	50-100
5	T_{9}	"	Perimetre E	0-50
6	T_{11}	"	Perimetre E	50-100
7	T_{13}	Kuruyange	Perimetre A_{1}	0-50
8	T_{15}	"	Perimetre A_{1}	50-100
9	T_{17}	"	Perimetre A_{2}	0-50
10	T_{19}	"	Perimetre A_{2}	50-100
11	T_{21}	"	Perimetre B_{1}	0-50
12	T_{23}	"	Perimetre B_{1}	50-100
13	T_{25}	"	Perimetre B_{2}	0-50
14	T_{27}	"	Perimetre B_{2}	50-100
15	T_{29}	"	Perimetre C_{1}	0-50
16	T_{31}	"	Perimetre C_{1}	50-100
17	T_{33}	"	Perimetre C_{2}	0-50
18	T_{35}	"	Perimetre C_{2}	50-100
19	T_{37}	Gishubi	Perimetre A	0-50
20	T_{39}	"	Perimetre A	50-100
21	T_{41}	"	Perimetre B	0-50
22	T_{43}	"	Perimetre B	50-100
23	T_{45}	"	Perimetre C	0-50
24	T_{47}	"	Perimetre C	50-100
25	T_{49}	"	Perimetre D	0-50
26	T_{51}	"	Perimetre D	50-100
27	T_{53}	"	Perimetre E	0-50
28	T_{55}	"	Perimetre E	50-100
29	T_{57}	Gitanga	Perimetre A	0-50
30	T_{59}	"	Perimetre A	50-100
31	T_{61}	"	Perimetre B	0-50
32	T_{63}	"	Perimetre B	50-100
33	T_{65}	"	Perimetre C	0-50
34	T_{67}	"	Perimetre C	50-100
35	T_{69}	"	Perimetre D	0-50
36	T_{71}	"	Perimetre D	50-100
37	T_{73}	"	Perimetre E	0-50
38	T_{75}	"	Perimetre E	50-100
39	T_{77}	Buyongwe	Perimetre A	0-50
40	T_{79}	"	Perimetre A	50-100
41	T_{81}	"	Perimetre B	0-50
42	T_{83}	"	Perimetre B	50-100
43	T_{85}	"	Perimetre C	0-50
44	T_{87}	"	Perimetre C	50-100
45	T_{89}	Nyamuswaga	Perimetre A	0-50
46	T_{91}	"	Perimetre A	50-100
47	T_{93}	"	Perimetre B	0-50
48	T_{95}	"	Perimetre B	50-100
49	T_{97}	"	Perimetre C	0-50
50	T_{99}	"	Perimetre C	50-100

Table 3. The main physical properties of the soils

Serial number	Sample	Specific weight	Hygro-scopicity hy	Particle size distribution, %; particle size, mm						
				>0.25	0.25-0.05	0.05-0.02	0.02-0.01	0.01-0.005	0.005-0.002	0.002 >
1	Ta_1	2.79	1.94	12.1	36.3	12.9	6.8	2.8	5.6	23.5
2	Ta_2	2.76	4.39	16.1	20.5	8.1	6.0	6.5	8.4	34.4
3	Ta_3	2.60	7.60	14.5	6.0	15.3	16.1	12.5	10.9	24.7
4	Ta_4	2.64	4.34	31.4	33.5	8.1	5.6	3.6	3.6	14.2
5	Ta_5	2.63	3.18	8.9	38.3	3.6	7.6	3.6	6.8	31.2
6	Ta_6	2.54	7.10	20.2	23.4	10.9	10.5	6.8	6.0	22.2
7	Ta_7	2.69	4.14	8.9	32.7	7.3	1.2	3.2	6.5	40.2
8	Ta_8	2.68	3.30	14.1	36.7	6.0	3.6	4.2	7.6	27.8
9	Ta_9	2.67	2.10	15.3	31.4	8.9	7.3	3.2	8.1	25.8
10	Ta_{10}	2.62	5.30	9.3	18.1	4.4	8.1	-	8.9	51.2

Table 4. The main chemical properties of the soils

Serial number	Sample	pH /H_2O/	y_1 **	Humus %	NH_4	NO_3+NO_2	P_2O_5	K_2O	Mg*	Na	Zn	Cu	Mn	SO_4^{2-}
					ppm									
1	Ta_1	5.93	22.87	3.48	13.0	20.0	36	358	164	41	10.0	5.2	294.6	0.4
2	Ta_2	4.98	42.12	6.52	14.4	8.2	6	82	.	25	1.0	17.4	52.0	0.6
3	Ta_3	4.03	91.75	12.92	19.6	66.0	24	184	26	24	5.0	4.2	76.3	1.4
4	Ta_4	5.26	38.62	7.44	7.8	10.8	5	206	36	30	1.0	3.2	17.4	1.8
5	Ta_5	5.51	26.87	4.92	14.6	6.0	2	72	126	17	1.0	5.0	7.8	1.6
6	Ta_6	4.64	90.62	9.76	39.0	3.8	6	57	26	29	1.8	2.4	27.6	6.2
7	Ta_7	4.77	-	4.80	15.6	4.8	4	24	14	24	1.2	5.6	5.4	7.6
8	Ta_8	5.34	-	5.24	19.8	2.2	3	50	40	20	0.8	2.8	10.0	0.2
9	Ta_9	5.57	-	2.76	12.8	6.2	7	56	186	37	3.0	5.0	246.8	0.2
10	Ta_{10}	4.55	-	6.12	15.0	5.4	5	36	.	36	2.2	2.6	9.8	0.2

Remarks:

* . = no determination was possible owing to the low amount of sampling material

** y_1 values were not determined for samples 7-10.

Table 5. Cation exchange capacity of the soils

Serial number	Sample	Ca	Mg	K	Na	S-value	T-value	Basic saturation %
		meq/100 g soil						
1	Ta_1	4.35	0.63	0.56	0.09	6.03	7.03	85.77
2	Ta_2	2.60	0.52	0.065	0.043	3.23	10.33	31.58
3	Ta_3	3.10	0.52	0.33	0.043	3.99	22.28	17.92
4	Ta_4	2.10	0.52	0.29	0.043	2.95	9.78	30.19
5	Ta_5	3.60	0.52	0.065	0.043	4.23	7.07	59.80
6	Ta_6	2.10	0.52	0.032	0.049	2.70	23.37	11.55
7	Ta_7	3.04	0.51	*	0.032	3.58	24.46	14.60
8	Ta_8	2.10	2.10	0.035	0.032	4.30	22.28	19.30
9	Ta_9	3.60	2.10	0.035	0.15	5.90	19.02	31.02
10	Ta_{10}	3.60	*	*	0.09	3.69	44.56	8.28

* in traces

Table 6. Physical properties of the air-dry average peat samples

Serial number	Sample	Place of origin	Volume weight g/cm^3	Water retention capacity %	Hygroscopicity /hy/ by particle size		
					< 2 mm	2 mm	2-3 mm
1	TT_1	Buyongwe	0.62	312	14.56	15.61	15.83
2	TT_2	Gishubi	0.64	224	15.29	1[illegible].48	19.46
3	TT_3	Gitanga	0.68	217	13.67	16.87	17.09
4	TT_4	Kashiru	0.56	220	15.50	19.06	19.55
5	TT_5	Kuruyange	0.55	274	14.80	16.73	16.75

<u>Table 7.</u> Chemical properties of the air-dry average peat samples /expressed in percentage of the air-dry matter/

erial umber	Sample	pH /H_2O/	y_1	y_2	Ignition losses %	NH_4	NO_3+NO_2	P_2O_5	K_2O	Mg	Na	Zn	Cu	Mn	SO_4^{2-}	Total S %
						ppm										
1	TT_1	4.62	164.5	12.0	78.70	918	37	134	723	782	144	14.4	2.8	54	258	0.4
2	TT_2	4.20	188.7	16.5	82.01	226	32	66	325	394	47	6.2	6.0	156	83	0.8
3	TT_3	4.40	144.5	22.25	71.19	250	12	69	82	214	27	4.2	5.0	36	139	0.5
4	TT_4	4.27	147.0	7.6	90.88	164	52	202	422	504	63	6.4	6.4	76	83	0.3
5	TT_5	4.20	219.0	20.5	86.46	220	87	225	642	540	67	7.2	7.8	61	129	0.3

Table 8. The total nitrogen /N/, phosphorus /P_2O_5/, potassium /K_2O/, calcium /Ca/ and magnesium /Mg/ content of the peat samples /expressed in percentage of the dry matter/

Serial number	Sample	N	P_2O_5	K_2O	Ca	Mg
				%		
1	2	3	4	5	6	7
1	I 1	1.72	0.25	0.22	0.17	0.14
2	3	1.63	0.23	0.13	1.03	0.11
3	5	1.79	0.18	0.12	-	0.05
4	7	1.76	0.23	0.16	0.22	0.08
5	9	2.15	0.23	0.07	-	0.03
6	11	1.75	0.30	0.24	0.21	0.23
7	13	1.67	0.23	0.15	-	0.03
8	15	1.67	0.25	0.16	0.10	0.04
9	17	1.68	0.25	0.15	0.02	0.05
10	19	1.72	0.21	0.12	-	0.03
11	21	1.66	0.21	0.08	-	0.04
12	23	0.84	0.11	0.04	-	0.01
13	25	0.90	0.16	0.04	0.22	0.03
14	27	1.55	0.21	0.07	0.29	0.05
15	29	1.62	0.21	0.04	-	0.02
16	31	1.79	0.18	0.04	-	0.07
17	33	1.61	0.21	0.07	0.16	0.05
18	35	1.72	0.18	0.06	0.01	0.06
19	37	1.93	0.18	0.10	0.02	0.03
20	•	•	•	•	•	•
21	41	1.79	0.16	0.04	0.04	0.05
22	•	•	•	•	•	•
23	45	1.77	0.25	0.11	-	0.05
24	47	1.86	0.21	0.05	0.02	0.05
25	49	1.80	0.27	0.13	0.94	0.08
26	51	1.56	0.23	0.21	0.80	0.19
27	53	1.93	0.25	0.06	0.05	0.05
28	55	1.60	0.18	0.04	0.01	0.05
29	57	1.57	0.32	0.05	-	0.03
30	59	1.53	0.18	0.03	0.03	0.10
31	61	2.00	0.25	0.04	0.01	0.04
32	63	1.72	0.27	0.08	-	0.05
33	65	1.54	0.18	0.17	-	0.03
34	67	1.41	0.18	0.12	0.01	0.06
35	69	1.94	0.25	0.04	-	0.05
36	71	1.71	0.23	0.12	0.33	0.09
37	73	2.13	0.30	0.05	0.02	0.04
38	75	2.07	0.21	0.04	0.02	0.03

Table 8. /Cont./

1	2	3	4	5	6	7
39	77	1.77	0.23	0.29	0.04	0.09
40	79	1.75	0.21	0.24	0.01	0.07
41	81	1.99	0.23	0.31	0.04	0.08
42	83	1.65	0.16	0.21	-	0.09
43	85	1.76	0.23	0.12	0.03	0.08
44	87	1.89	0.16	0.15	0.20	0.12
45	89	1.72	0.23	0.16	-	0.03
46	91	1.68	0.21	0.11	-	0.03
47	93	1.49	0.30	0.12	-	0.09
48	.	.	.	.	.	.
49	97	1.71	0.25	0.25	-	0.04
50	99	1.81	0.23	0.13	-	0.06

Remarks:

. = No determination was possible, owing to the low amount of sample material

Table 9. Chemical properties of the peat samples /expressed in percentage of the dry matter/

Serial number	Sample	pH /H_2O/	Ignition losses %	NH_4	NO_3+NO_2	P_2O_5	K_2O	Mg	Na	Zn	Cu	Mn	SO_4^{2-}
				ppm									
1	2	3	4	5	6	7	8	9	10	11	12	13	14
1	T 1	4.32	93.09	•	•	591	1050	•	160	•	•	•	•
2	3	5.46	92.30	194	74.8	268	596	822	132	•	•	•	388
3	5	4.12	83.88	174	12.6	60	176	324	64	4.4	4.0	39.0	108
4	7	4.46	86.62	282	44.0	176	320	612	99	•	•	•	256
5	9	3.66	91.03	236	4.8	70	197	224	49	7.6	7.2	31.6	118
6	11	6.00	89.50	142	131.2	633	1230	720	166	14.2	7.0	66.6	792
7	13	4.14	84.29	154	7.6	13	126	108	36	5.2	7.4	28.8	128
8	15	4.60	84.59	232	60.0	155	412	298	57	•	•	•	268
9	17	4.23	80.91	280	51.8	215	516	488	76	•	•	•	240
10	19	3.96	85.42	250	11.8	12	112	96	28	6.6	4.4	25.4	132
11	21	3.94	87.06	242	10.2	11	120	212	44	7.6	3.6	49.2	164
12	23	3.94	88.18	170	7.6	12	152	160	42	•	•	•	108
13	25	4.59	82.20	250	140.0	118	435	316	74	•	•	•	373
14	27	4.76	95.41	•	4.8	47	182	•	51	•	•	•	73
15	29	3.94	90.60	138	6.6	4	57	114	33	4.2	5.2	27.2	72
16	31	3.77	89.38	288	5.8	13	55	176	33	5.2	3.6	40.6	179
17	33	4.59	91.20	310	71.6	192	430	412	71	7.0	4.6	47.6	288
18	35	3.87	89.26	284	6.4	11	57	258	42	9.6	8.0	68.4	248
19	37	3.71	87.72	378	139.4	•	•	356	•	12.4	4.4	110.4	424
20	39	4.99	91.24	226	308.0	1380	2740	798	236	16.2	5.0	79.4	400
21	41	3.66	90.62	308	26.6	•	•	334	•	4.2	11.4	62.8	224
22	43	3.92	90.77	290	6.4	58	63	268	47	6.6	8.0	62.6	188
23	45	4.02	68.03	164	6.0	35	81	190	47	3.2	3.2	61.8	155

Table 9. /Cont./

1	2	3	4	5	6	7	8	9	10	11	12	13	14
24	T 47	3.75	88.21	314	11.4	16	73	268	51	5.4	8.4	74.6	256
25	49	5.53	72.28	206	58.0	156	466	522	96	8.2	8.2	64.0	548
26	51	5.89	91.65	166	66.8	305	699	692	165	20.6	8.4	136.2	936
27	53	4.04	85.66	168	13.4	38	90	286	55	8.2	9.4	63.0	228
28	55	3.81	92.94	180	12.8	10	54	324	43	.	.	.	332
29	57	3.76	82.03	76	4.6	41	109	242	44	12.0	1.8	25.0	640
30	59	3.74	89.42	192	3.4	4	63	714	47	7.6	2.6	142.0	712
31	61	3.81	87.36	102	5.4	15	111	238	69	11.0	3.4	61.6	376
32	63	3.06	81.96	120	31.2	8	113	258	84	21.6	2.4	71.2	2396
33	65	3.75	80.16	190	21.8	31	107	216	47	8.0	3.6	55.0	428
34	67	3.95	85.52	246	4.4	17	79	532	69	5.6	9.6	90.2	608
35	69	3.60	73.64	212	7.4	53	52	282	35	14.4	4.2	69.2	1084
36	71	4.40	90.76	278	69.8	312	720	616	102	15.0	9.4	82.8	612
37	73	3.94	75.58	204	5.8	27	141	208	60	7.8	7.0	58.0	404
38	75	3.67	88.36	218	4.4	26	97	178	46	5.8	2.0	54.6	460
39	77	3.89	72.74	320	56.2	43	465	624	116	25.0	8.6	112.6	1096
40	79	3.57	75.86	322	3.6	3	152	486	81	18.8	4.2	100.4	948
41	81	3.78	76.07	248	164.6	44	592	796	150	25.8	6.4	102.0	804
42	83	3.87	74.33	262	5.6	7	105	568	64	22.4	7.2	170.8	632
43	85	3.61	77.25	270	20.4	37	174	792	83	21.6	4.6	200.6	1184
44	87	3.87	86.33	298	3.0	1	115	1056	89	7.0	4.4	272.6	872
45	89	4.25	74.47	114	3.6	7	59	192	38	3.6	5.6	72.0	232
46	91	3.86	81.92	218	4.2	20	42	218	38	5.4	5.6	58.4	300
47	93	4.25	50.01	188	17.2	18	484	468	64	8.0	5.4	88.8	404
48	95*												
49	97	4.03	72.04	172	4.8	37	138	260	49	4.2	9.4	49.2	284
50	99	4.01	75.48	228	8.6	31	148	344	57	3.8	5.6	81.2	316

Remarks: * Sample was missing; . = No determination was possible, owing to the low amount of sample material.

Table 10. Mixtures of air-dry average peat samples and stable manure

Serial number	Sample	Peat and stable manure mixture	Proportion
1	K_1	Buyongwe peat /TT_1/ + stable manure /I/	2 : 1
2	K_2	" "	1 : 1
3	K_3	" "	1 : 2
4	K_4	Gishubi peat /TT_2/ + stable manure /I/	2 : 1
5	K_5	" "	1 : 1
6	K_6	" "	1 : 2
7	K_7	Gitanga peat /TT_3/ + stable manure /I/	2 : 1
8	K_8	" "	1 : 1
9	K_9	" "	1 : 2
10	K_{10}	Kashiru peat /TT_4/ + stable manure /I/	2 : 1
11	K_{11}	" "	1 : 1
12	K_{12}	" "	1 : 2
13	K_{13}	Kuruyange peat /TT_5/ + stable manure /I/	2 : 1
14	K_{14}	" "	1 : 1
15	K_{15}	" "	1 : 2
16	KL_1	Kashiru peat /TT_4/ + 1% $CaCO_3$	
17	KL_2	Kashiru peat /TT_4/ + stable manure /I/ 1:1 + 1% $CaCO_3$	
18	KL_3	Stable manure /I/ + 1% $CaCO_3$	

Table 11. Total nitrogen /N/, phosphorus /P_2O_5/, potassium /K_2O/, calcium /Ca/, magnesium /Mg/ and easily available nitrogen contents of mixtures of air-dry average peat samples and stable manure and limestone powder
/expressed in percentage of the dry matter/

Serial number	Sample	N	P_2O_5	K_2O	Ca	Mg	Easily available N, ppm
				%			
Peat							
1	TT 1	2.83	0.37	0.28	0.02	0.14	975
2	2	1.63	0.25	0.15	-	0.07	174
3	3	1.77	0.30	0.16	-	0.03	203
4	4	1.90	0.18	0.07	0.03	0.10	181
5	5	1.94	0.23	0.07	-	0.04	261
Stable manure							
6	I	1.52	1.74	2.20	1.74	1.16	1144
Mixtures of peat and stable manure							
7	K 1	2.15	0.82	0.98	0.52	0.49	1179
8	2	1.87	0.98	1.28	0.91	0.62	1303
9	3	1.77	1.19	1.49	1.30	0.80	1349
10	4	1.55	0.76	0.97	0.50	0.45	729
11	5	1.60	0.94	1.22	0.83	0.57	981
12	6	1.66	1.21	1.60	1.37	0.78	1129
13	7	1.65	0.76	0.82	0.22	0.40	634
14	8	1.64	0.96	1.11	0.69	0.58	864
15	9	1.52	1.21	1.55	1.19	0.82	1104
16	10	1.77	0.71	0.85	0.66	0.48	680
17	11	1.68	0.98	1.26	1.12	0.70	1024
18	12	1.63	1.28	1.60	1.48	0.80	1125
19	13	1.72	0.76	0.85	0.58	0.42	705
20	14	1.71	0.96	1.23	0.97	0.58	968
21	15	1.51	1.21	1.52	1.16	0.81	1107
Mixtures containing limestone powder							
22	KL 1	1.78	0.16	0.07	0.59	0.33	196
23	2	1.65	0.94	1.08	1.78	1.24	954
24	3	1.62	1.65	2.17	3.10	1.54	1304

Table 12. Chemical properties of the stable manure, the mixtures of peat and stable manure and the mixtures containing limestone powder /expressed in percentage of the dry matter/

Serial number	Sample	pH /H_2O/	Ignition losses %	NH_4	NO_3+NO_2	P_2O_5	K_2O	Mg	Na	Zn	Cu	Mg	SO_4^{2-}
							ppm						
1	I	8.04	50.8	134	292	9080	12700	1296	680	72	7.8	192	1236
2	K 1	5.81	63.8	702	203	1940	4380	882	371	54	5.6	144	720
3	2	6.30	55.9	498	234	3440	6600	940	580	57	6.2	158	860
4	3	6.59	46.9	208	255	5760	10000	1208	666	62	7.2	182	1040
5	4	6.14	60.8	194	232	2900	6160	690	231	48	5.6	161	596
6	5	6.34	55.3	164	249	3620	7040	832	364	50	6.4	162	728
7	6	6.86	43.9	162	259	6660	10800	1006	670	60	6.6	182	1016
8	7	5.81	56.9	280	221	2440	5100	596	178	47	6.4	111	648
9	8	6.26	51.1	166	245	4500	7900	794	334	50	6.6	119	824
10	9	6.69	44.1	132	257	6240	9580	906	617	60	7.4	120	992
11	10	6.21	68.1	164	241	4580	7220	720	320	47	6.0	115	700
12	11	6.38	59.6	156	251	5720	8260	858	473	56	6.8	119	808
13	12	6.62	49.8	126	251	6820	9900	1106	666	57	7.6	125	1036
14	13	5.91	65.5	224	223	3080	5000	878	368	49	6.2	108	632
15	14	6.42	54.2	184	247	5820	8820	912	502	50	6.4	115	760
16	15	6.87	47.8	168	248	6880	9780	1114	669	53	6.8	116	1060
17	KL 1	6.31	89.0	164	52	200	380	1364	60	6	6.6	76	83
18	2	6.86	61.7	156	259	5880	8600	1392	440	63	7.4	108	804
19	3	8.88	30.6	118	260	9080	12200	1402	670	65	7.8	129	1216

Table 13. Changes in the pH values of the air-dry average peat samples mixed with limestone powder in the function of admixture rates

Serial number	Sample	Weight ratio		pH
		Peat	Limestone powder	
1	TT_1	100	-	4.62
2	/Buyongwe/	100	1	5.25
3		100	2	5.80
4		100	3	6.30
5		100	4	6.55
6		100	6	8.90
7		100	8	9.25
8	TT_2	100	-	4.20
9	/Gishubi/	100	1	6.15
10		100	2	6.80
11		100	3	7.20
12		100	4	7.45
13		100	6	10.55
14		100	8	11.00
15	TT_3	100	-	4.40
16	/Gitanga/	100	1	5.90
17		100	2	6.40
18		100	3	6.80
19		100	4	7.40
20		100	6	10.35
21		100	8	10.70
22	TT_4	100	-	4.27
23	/Kashiru/	100	1	6.05
24		100	2	6.40
25		100	3	6.80
26		100	4	7.40
27		100	6	9.50
28		100	8	9.90
29	TT_5	100	-	4.20
30	/Kuruyange/	100	1	5.30
31		100	2	5.85
32		100	3	6.40
33		100	4	6.65
34		100	6	8.70
35		100	8	9.00

Table 14. Changes in the pH-values of the mixtures of air-dry average peat samples and stable manure and limestone powder in the function of admixture rates

Serial number	Sample	Weight ratio			pH
		Peat	Stable manure	Limestone powder	
1	TT_1	100	-	-	4.62
2	/Buyongwe/	75	25	-	5.59
3		50	50	-	6.35
4		25	75	-	6.70
5		-	100	-	7.78
6		100	-	1	5.45
7		75	25	1	6.20
8		50	50	1	6.65
9		25	75	1	7.35
10		-	100	1	8.75
11	TT_2	100	-	-	4.20
12	/Gishubi/	75	25	-	5.72
13		50	50	-	6.28
14		25	75	-	6.70
15		100	-	1	5.50
16		75	25	1	6.20
17		50	50	1	6.60
18		25	75	1	7.10
19	TT_3	100	-	-	4.40
20	/Gitanga/	75	25	-	6.00
21		50	50	-	6.30
22		25	75	-	6.75
23		100	-	1	6.05
24		75	25	1	6.45
25		50	50	1	6.80
26		25	75	1	7.30
27	TT_4	100	-	-	4.27
28	/Kashiru/	75	25	-	5.82
29		50	50	-	6.35
30		25	75	-	6.75
31		100	-	1	6.48
32		75	25	1	6.60
33		50	50	1	6.75
34		25	75	1	7.45
35	TT_5	100	-	-	4.20
36	/Kuruyange/	75	25	-	5.40
37		50	50	-	6.10
38		25	75	-	6.60
39		100	-	1	5.30
40		75	25	1	5.90
41		50	50	1	6.50
42		25	75	1	7.10

Table 15. Changes in the pH-values of the mixtures composed of soil, peat, limestone powder and rock phosphate

Serial number	Sample	Soil	Peat	Limestone powder	Rock phosphate	pH
		g				
1	2	3	4	5	6	7
1	Buyongwe soil /Ta_1/ and peat /TT_1/	30	-	-	-	5.72
2		30	0.10	-	-	5.70
3		30	0.25	-	-	5.55
4		30	0.50	-	-	5.50
5		30	0.75	-	-	5.45
6		30	1.00	-	-	5.35
7		30	-	0.001	-	5.72
8		30	-	0.0025	-	5.72
9		30	-	0.005	-	5.72
10		30	-	0.0075	-	5.75
11		30	-	0.01	-	5.85
12		30	0.10	0.001	-	5.75
13		30	0.25	0.0025	-	5.70
14		30	0.50	0.005	-	5.65
15		30	0.75	0.0075	-	5.60
16		30	1.00	0.01	-	5.60
17		30	0.50	0.005	0.01	5.65
18	Gishubi soil /Ta_2/ and peat /TT_2/	30	-	-	-	5.00
19		30	0.10	-	-	4.85
20		•	•	•	•	•
21		30	0.50	-	-	4.85
22		•	•	•	•	•
23		30	1.00	-	-	4.85
24		•	•	•	•	•
25		30	-	0.0025	-	5.15
26		30	-	0.005	-	5.15
27		•	•	•	•	•
28		30	-	0.01	-	5.15
29		•	•	•	•	•
30		30	0.25	0.0025	-	5.00
31		30	0.50	0.005	-	5.10
32		•	•	•	•	•
33		30	1.0	0.01	-	5.10
34		30	0.50	0.005	0.01	5.00

Table 15. /Cont./

1	2	3	4	5	6	7
35	Gisozi-Kuruyange soil /Ta$_3$/ and Kuruyange peat /TT$_5$/	30	-	-	-	4.55
36		30	0.10	-	-	4.55
37		30	0.25	-	-	4.55
38		30	0.5	-	-	4.55
39		30	0.75	-	-	4.50
40		30	1.00	-	-	4.50
41		30	-	0.001	-	4.62
42		30	-	0.0025	-	4.62
43		30	-	0.005	-	4.65
44		30	-	0.0075	-	4.70
45		30	-	0.01	-	4.75
46		30	0.10	0.001	-	4.55
47		30	0.25	0.0025	-	4.58
48		30	0.50	0.005	-	4.68
49		30	0.75	0.0075	-	4.68
50		30	1.00	0.01	-	4.70
51		30	0.50	0.005	0.01	4.65
52	Gitanga soil /Ta$_4$/ and Gitanga peat /TT$_3$/	30	-	-	-	5.05
53		30	0.10	-	-	5.05
54		30	0.25	-	-	5.05
55		30	0.50	-	-	5.02
56		30	0.75	-	-	5.02
57		30	1.00	-	-	4.95
58		30	-	0.001	-	5.15
59		30	-	0.0025	-	5.35
60		30	-	0.005	-	5.35
61		30	-	0.0075	-	5.40
62		30	-	0.01	-	5.40
63		30	0.10	0.001	-	5.15
64		30	0.25	0.0025	-	5.20
65		30	0.50	0.005	-	5.22
66		30	0.75	0.0075	-	5.30
67		30	1.00	0.01	-	5.35
68		30	0.5	0.005	0.01	5.42

Table 15. /Cont./

1	2	3	4	5	6	7
69	Kajondi soil /Ta_5/ and Gishubi peat /TT_2/	30	-	-	-	5.45
70		30	0.10	-	-	5.30
71		30	0.25	-	-	5.25
72		30	0.50	-	-	5.20
73		30	0.75	-	-	5.20
74		30	1.0	-	-	5.20
75		30	-	0.001	-	5.45
76		30	-	0.0025	-	5.50
77		30	-	0.005	-	5.55
78		30	-	0.0075	-	5.55
79		30	-	0.01	-	5.55
80		30	0.10	0.001	-	5.25
81		30	0.25	0.0025	-	5.25
82		30	0.50	0.005	-	5.30
83		30	0.75	0.0075	-	5.30
84		30	1.0	0.01	-	5.35
85		30	0.5	0.005	0.01	5.30
86	Kashiru soil /Ta_6/ and Kashiru peat /TT_4/	30	-	-	-	5.02
87		30	0.10	-	-	5.02
88		30	0.25	-	-	5.02
89		30	0.50	-	-	5.00
90		30	0.75	-	-	4.95
91		30	1.0	-	-	4.95
92		30	-	0.001	-	5.02
93		30	-	0.0025	-	5.02
94		30	-	0.005	-	5.10
95		30	-	0.0075	-	5.10
96		30	-	0.01	-	5.10
97		30	0.10	0.001	-	5.02
98		30	0.25	0.0025	-	5.05
99		30	0.5	0.005	-	5.10
100		30	0.75	0.0075	-	5.12
101		30	1.0	0.01	-	5.15
102		30	0.5	0.005	0.01	5.05

Remarks: No determination was possible owing to the low amount of sample material

Table 16. Changes in the pH values of the soil in function of the added limestone powder

Serial number	Soil sample	Soil g	Limestone powder g	pH
1	Buyongwe /Ta_1/	30	0.01	5.85
2		30	0.05	6.40
3		30	0.1	7.20
4		30	0.2	7.90
5	Gishubi /Ta_2/	30	0.01	5.15
6		30	0.05	5.50
7		30	0.1	6.00
8		30	0.2	6.75
9	Gisozi-Kuruyange /Ta_3/	30	0.01	4.75
10		30	0.05	4.85
11		30	0.1	5.25
12		30	0.2	5.85
13	Gitanga /Ta_4/	30	0.01	5.40
14		30	0.05	5.80
15		30	0.1	6.30
16		30	0.2	6.85
17	Kajondi /Ta_5/	30	0.01	5.55
18		30	0.05	6.10
19		30	0.1	6.70
20		30	0.2	7.35
21	Kashiru /Ta_6/	30	0.01	5.10
22		30	0.05	5.15
23		30	0.1	5.35
24		30	0.2	5.95

Table 17. Data of moisture retention /pF/ curves

erial umber*	Particle density	Bulk density	Total porosity	Moisture content in volume percentage at pF										
	g/cm^3		vol.%	0	0.4	1.0	1.5	2.0	2.3	2.7	3.4	4.2	6.2	AMR pF 2.5- -pF 4.2
1	2.68	0.98	63.4	63.2	60.6	59.1	57.7	54.3	50.8	43.8	22.2	14.8	3.7	32.0
2	2.50	0.88	64.8	64.6	62.3	60.7	59.4	57.6	54.1	46.9	22.9	15.2	4.5	36.0
3	2.31	0.84	63.6	63.7	61.4	58.7	56.1	53.3	49.2	39.6	24.7	18.1	5.5	30.6
4	1.95	0.73	62.8	56.7	54.5	51.3	48.3	44.5	40.8	34.5	26.2	19.4	6.1	18.1
5	2.69	0.96	64.3	64.8	62.1	60.5	58.5	52.0	45.0	32.6	20.3	14.1	4.5	24.2
6	2.51	0.91	63.7	64.4	63.1	61.2	59.6	57.5	53.4	41.1	21.7	15.6	5.1	33.0
7	2.33	0.85	63.5	65.5	64.2	61.5	58.7	54.5	50.6	42.1	23.3	16.8	6.2	30.0
8	1.97	0.76	61.4	61.5	60.0	57.6	55.3	50.5	47.1	40.9	28.9	21.2	6.3	22.5
9	2.76	0.93	66.3	62.6	60.7	58.4	56.0	49.8	41.3	34.8	25.8	18.1	4.7	18.7
10	2.57	0.87	66.1	63.7	62.3	60.9	59.6	58.0	55.0	45.4	27.5	20.0	5.1	30.4
11	2.38	0.81	65.9	66.0	64.6	63.5	61.9	58.7	56.9	50.8	30.0	21.3	5.5	31.7
12	2.00	0.73	63.5	69.5	69.0	67.2	64.9	61.5	58.6	53.4	35.7	25.4	6.2	30.9
13	2.79	1.18	57.7	52.0	50.6	47.6	46.2	43.1	38.6	33.2	21.2	14.0	2.7	22.1
14	2.60	0.77	70.3	67.8	67.0	65.4	64.5	62.1	60.4	54.9	35.2	23.2	6.2	34.2
15	2.54	0.76	70.0	69.8	67.5	65.2	64.0	61.5	57.6	51.9	26.9	17.4	5.9	37.7

For soil and peat variants see Table 18.

Table 18. Hydraulic conductivity of the soils studied
/K = cm/day/

Serial number	Variant		Saturated hydraulic conductivity /K/ /range/, cm/day
	Soil	Peat	
1	Ta_8 100%	-	130-150
2	Ta_8 90%	TT_2 10%	120-140
3	Ta_8 80%	TT_2 20%	110-125
4	Ta_8 60%	TT_2 40%	60- 70
5	Ta_7 100%	-	130-140
6	Ta_7 90%	TT_4 10%	115-130
7	Ta_7 80%	TT_4 20%	110-120
8	Ta_7 60%	TT_4 40%	80-100
9	Ta_2 100%	-	110-120
10	Ta_2 90%	TT_1 10%	60- 70
11	Ta_2 80%	TT_1 20%	30- 40
12	Ta_2 60%	TT_1 40%	25- 30
13	Ta_1 100%	-	10- 15
14	Ta_3 100%	-	20- 25
15	Ta_6 100%	-	140-160

Table 19. The titration values of the soil, peat, manure and their mixture

erial umber	Variant	meq HCl/10 g soil							meq NaOH/10 g soil				
		1.0	0.7	0.5	0.3	0.1	0.0	0.0	0.05	0.15	0.25	0.35	0.5
1	Kajondi soil /Ta_5/	3.380	3.590	3.778	3.903	4.490	5.08	5.124	5.440	5.975	6.285	6.430	6.667
2	Gishubi peat /TT_2/	3.535	3.665	3.753	3.855	4.025	4.150	4.168	4.275	4.405	4.475	4.550	4.700
3	Stable manure	7.618	7.785	7.915	7.990	8.028	8.108	8.089	8.125	8.168	8.230		
4	Soil+peat+ + manure	3.505	3.750	4.090	5.040	5.650	5.994	5.946	6.190	6.450	6.650	6.860	7.050

Table 20. Analysis of the limestone powder from the Mosso area

Chemical composition	%	Minerals	%
SiO_2	1.76	Brucite	40.0
TiO_2	0.13	Calcite	20.0
Al_2O_3	0.62	Portlandite	37.0
Fe_2O_3	0.54	Goethit	0.6
MnO	0.06	Quartz+Al/OH_3/	2.4
CaO	39.90		
MgO	29.20		
$CaCO_3$	24.40		
Na_2O	0.06		
K_2O	0.10		
P_2O_5	0.15		

Table 21. Analysis of rock-phosphate from the Matongo area

Chemical composition	%
HCl-insoluble part	39.47
Moisture content	1.39
P_2O_5	11.24
SiO_2	20.06
$CaCO_3$	7.42
Mg	0.70
Fe	11.50

Figure 1a. pF-curves.

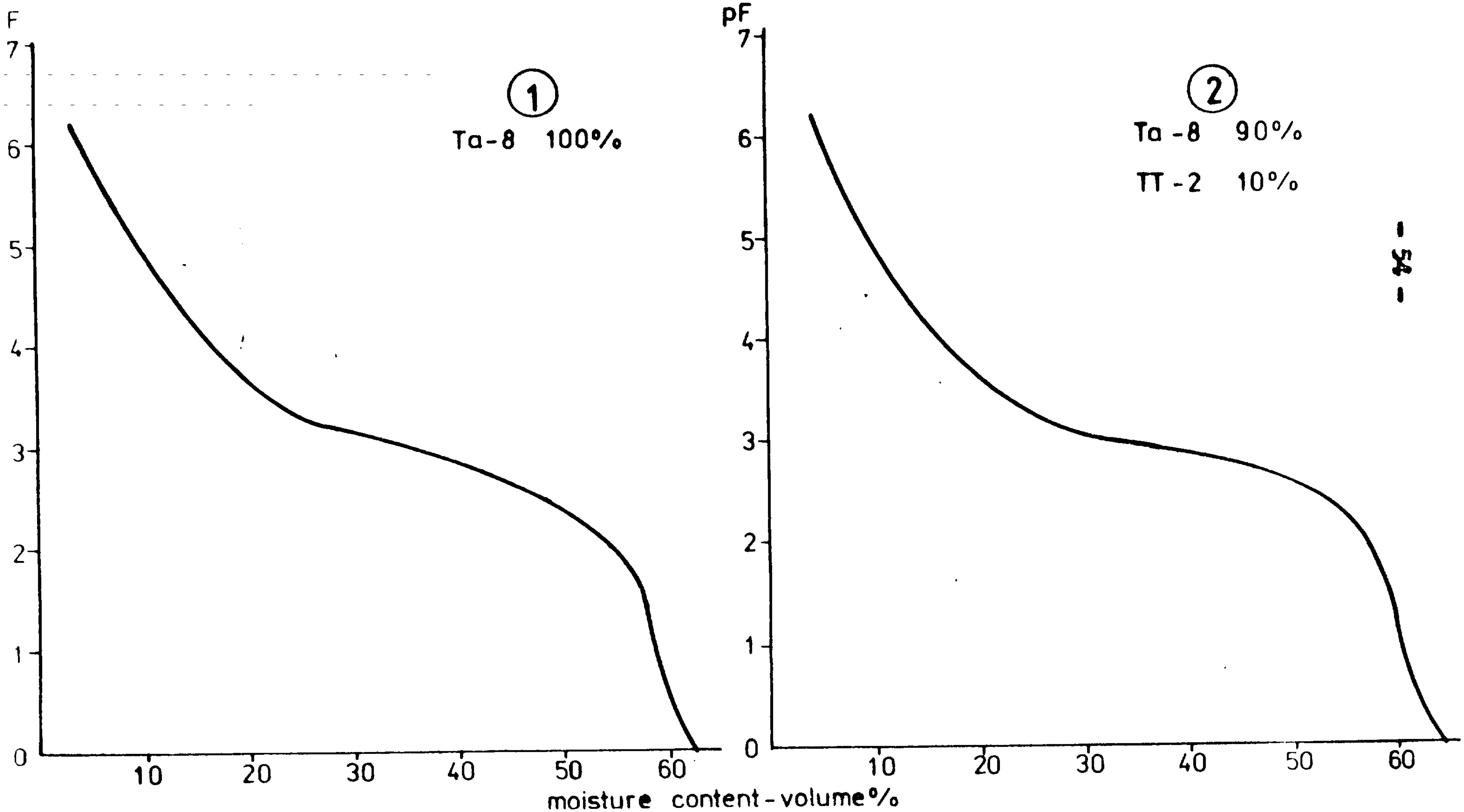


Figure 1b. pF-curves.

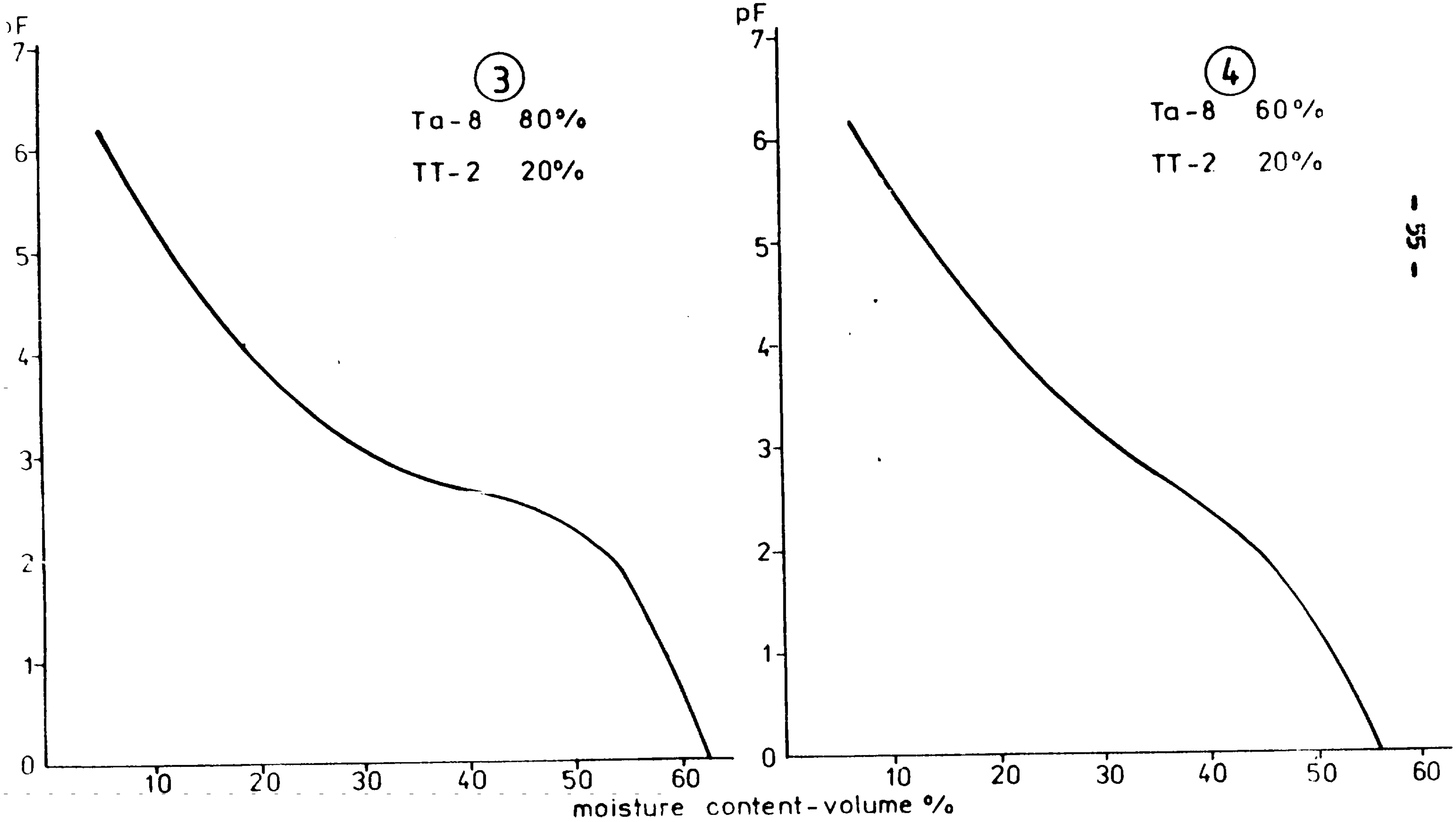


Figure 1c. pF - curves.

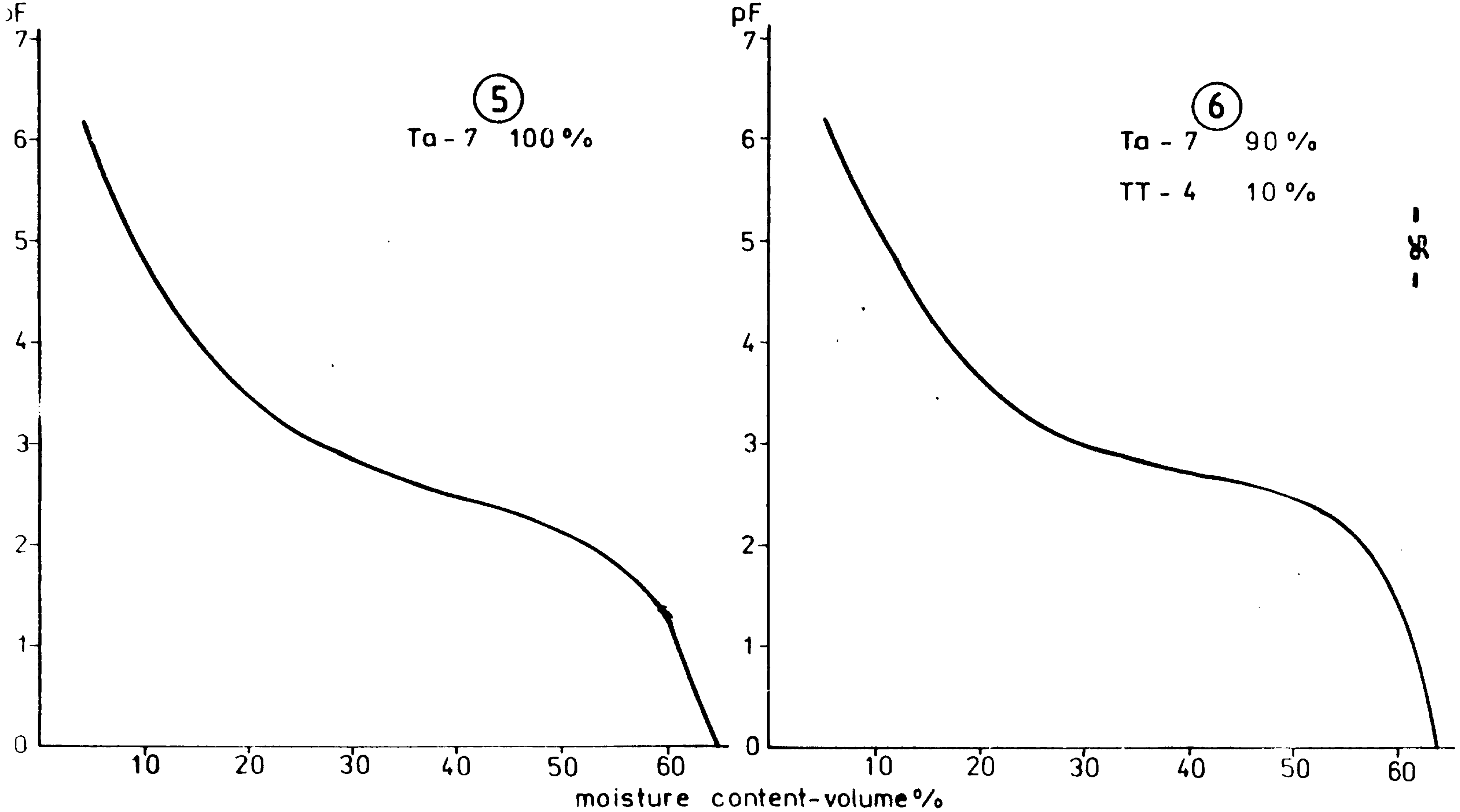


Figure 1d. pF-curves.

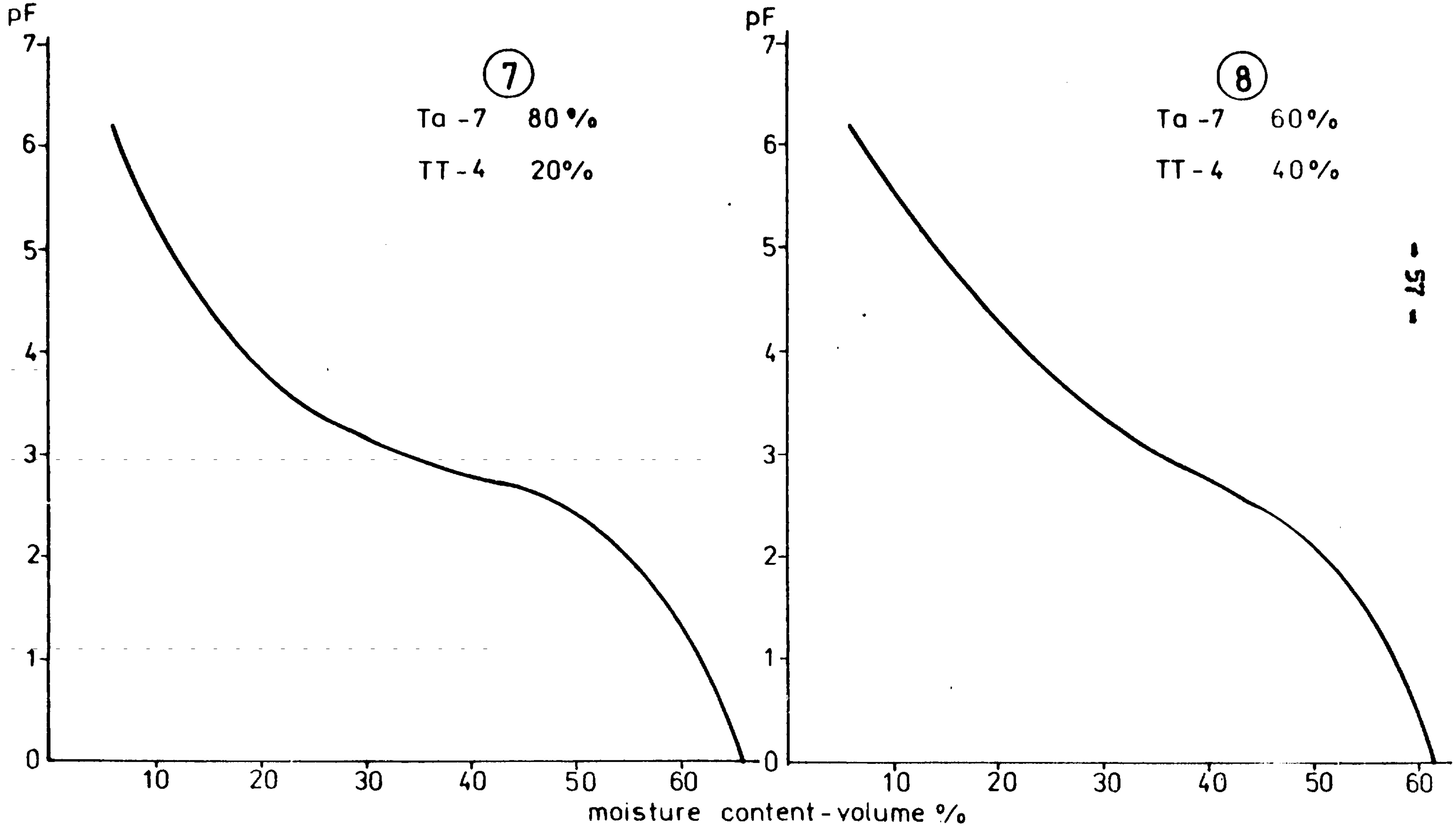


Figure 1e. pF-curves.

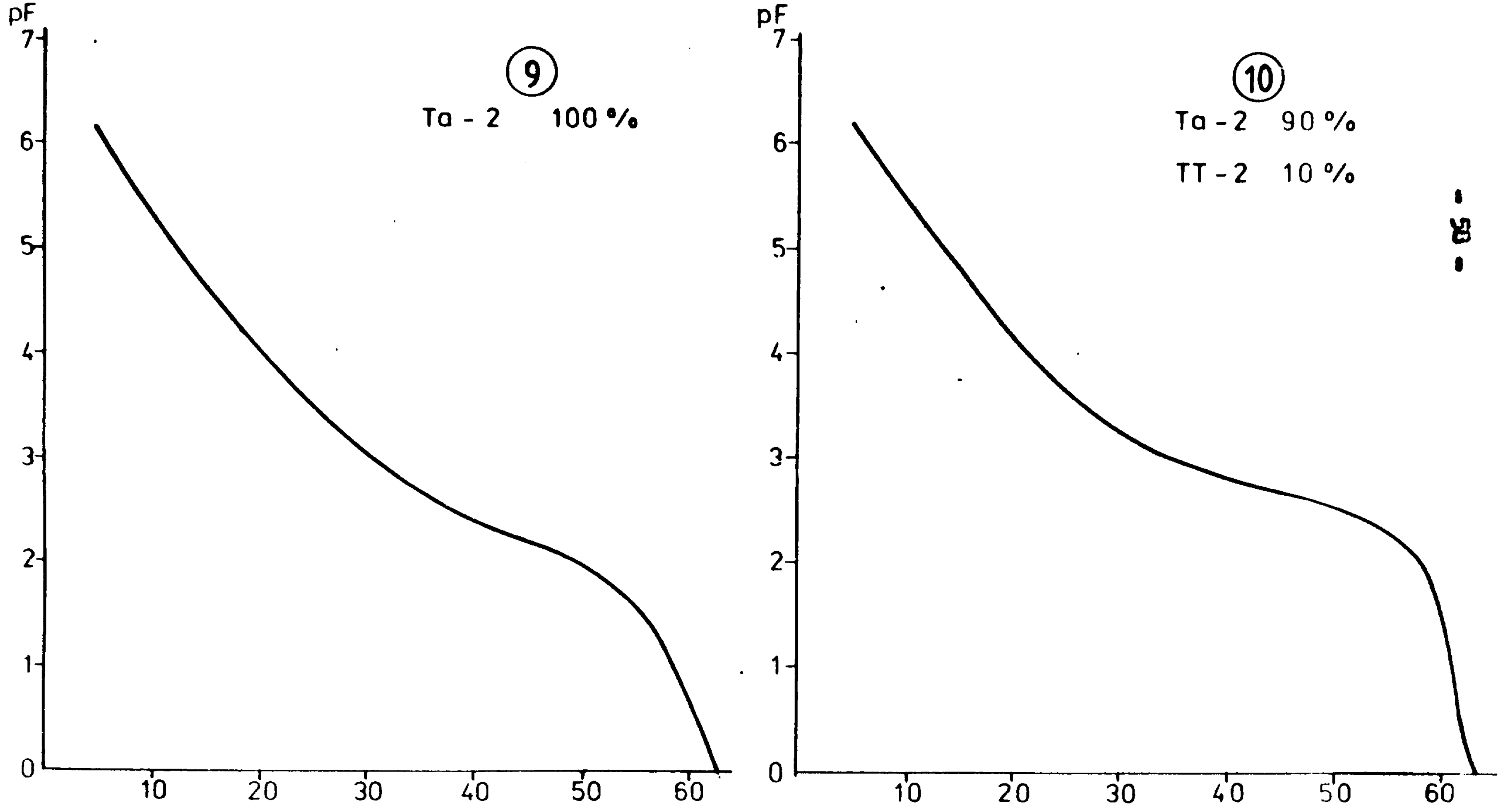


Figure 1f. pF- curves.

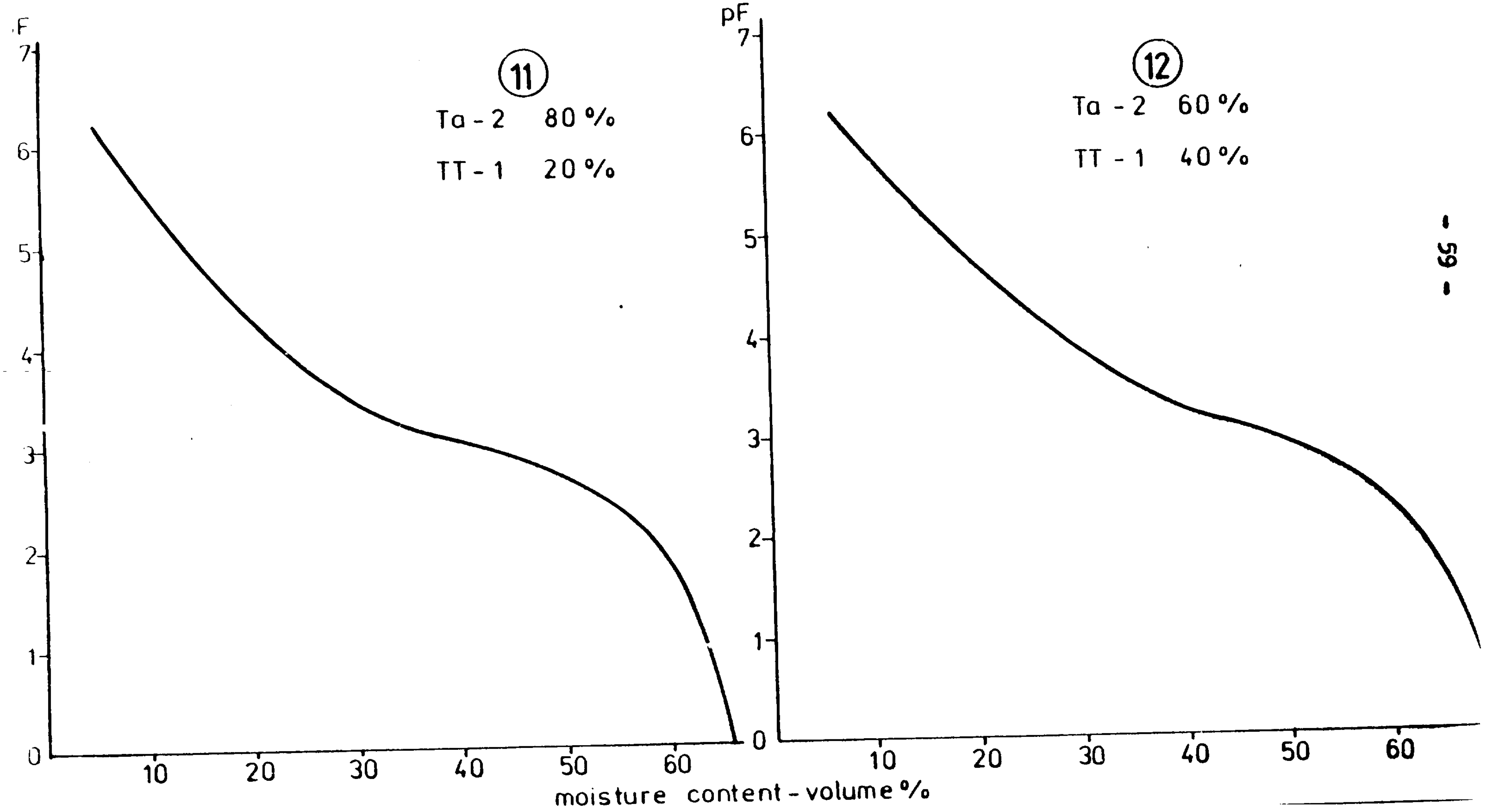


Figure 1g. pF-curves.

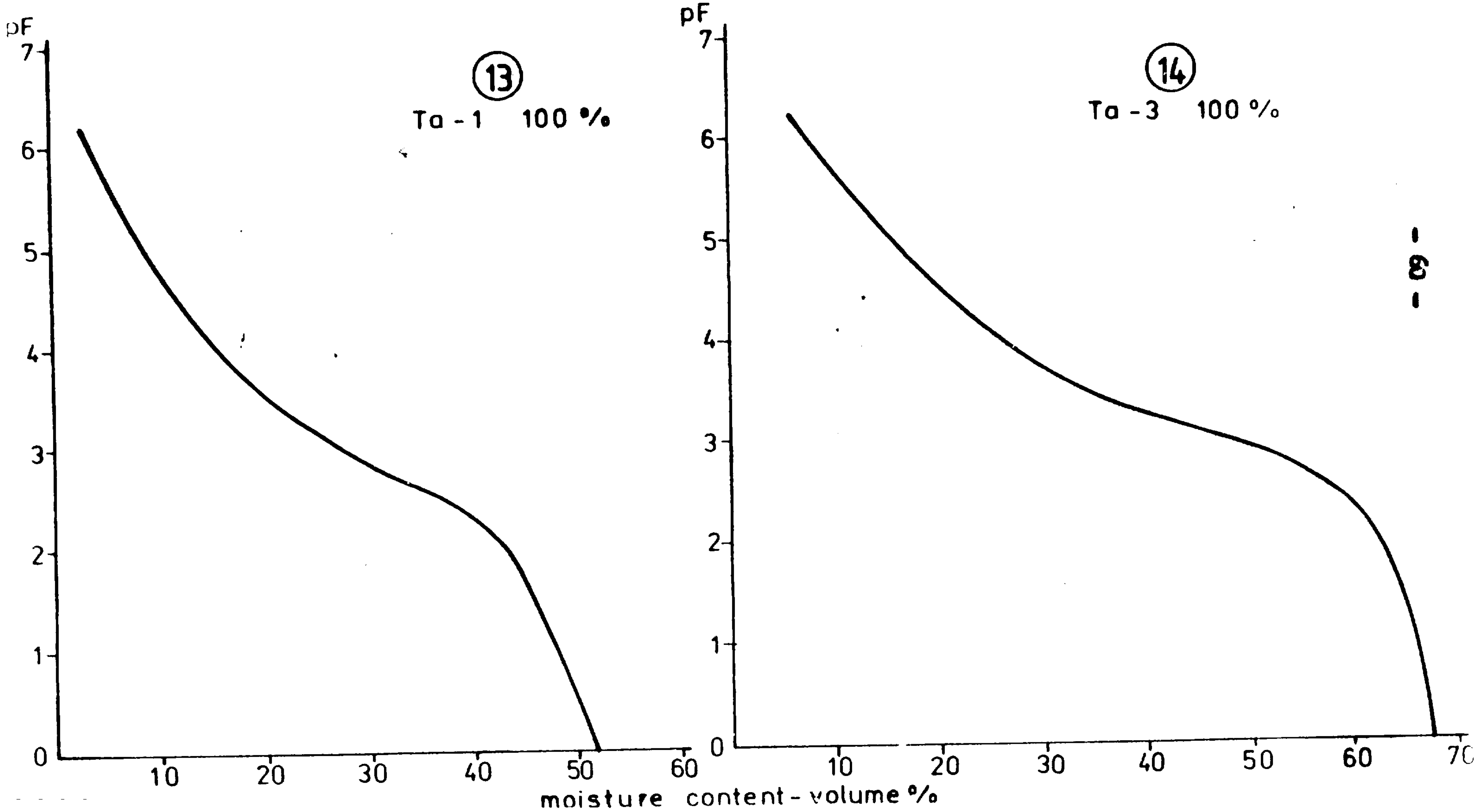


Figure 1h. pF-curves.

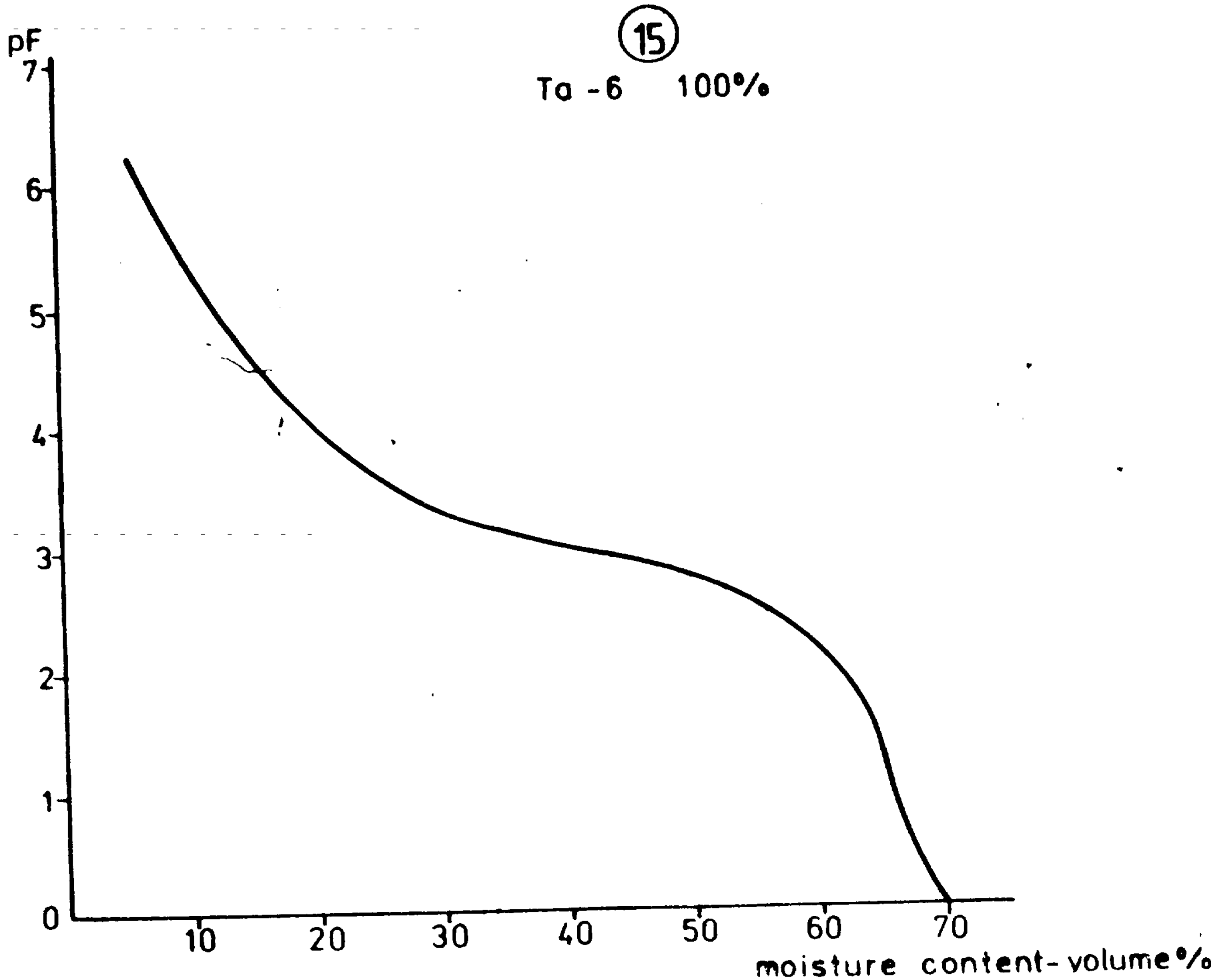
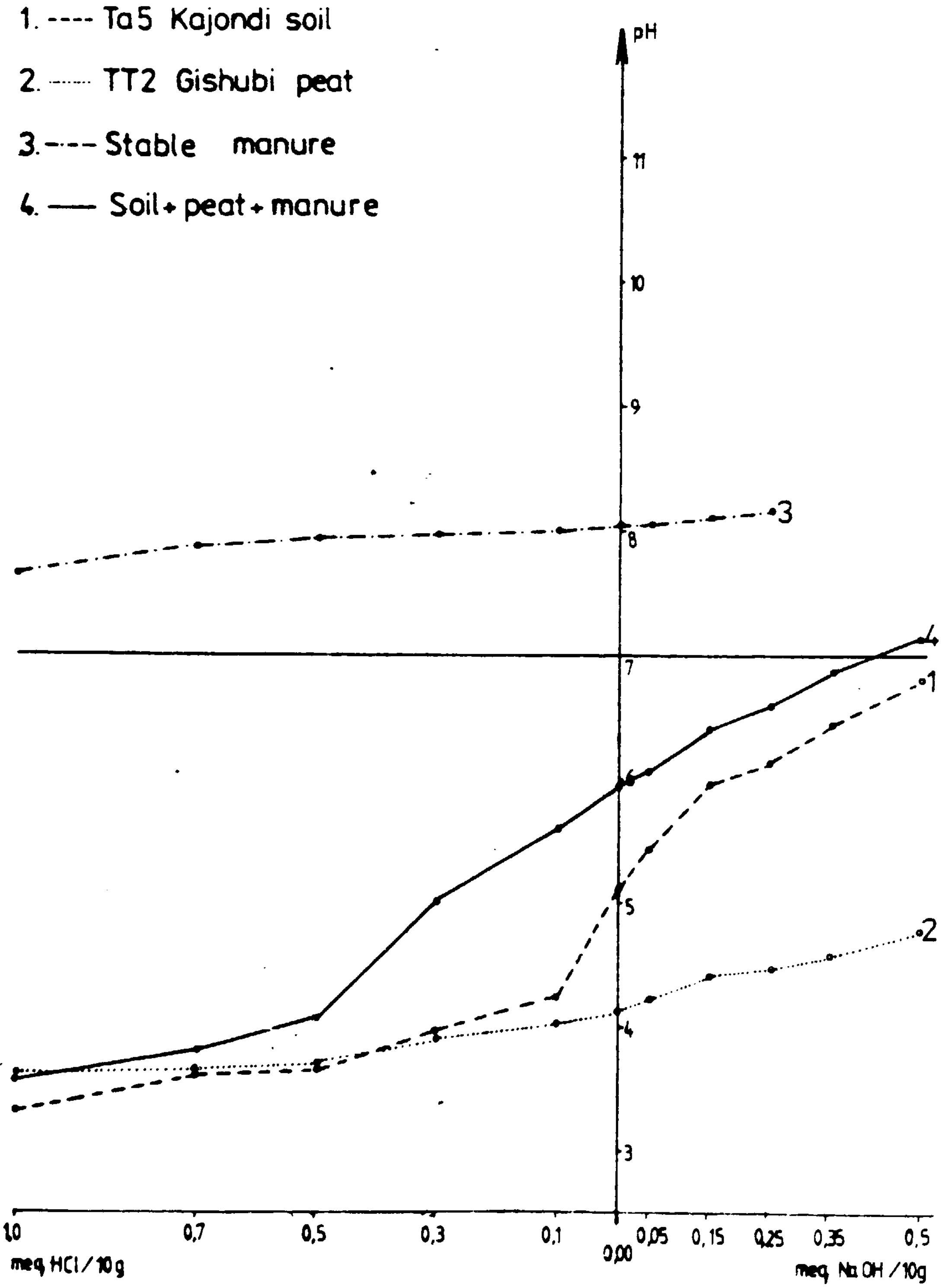


Figure 2. The titration curves



IV. APPENDIX

Chemical and Physical Determinations of the Soils and Peats

Determination of N, P, K, Ca, Mg

Measure: 1 g air-dry material /peat, stable manure mixture/

Decomposition: 10 cm^3 H_2SO_4 + required amount of 30% H_2O_2 in Kjeldahl test-tube.

Fill-up: to 110 cm^3.

Determination of nitrogen

Titration with potassium-hypobromite, with Dead-stop end-point indication.

Standard solution made of: analytical purity $/NH_4/_2SO_4/$.

The determination was made in the range of solution concentration containing 0.1 - 1.2 mg N.

Determination of phosphorus

Production of molybdenum-blue colour reaction with ammonium-molybdenate and eiconogen, followed by photometric measurement at a wave-length of 600 nm.

Standard solution made of: analytical purity KH_2PO_4 and analytical purity KCl as specified by Sörensen.

Measuring interval: 0.2 - 6.5 mg P/L.

Determination of potassium

Measurement performed by flame-photometric method at 766.65 nm wave-length by means of an atomic absorption spectrophotometer in emissive operation.

Standard solution made of: the same as the one specified under the determination of P.

Measurement interval: 1.5 - 16.5 mg K/L.

Determination of calcium

Measurement: with flame photometer by the emissive method.

Standard solution made of: calcium standard solution Titrisol, MERCK

Concentration range of measurement: 1.0 - 20.0 mg Ca/L.

Determination of magnesium

Measurement: by atomic absorption spectrophotometer

Standard solution made of: Magnesium-Standardlösung Titrisol, MERCK.

Concentration range of measurement: 0.1 - 1.5 mg Mg/L.

Determination of humic acid

Start-up measure: air-dry peat equivalent to 1.0 g dry matter.

Shake-out solution: 50 cm^3, 0.1 mol NaOH/L.

Preparation of extraction: the 50 cm^3 0.1 mol/L level NaOH solution is poured over the peat to be analysed, then it is left to rest for 16 hours and after this period it is shaken through 8 hours on a circular shaker machine. The suspension is centrifuged after this shaking process. The supernatant part is poured into a cooking cup, 0.01 mol/L level NaOH solution is added to the sediment and stirred up and then poured into the solution in the cup. This operation is repeated until the supernatant solution turns into a light colour. The solution collected in the cooking cup is made acidic with 2.5 mol H_2SO_4/L. The separated humic acids are then centrifuged /through several stages/ in a glass centrifugation tube that has been previously weighed on an analytical scale. The sediment is then dried up to permanent weight at 105 °C. After cooling in exsiccator, its weight is determined.

Determination of hydrolysable N

20.0 g air-dry material is measured into a 250-300 cm^3 test tube; 0.25 mol H_2SO_4/L is added in 100 cm^3 quantity, the liquid is then strongly shaken through 3 minutes then is left to rest overnight. The next day it is screened into a 100 cm^3 test-tube. 0.5 g reductive mixture /1 part Fe powder + 9 parts Zn powder/ is added to 50 cm^3 of the screened material, it is then heated to boiling and to the complete dissolution of the mixture. In the meantime, the test tube should be covered with a funnel. After cooling, 5 cm^3 96% H_2SO_4 are added and the liquid is then made to vaporize over electric oven until white steam appears and the liquid turns brown in colour. 2.5 cm^3 10% potassium-bicromate solution are then admixed and the material is boiled for 10 minutes until the solution takes on a green colour. During boiling, the liquid is covered with a funnel. After cooling, the solution is washed through in a water vapour distilling device, then made alkaline by adding 20 cm^3 50% NaOH solution. Subsequently, the NH_3 is distilled into 20 cm^3 2% boric acid solution. The end-point indication of titration is performed by means of methyl-red-methylene-blue indicator. The titrating acid is: 0.05 mol H_2SO_4/L.

Aqueous pH

5 g material + 12.5 cm^3 boiled-out and cooled down distilled water.

Measurement: by digital pH gauge and combined glass electrode.

Determination of total organic material

For soils: 1 g air-dry soil + 10 cm^3 1/6 mol/L potassium-bicromate + 20 cm^3 96% H_2SO_4 is mixed, after cooling, with 100 cm^3 distilled water, then stirred and left to settle until the next day. The next day, a little amount is carefully removed from the pure part of the liquid and is subjected to measurement with spectrophotometer at 590 nm wave-length.

Preparation of standard solution: from analytical purity glucose.

Measuring interval: 0.1 - 5% organic matter content, calculated in terms of soil.

Peats, mixtures: The method of determination is identical with the one for soils, except for: 0.5 g air-dry peat + 20 cm^3 1/6 mol/L potassium-bicromate + 40 cm^3 96% H_2SO_4 + 200 cm^3 distilled water.

Measuring range: 0.4 - 2.0% organic matter for peat and for mixture in calculation.

Ammonium-lactate /AL/ soluble P_2O_5, K_2O, Na

Preparation of filtrate: by Egnér-Riehm-Domingo

5.0 g air-dry material is placed into shaker bottle from which 100 cm^3 AL solution is made /which amounts to 0.1 mol/L ammonium-lactate and to 0.4 mol/L acetic acid, pH = 3.7/. The mixture is then shaken on the shaker machine for 2 hours at a temperature of 20 ± 2 °C and with revolution number 35-40/min. The P_2O_5-, K_2O- and Na content of the solution is determined after screening.

Determination of ammonium-lactate /AL/ soluble P_2O_5

The determination is performed by flow-system photometer, from warmed up solution /to 90°C/ with "molybdenum-blue" reaction, and after reduction with ascorbic acid. The photometric measurement is made at 660 nm wave-length.

The standard solution is made of: analytical purity KH_4PO_4 after Sörensen.

Range of concentration: 1.0 - 25.0 mg P_2O_5/L.

Determination of ammonium-lactate /AL/ soluble K_2O

This is performed by the emissive method with flame photometer.

Concentration range: 1.0 - 25.0 mg K_2O/L.

Standard solution is made of: analytical purity KH_2PO_4 + KCl as specified by Sörensen /with the same standard as for P_2O_5/.

Sensing: at the wave-length of 770 nm.

Determination of ammonium-lactate /AL/ soluble Na

This is also performed by the emissive method, with flame photometer.

Concentration range: 1.0 - 25.0 mg Na/L.

Standard solution made of: analytical purity NaCl.

Sensing: at 590 nm wave-length.

Determination of KCl-soluble NH_4-, NO_3+NO_2-, SO_4-, Mg

Preparation of KCl extraction

20.0 g air-dry material is placed into shaker bottle and then 50 cm^3 1 mol KCl/L solution is poured onto it. This is then shaken for an hour in a manner as described for the AL solution.

Determination of KCl-soluble NH_4^+-N

This determination is conducted by using the "indophenol-blue" reaction.

Photometric measurement: at 640 nm wave-length.

Concentration range: 2.0-20.0 mg NH_4^+-N.

Standard solution made of: analytical purity NH_4Cl.

Determination of KCl-soluble NO_3+NO_2-N

The determination is performed by way of the "Griess-Ilosvay" reaction.

Photometric measurement: at 520 nm wave-length.
Concentration range: 2.0 - 20.0 mg NO_3+NO_2-N mg/L.
Standard solution made of: analytical purity KNO_3.

Determination of KCl-soluble SO_4-S.

Determination is conducted turbidimetrically.
Photometric measurement: at 540 nm wave-length.
Concentration range: 2.0 - 20.0 SO_4-S mg/L.
Standard solution made of: analytical purity $/NH_4/_2SO_4$.

Determination of KCl-soluble Mg

Determination is made by atomic absorption spectrophotometer.
Absorption measurement: 285, 2 nm wave-length.
Concentration range: 20-160 mg Mg/L.

Determination of EDTA-soluble Mn, Zn, Cu

Preparation of extraction:

25.0 g air-dry material is placed into shaker bottle. 50 cm^3 shaker solution /0.05 mol/L EDTA and 0.1 mol/L KCl specific/ is poured onto this, - extraction is then performed relative to the AL- soil extract.

Determination of EDTA-soluble Mn

This determination is made by means of atomic absorption spectrophotometer.

Absorption measurement: 279.5 nm wave-length.
Concentration range: 2.5 - 60 mg Mn/L.

Determination of EDTA-soluble Cu

Determination is made with atomic absorption spectrophotometer.

Absorption measurement: at the 324.7 nm wave-length.

Concentration range: 0.25 - 6.0 mg Cu/L.

Determination of EDTA-soluble Zn

This determination is made with atomic absorption spectrophotometer.

Absorption measurement: at the 213.8 nm wave-length.

Concentration range: 2.25 - 6.0 mg Zn/L.

Determination of ammonium-lactate /AL/ soluble Ca

Determination is carried out with atomic absorption spectrophotometer.

Absorption measurement: at the 422.7 nm wave-length.

Concentration range: 2.5 - 30.0 mg Ca/L.

Standard solutionis made of: from the standard solution of the British BDH Firm.

Determination of organic matter /combustion losses/ for peat

The air-dry material is kept in muffle furnace at 700 °C for three hours, then cooled down to 100 °C. The material in the recipient is further cooled at room temperature in an exsiccator with $CaCl_2$. Its bulk is filled back into a measuring recipient in the end.

Determination of hydrolytic acidity /y_1 - value/

The acidic-type soil is mixed with salt solution that is hydrolytically decomposable /n $Ca/CH_3Coo_2/.H_2O$/. The metal cations of the salt are bound by the soil, while a weak acid is formed in the solution from the anion of the salt. This weak acid is difficult to dissociate. The hydrolytic acidity /y_1 - value/ is calculated from the released acid bulk which

is determined by alkalotic titration /in the presence of phenophthalein indicator with 0.1 n NaOH measure solution to pale pink colour/.
The y_1-value indicates the acidity of 50 g soil.

Determination of exchange acidity /y_2-value/

The soil is mixed with neutrally dissociating n KCl solution, and the amount of H^+-ions dissolved is measured through titration with 0.1 n NaOH.

By multiplying the ml-s of the NaOH measuring solution /0.1 n NaOH/ used in titrating the n KCl soil extraction equivalent to 50 ml soil /20 g/ by 2.5, one obtains the y_2-value featuring the exchange acidity of the soil.

Determination of exchangeable cations

The exchangeable cations are determined by means of an NH_4 acetate solution of pH 7. The sodium and potassium concentrations of the extraction are determined by flame photometry, whereas those of calcium and magnesium ions are determined complexometrically.
The sum of the metal cations expressed in terms of meq/100 g soil is the S-value.

Complete chemical analysis

The heated soil is extracted at 800-900 °C in platinum recipients with a mixture of K_2SO_3-Na_2CO_3 in ratio 1:6. Subsequent to neutralization by hydrochloric acid and to multiple panning, SiO_2 is separated, which is determined gravimetrically. The amount of R_2O_3 and the sulphate content are also determined gravimetrically from the distillate. The content of iron, manganese, calcium and magnesium are determined by atomic spectral photometry, while that of phosphoric acid /P_2O_5/ is determined by the colorimetric method. The amount of Al_2O_3 is determined by taking the difference of the amounts of R_2O_3

and iron content /Fe_2O_3/.
Sodium /Na_2O/ and potassium /K_2O/ are extracted by means of $CaCO_3$-NH_4Cl. Determination is made by flame photometry.

Determination of the mechanical composition of soil

An amount of 25 g is measured from the soil sifted through 2 mm mesh-size sieve; 0.5 n sodium-phosphate solution is then admixed. The suspensions are then washed into a shaker recipient with the help of distilled water. The material is washed into 1000 ml volume recipient. The suspensions are then shaken over 6-10 hours.
After shaking, the material is put into a calibrated, 1000 ml cylindrical recipient through 0.25 mm mesh-size sieve, and the recipient is filled up with distilled water to the mark. The following fractions are removed from pre-calculated depths by means of an automatic pipette;
>0.25 mm, 0.25-0.05 mm, 0.05-0.02 mm, 0.02-0.01 mm, 0.01-0.00 mm, 0.005-0.02 mm, <0.002 mm.

Determination of soil hygroscopicity /hy/

5-10 g air-dry soil is measured into a calibrated recipient. These are then placed onto the porcelaine plate of an exsiccator.
$CaCl_2 6H_2O$ is then put into the lower part of the exsiccator. The exsiccator is then covered and left to rest for 48 hours. After this period, the samples are measured, then dried out in drying chamber at 105 °C and measured again. The difference between the last two measures provides the soil moisture content corresponding to the hygroscopicity of the soil.

Determination of total sulphur /S/ - from peat

The peat sample, along with Eschka-mixture, is burnt in an oxidative atmosphere, the sulphate thus formed is removed by dissolving, the sulphate ions are precipitated in the form of barium-sulphate /$BaSO_4$/ and their mass is determined.

Determination of the pF curve

Water retention /pF/ curves of soils and soil-peat mixtures were determined in Várallyay sand- and kaolin-boxes within the low suction range /pF 0 - pF 2.7/; and in pressure-membrane apparatus within the high suction range /pF 3.4 - pF 4.2/. pF 6.2 was calculated from the hygroscopic moisture content /hy/.

Saturated hydraulic conductivity /K = cm/day/ was determined on disturbed soil /and soil-peat mixture/ samples, in the laboratory, by falling-head method.

Both pF-curves and K values were measured in two replicates, /parallels/.

Determination of the buffer titration curves

A series of suspensions was prepared using 10 g soil and 50 ml acid/base, containing the different amounts of hydronium/ /hydroxid ions. The concentrations applied were: o meq and 0.1 meq, 0.3 meq, 0.5 meq, 0.7 meq, 1.0 meq HCl and 0.05 meq, 0.15 meq, 0.25 meq, 0.35 meq, 0.50 meq NaOH per 10 g soil. The traditional 1:2.5 soil:solution ratio was followed. The suspensions were end over end shaken for 6 hours, then they were left to rest overnight. The next day they were shaken for 3 hours again. The suspensions were centrifuged at 3500--4000 revolutions per minute for 15-20 minutes. The pH was measured in the supernatant liquid at 25 °C. The soil and the solution were in equilibrium for about 24 hours.