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Morphological and physico-chemical aspects of three soils developed in peat in the Netherlands and their classification

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Summary

Three organic soils developed in oligotrophic peat (Sphagnum and Sphagnum-Eriophorum), and in mesotrophic peat (Carex), respectively, were studied morphologically and physico-chemically.

Micromorphologically Soil 1 (oligotrophic) shows a varying but rather high amount of histons. Fungons are a characteristic phenomenon whereas the little faunal decomposition is governed by Oribatid mites. Rubbed fibre content and physico-chemical data also point to a little proceeded decomposition (hemic soil material changing with depth into fibric soil material). Soil 2 (oligotrophic) also shows a varying, but rather high amount of histons. Fungons occur in low amounts and cannot be considered characteristic whereas faunal decomposition has increased relative to soil 1; considerable activity of Oribatid mites and a moderate activity of earthworms (probably a *Dendrobaena* species). Sporadically activity of Enchytraeidae could be observed. Decomposition has proceeded to almost sapric soil material in the top 7 cm changing with depth into hemic and fibric soil material which is in accordance with rubbed fibre content and physico-chemical data. Soil 3 (mesotrophic) contains some mineral material and a low amount of histons. Fungons are almost absent whereas the considerable faunal decomposition is governed by dipterous larvae and earthworms (probably a *Dendrobaena* species and/or *Lumbricus rubellus*) and to a lesser extent by Oribatid mites. Decomposition has proceeded to sapric soil material to 51 cm, changing with depth into hemic soil material which agrees with rubbed fibre content and physico-chemical data. The activity of the soil morphologically characteristic fauna increases quantitatively from Soil 1 to Soil 3; the number of species also increases, whilst fungal activity decreases. Decomposition proceeds further and to greater depths from Soil 1 to Soil 3 which can also be read from physico-chemical data as maximum water content, bulk density,

pH and C/N ratio. This correlates very well with the oligotrophic or mesotrophic character of the peat.

Soil classification according to the Soil Taxonomy, the Dutch system and the FAO-Unesco system of the three soils is given and critically discussed.

Introduction

The aim of this investigation was to study the soil formation (in particular the decomposition of the organic material) in different peats.

Therefore three organic soils were selected in the area of Winterswijk (Fig. 1). Two soils developed in oligotrophic peat (Sphagnum and Sphagnum-Eriophorum), that occurs on the higher parts of the coversand and glacial till landscape (about 50 m above Ordnance Datum). Soil 1 is poorly drained, whilst soil 2 is moderately

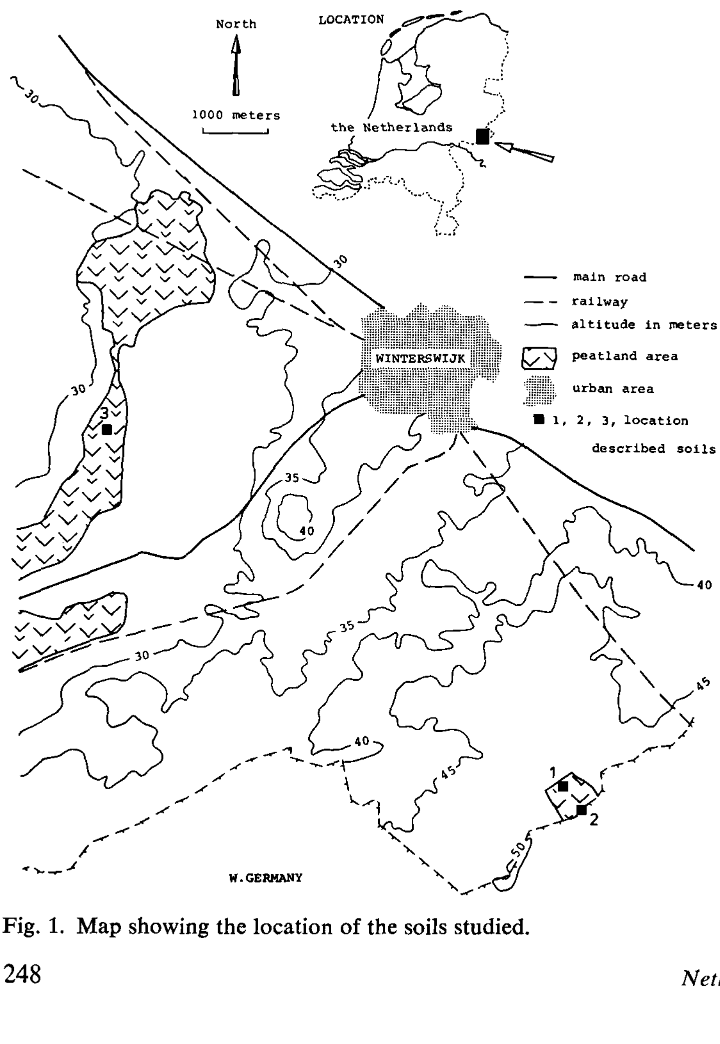

Fig. 1. Map showing the location of the soils studied.

well to well-drained. The present vegetation on these two soils is mixed woodland with *Betula pubescens* and *Pinus sylvestris* and *Molinia coerulea, Calluna vulgaris* and grasses whilst Sphagnum is present in pits formerly excavated for fuel supply. Soil 3 is moderately well-drained, and developed in mesotrophic peat (Carex) situated in a glacial valley at an elevation of 28 meters above Ordnance Datum. The present vegetation is a mixed swamp forest, characterized by *Alnus glutinosa, Sambucus niger, Rubus* spp., *Galium* spp., *Carex* spp. and grasses. The soils were described in the field and sampled for micromorphological, chemical and physical analyses. The results, together with a discussion of the soil classification, are subject of this paper.

Methods

The field description of the soils was done according to the Soil Taxonomy (Soil Survey Staff, 1970) with horizon symbols according to Pons (1960). Thin sections were prepared according to the method of Miedema et al. (1974); their description according to Bal (1973). These sections were studied in plain transmitted light and under crossed polarizers with magnifications to × 200. For bulk density undisturbed core samples of a known volume have been taken, oven-dried at 105 °C and bulk density calculated from oven-dry weight and known field volume. Loss on ignition is the weight loss when samples dried at 105 °C are heated to 400 °C for 12 h (Mitchell, 1932). Soil reaction has been measured by means of a glass electrode pH meter in a 1 : 5 soil-water and soil-0.01 *M* $CaCl_2$ system. Total organic carbon has been determined by wet oxidation with hot H_2SO_4-$K_2Cr_2O_7$ (Begheyn & van Schuylenborgh, 1971). Total nitrogen has been determined after destruction of the organic substance with sulphuric acid and a selenium mixture, liberation of ammonia with excess alkali, steam destillation of the ammonia into a solution of boric acid and back titration of the ammonium-borate to boric acid (Begheyn & van Schuylenborg, 1971).

Observations

Macromorphology Soil 1

A00 (+3 - 0 cm)	Non-decomposed, recognizable plant remains (leaves and branches).
A1 (0 - 7 cm)	Dark reddish brown (5YR 2/2, moist) moderately decomposed organic material with a weak medium granular structure; friable; rubbed fibre content 30 - 40 %; sodium pyrophosphate extract on white filter paper yellowish red (5YR 4/6).
C11 (7 - 18 cm)	Dark reddish brown (5YR 2/2, moist) moderately decomposed organic material; soft; rubbed fibre content 30 - 50 %; sodium pyrophosphate extract on white filter paper dark reddish brown (5YR 3/3).
C12 (18 - 92 cm)	Dark reddish brown (5YR 2/2, wet) moderately decomposed organic material with recognizable Eriophorum fibres between more decomposed Sphagnum; soft; rubbed fibre content 40 - 50 %; sodium pyrophosphate extract on white filter paper yellowish brown (10YR 5/4).
C13 (92 - 117 cm)	Reddish brown (5YR 4/4, wet) least decomposed organic material; soft;

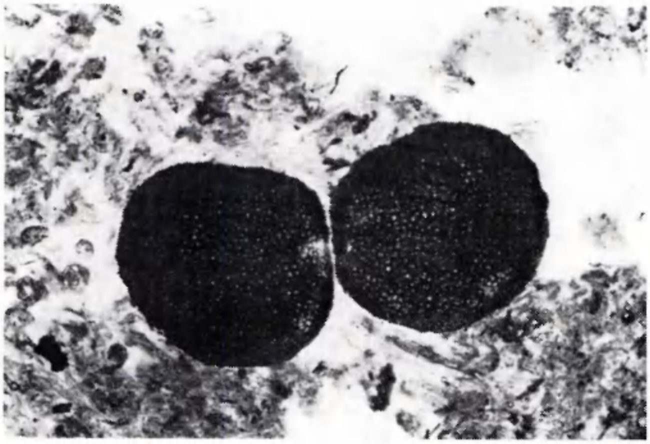

Fig. 2. Sclerotia (Ø 300 μm) in the C12 horizon of soil 1; × 100.

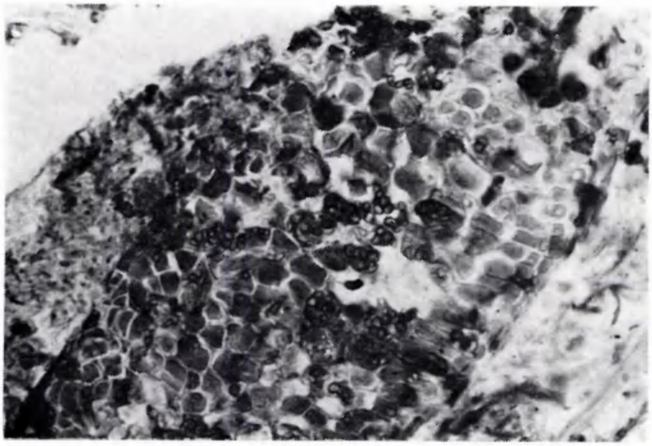

Fig. 3. Radiocohist with phellemic internal arrangement and presence of many spore fungons occurring as clusters of spores (Ø individual spores 5 - 10 μm) in the C13 horizon of soil 2; × 160.

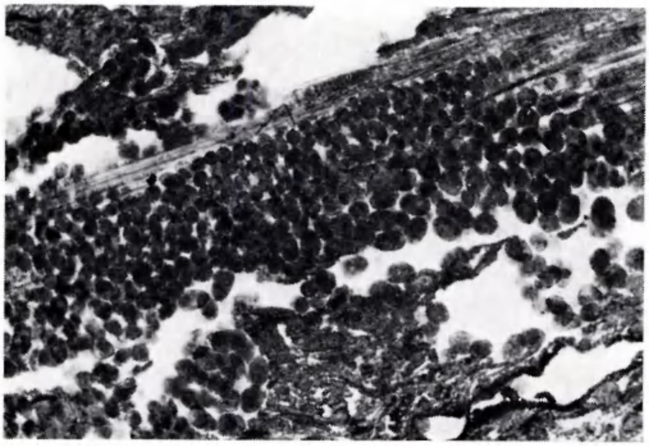

Fig. 4. Heaped fine (25 - 75 μm) organic ellipsoidal excrements of Oribatid mites in the A12 horizon of soil 2; × 63.

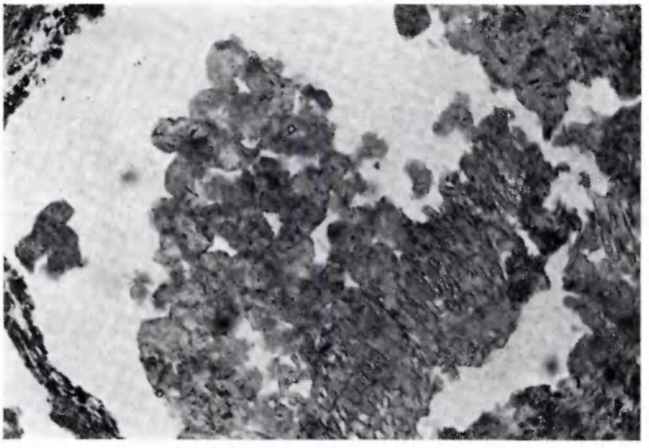

Fig. 5. Strongly welded moderately fine (150 - 220 μm) cylindrical excrements of Dipterous Larvae occurring within a histon in the A12 horizon of soil 3; × 63.

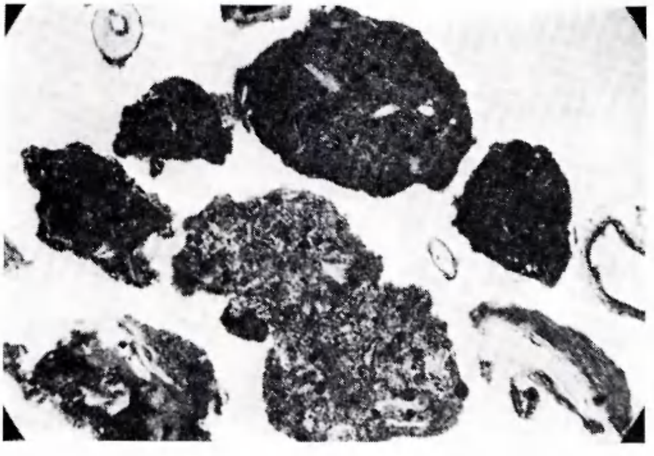

Fig. 6. Medium coarse (700 - 800 μm) bacillo-cylindrical earthworm excrements (probably of a Dendrobaene species and/or *Lumbricus rubellus*) in the A12 and C1 horizons of soil 3; × 15.

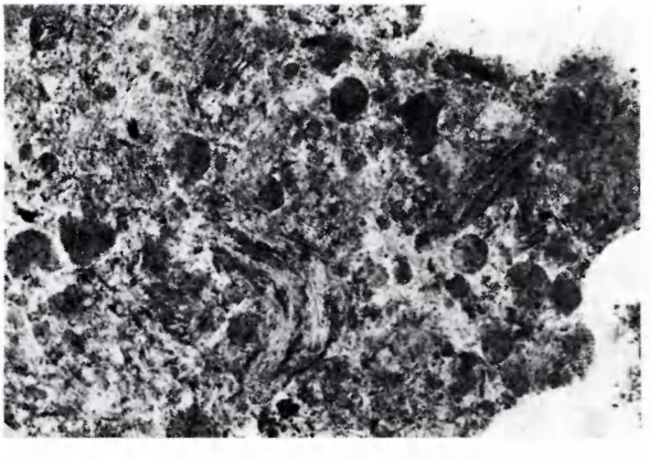

Fig. 7. Embedded fine ellipsoidal excrements of Oribatid mites in bacillo-cylindrical earthworm excrements in the A12 and C1 horizons of Soil 3; × 63.

	rubbed fibre content 60 - 70 %; sodium pyrophosphate extract on white filter paper yellowish brown (10YR 5/4).
G1 (117 - 127 cm)	Black (10YR 2/1, wet) sandy gyttja; non-plastic and sticky; sodium pyrophosphate extract on white filter paper very dark brown (10YR 2/2).
G2 (127 - 150 cm)	Dark brown (10YR 3/3, wet) fine sand; non-plastic and non-sticky.

Micromorphology Soil 1

Samples from 0 - 60 cm depth have been described.

Histons

The A1 horizon is nearly completely composed of histons, which can be weakly damaged. The majority of these histons occur in two kinds of alternating layers (microhorizons) approximately parallel to the soil surface. One kind is composed of histons with a coniatic internal arrangement (yellowish o-plasma) and is characterized by clear birefringement of (cellulose in) the cell walls under crossed polarizers. The other kind of microhorizon is composed of histons with a pleistoplasmatic internal arrangement (reddish brown o-plasma), and some o-matrix. It has much less birefringement of (cellulose in) the cell walls; this is due to decomposition, but may partly also be due to the covering of the cellulose-containing cell walls with o-plasma (Handley, 1954, p. 63; Babel, 1964; Grosse-Brauckmann & Puffe, 1964).

Also weakly to strongly damaged radicohists with a coniatic and/or phellemic internal arrangement are present. These are thought to be of the current vegetation.

In the C12 horizon the amount of histons is much smaller. They may occur in layers approximately parallel to the soil surface, but also more or less chaotically. The histons are characterized mainly by a pleistoplasmatic internal arrangement, some radicohists (probably of the current vegetation) by a coniatic and/or phellemic internal arrangement.

S-matrix

The S-matrix is completely composed of o-matrix plus voids. In the A1 horizon the amount of S-matrix is negligible and is part of the microhorizons with a pleistoplasmatic internal arrangement described above.

In the C12 horizon the S-matrix occurs in between the (layers of) histons. Partly it has a densely packed, and partly a highly vughy o-porphyroskelic fabric (medium and sometimes high plasma). The o-plasma is yellowish brown; the o-skeleton grains vary from 2 to some 100 μm in size. Some vughs, compound packing voids and (welded) channels (Ø approx. 125 μm) occur.

Pedological features

These are made up of several kinds of fungons, melanons, excrements, and o-granotubules.

Fungons. These are found in the A and C horizon especially as (α- and β-) hyphons, sclerotia, and spore fungons. The spore fungons usually occur as small clusters and strings of spores (each spore about 7 μm). The sclerotia are usually melanotic, whereas some hyphons are also melanotic.

Melanons. Melanons formed by accumulation of dark coloured or opaque o-plasma in histons and fungons are found. They occur both in the A and C horizon, but particularly in the C horizon (Fig. 2.).

Fungons are a characteristic phenomenon in this soil. Moreover it is striking that in the A horizon the fungons and melanons especially ocur accumulated in the microhorizons composed of histons with a pleistoplasmatic internal arrangement (reddish brown o-plasma) described above.

Excrements. In the A1 horizon only a small amount of excrements is present. Some occur within a histon, but more in voids between histons. The excrements are heaped to strongly welded, fine (40 - 80 μm), organic, ellipsoidal to cylindrical modexi, which are characterized by a pleistoplasmatic internal arrangement. They usually occur in modexotubules var. 1. In the A1 horizon also some weakly to extremely welded, medium coarse (approx. 600 μm) organic bacillocylinders with a pleistoplasmatic internal arrangement are found.

The C12 horizon is characterized by the presence of a higher quantity of excrements. In the S-matrix and in histons modexotubules var. 1 occur composed of heaped to strongly welded, fine (40 - 80 μm), organic ellipsoidal to cylindrical excrements. These modexi have a pleistoplasmatic to extremely fine o-porphyroskelic internal arrangement. These modexi can also occur embedded in a sporadic basic distribution pattern in the S-matrix.

Also clusters of medium coarse to very coarse (600 - 1600 μm) bacillocylinders are present with an o-porphyroskelic internal arrangement.

Moreover, some sporadically distributed bacillocylinders of some 300 μm occur.

o-granotubules. In the C12 horizon some granotubules (Ø 125 - 150 μm) occur in the S-matrix. They are composed of o-skeleton grains (25 - 200 μm) in a sporadic basic distribution pattern.

Macromorphology Soil 2

A00 (+6 - +2 cm)	Non-decomposed, recognizable plant remains (leaves and branches).
A0 (+2 - 0 cm)	Partly decomposed plant remains (branches recognizable).
A11 (0 - 7 cm)	Very dark brown (10 YR 2/2, moist) well decomposed organic material with a weak fine granular structure; friable; rubbed fibre content 10 - 15 %; sodium pyrophosphate extract on white filter paper dark brown (10 YR 3/3).
A12 (7 - 24 cm)	Dark reddish brown (2.5 YR 3/4, moist) well decomposed organic material with a weak fine granular structure; friable; rubbed fibre content 15 - 25 %; sodium pyrophosphate extract on white filter paper yellowish brown (10 YR 5/4).
A13 (24 - 35 cm)	Dark reddish brown (5 YR 2/2, moist) well decomposed organic material with a very weak fine subangular blocky structure; friable; rubbed fibre content 10 - 20 %; sodium pyrophosphate extract on white filter paper yellowish brown (10 YR 5/6).
C11 (35 - 55 cm)	Dark reddish brown (5 YR 2/2), moist moderately decomposed organic material with recognizable Eriophorum fibres in more decomposed Sphagnum; rubbed fibre content 40 - 50 %; sodium pyrophosphate extract on white filter paper very pale brown (10 YR 7/4).
C12 (55 - 86 cm)	Dark reddish brown (5 YR 3/3, moist) least decomposed organic material; soft; rubbed fibre content 90 - 95 %; sodium pyrophosphate extract on white filter paper very pale brown (10 YR 7/4).
C13 (86 - 120 cm)	Dark reddish brown (5 YR 2/2, moist) moderately to least decomposed organic material with recognisable Eriophorum fibers between more decomposed Sphagnum; soft; rubbed fibre content 80 - 90 %; sodium pyrophosphate extract on white filter paper very pale brown (10 YR 7/3).
G1 (120 - 142 cm)	Very dark brown (10 YR 2/2, moist) least decomposed organic material; soft; rubbed fibre content 70 - 80 %; sodium pyrophosphate extract on white filter paper very pale brown (10 YR 8/3).
G2 (> 142 cm)	Dark yellowish brown (10 YR 3/4, moist) least decomposed organic material; soft; rubbed fibre content 80 - 90 %; sodium pyrophosphate extract on white filter paper white (10 YR 8/3).

Micromorphology Soil 2

Samples from 0 - 120 cm depth have been described.

Histons

In the A11, A12 and C13 horizons histons occupy approximately 20 % of the organic volume. In the C12 horizon, on the contrary, the amount of histons is over 50 - 70 % of the organic volume. Histons in the C12 horizon occur in layers approximately parallel to the soil surface locally embedded in the o-matrix. In the C13 horizon they occur embedded in the o-matrix.

Histons in the A11, A12 and C13 horizons are usually moderately to strongly damaged and characterized by a coniatic or pleistoplasmatic internal arrangement (yellowish and brownish o-plasma). In the C12 horizon the histons are only weakly damaged and have a histonic or coniatic internal arrangement (yellowish o-plasma).

Recognizable radicohists are usually moderately to strongly damaged and have a phellemic (Fig. 3) and/or coniatic internal arrangement.

From the histons individual cells or small groups of cell may come off; especially parts with phellemic internal arrangement can be characterized by this phenomenon.

Characteristics on birefringement are as described under Soil 1.

S-matrix

The S-matrix is completely composed of o-matrix plus voids. The amount of S-matrix in the A11 and A12 horizons is rather small occurring in clusters (peds) or embedded between histons. In the C12 horizon S-matrix occurs only in very small amounts as spots enclosed between histons. Of the C13 horizon, on the contrary, approximately 60 - 70 % of the organic volume is occupied by S-matrix in apedal soil material.

The S-matrix usually has a densely packed o-porphyroskelic fabric (medium plasma; sometimes high or low plasma). The o-plasma is brownish; the o-skeleton grains vary from 2 to some 200 μm in size.

Irregular vughs (which may vary greatly in their cross sectional size) and some welded channels are found throughout the soil.

Pedological features

These are made up of some kinds of excrements and pedotubules, melanons and fungons.

Excrements. The upper part of the A12 horizon is largely composed (70 - 80 % of the organic volume) of heaped (sometimes weakly or strongly welded), fine (25 - 75 μm), organic ellipsoids (Fig. 4). Principally these modexi occur in modexotubules var. 1 in histons, but as these histons have almost completely been ingested the basic distribution pattern of the ellipsoids is as described above).

These modexi have a pleistoplasmatic to extremely fine o-porphyroskelic internal fabric; the o-plasma usually (dark) reddish brown, but can also be yellow. Some occur embedded in the o-matrix.

These ellipsoids occur much less in the lower part of the A12 horizon, whereas in the C12 and C13 horizon only some of them occur in modexotubules var. 1.

Some moderately to medium coarse (400 - 700 μm), organic bacillocylinders with an internal fabric which is identical to that of the S-matrix occur in the lowest part of the A12, C12 and C13 horizons.

Pedotubules. In the A12 horizon o-grano-/modexotubules with a cross sectional size of 150 - 250 μm are found. They contain o-skeleton grains of 50 - 60 μm in a sporadic basic distribution pattern, as well as sporadic and heaped, medium fine (50 - 60 μm), organic bacillocylindrical excrements.

In the C13 horizon one fragmotubule[1] with a cross sectional size of approximately 600 μm

[1] Fragmotubule according to Jongerius (1970) contains reworked soil of widely varying dimensions. The term aggrotubule cannot be used here in view of the presence of angular fragments.

was found, containing irregular organic aggregates, o-skeleton grains and some ellipsoidal excrements of the type described above.

Melanons. Some melanons formed in, or derived from histons are found throughout the soil. Sometimes they are thought to have been derived from melanotic fungons.

Fungons. These are found in low amounts throughout the soil as sclerotia and spore fungons. Melanotic sclerotia especially occur in the A12 horizon more or less accumulated (sporadically or clustered) in layers parallel to the soil surface. The opaque o-plasma is particularly accumulated in the cortex of the sclerotia.

In the C12 horizon some small-sized spore fungons are present; diameter of the individual spores 5 μm.

Probably apart from the melanotic sclerotia in the A12 horizon, the occurrence of fungons cannot be mentioned characteristically; especially not in relation to the occurrence of fungons in soil 1.

Macromorphology soil 3

A00 (+5 - 0 cm)	Non-decomposed, recognizable plant remains (leaves and branches).
A11 (0 - 18 cm)	Very dark brown (10 YR 2/2), moist) well decomposed organic material with a weak fine granular structure; friable; rubber fibre content 10 - 15 %; sodium pyrophosphate extract on white filter paper dark reddish brown (5 YR 2/2).
A12 (18 - 51 cm)	Very dark greyish brown (10 YR 3/2, moist) well decomposed organic material; soft; rubbed fibre content 30 - 40 %; sodium pyrophosphate extract on white filter paper dark reddish brown (5 YR 3/3).
C1 (51 - 78 cm)	Dark reddish brown (5 YR 2/2), moist) moderately decomposed organic material; soft; rubbed fibre content 30 - 40 %; sodium material; soft; rubbed fibre content 30 - 40 %; sodium pyrophosphate extract on white filter paper dark reddish brown (5 YR 3/3).
G1 (78 - 100 cm)	Dark reddish brown (5 YR 3/3, moist) sandy loamy gyttja; non-plastic and sticky; sodium pyrophosphate extract on white filter paper reddish brown (5 YR 6/4).
G2 (> 100 cm)	Light grey (10 YR 7/1, wet) fine sand; non-plastic and non-sticky.

Micromorphology soil 3

Samples from 0 - 70 cm depth have been described.

Histons

In the A11 and A12 horizons the number of histons is little. In the C1 horizon, however, their number increases with depth to about 30 - 40 % of the volume of organic soil material. Many of the histons are strongly damaged, and characterized by a coniatic, phellemic and/or pleisto-plasmatic internal arrangement.

S-matrix

The S-matrix is composed of (minero-)organic soil material plus voids. The organic materials dominate over the mineral part; the latter essentially recognizable by the sporadically distributed mineral skeleton grains.

The basic fabric of the S-matrix in the A12 and C1 horizon is o-porphyroskelic (high plasma) accompanied by vughs, compound packing voids and some channels. The o-skeleton grains of greatly varying dimensions.

Pedological features

These are essentially made up of excrements and only some melanons and fungons.

Excrements. The A11 horizon almost completely consists of weakly to strongly (but mainly moderately) welded, moderately fine (150 - 220 μm) cylindrical excrements. Their internal arrangement being pleistoplasmatic with yellow to light brown o-plasma. Besides, some welded, medium fine (50 - 70 μm) ellipsoids occur.

In the A12 and C1 horizons these excrements occur also in modexotubules var. 1; in the C1 horizon these are rather frequently found within histons (Fig. 5).

In the A12 and C1 horizons some groups or clusters of medium coarse (700 - 800 μm) bacillocylinders occur (Fig. 6). In these horizons the S-matrix is composed of strongly to extremely welded excrements of both types. Some of the moderately fine cylinders together with the medium fine ellipsoids being sporadically embedded (Fig. 7). S-matrix derived from the fine modexi is characterized by the absence of recognizable o-skeleton grains, or by the presence of very fine o-skeleton grains only.

Melanons and fungons. Melanons formed bij an accumulation of opaque organic plasma in xylem of histons as well as melanotic hyphons and spore fungons were only occasionally found in the C1 horizon.

Physico-chemical characteristics of soils 1, 2 and 3

The results are given in Table 1.

Discussion

From the macromorphological description it is clear that the soils investigated differ in their parent material. Soils 1 and 2 have developed in oligotrophic Sphagnum and Sphagnum-Eriophorum peat, whereas Soil 3 formed in a mesotrophic Carex peat. Moreover, Soil 1 is poorly drained whilst Soil 2 is moderately well to well drained and Soil 3 is moderately well drained.

Micromorphologically Soil 1 shows especially in the A1 and the deepest part of the C12 a rather weak decomposition as evidenced by a rather high amount of weakly damaged histons (coniatic internal arrangement). In the A1 these occur as microhorizons alternating with microhorizons composed of histons which are moderately decomposed (pleistoplasmatic internal arrangement). Organic plasma formed by biochemical processes covers the histons giving rise to the pleistoplasmatic internal arrangement.

Recent fungal activity is high in the A1 in view of the occurrence, often in layers, of high amounts of fungal hyphae, spores and sclerotia. These features decrease in quantity with depth but remain at a considerable level, which points to fossil fungal activity. The opaque organic plasma of the melanons found throughout the soil is presumably also due to fungal activity. Puffe & Grosse-Brauckmann (1963) and Grosse-Brauckmann & Puffe (1964) also reported high fungal activity in these kinds of organic soils.

Faunal activity was very low in the A1 and somewhat stronger in the C12. The ellipsoidal, often welded excrements originate from Oribated mites, whereas the

Table 1. Some physico-chemical data of Soils 1, 2 and 3.

Horizon and depth (cm)	Bulk density (g/cm³)	pH-H_2O	pH-$CaCl_2$	Loss on ignition (%)	Mineral (%)	C(%)	N(%)	C/N ratio
Soil 1								
A1 (0– 7)	0.20	3.1	2.6	94.2	5.8	54.3	1.01	53.8
C11 (7– 18)	0.14	3.0	2.5	96.9	3.1	58.8	1.03	57.1
C12 (18– 92)	0.12	3.3	2.9	97.3	2.7	62.9	1.13	55.7
C13 (92–117)	0.10	4.3	3.8	96.1	3.9	61.7	1.55	39.8
G1 (117–127)	0.14	4.9	4.2	15.8	84.2*	6.8	0.22	30.9
G2 (127–150)	—	5.3	4.5	1.6	98.4*	0.6	0.03	20.3
Soil 2								
A11 (0– 7)	0.24	3.1	2.5	91.2	8.8	56.1	1.28	45.8
A12 (7– 24)	0.15	3.1	2.5	98.8	1.2	57.1	0.69	82.7
A13 (24– 35)	0.14	3.1	2.4	99.2	0.8	62.7	0.82	76.5
C11 (35– 55)	0.13	3.0	2.4	98.8	1.2	57.9	0.80	72.4
C12 (55– 86)	0.10	3.2	2.6	94.2	5.8	53.7	0.64	83.9
C13 (86–120)	0.13	3.0	2.5	98.6	1.4	61.3	0.96	63.9
G1 (120–142)	0.10	3.1	2.5	99.0	1.0	64.1	0.93	68.9
G2 (> 142)	—	3.4	2.9	96.9	3.1	56.9	0.65	87.5
Soil 3								
A11 (0– 18)	0.22	3.5	3.2	78.6	21.4**	47.8	2.97	16.1
A12 (18– 51)	0.27	5.0	4.6	80.6	19.4**	49.0	2.76	17.6
C1 (51– 78)	0.16	5.3	5.0	84.6	15.4**	54.0	2.52	21.4
G1 (78–100)	0.14	5.7	5.3	29.8	70.2**	17.7	0.68	26.0
G2 (> 100)	—	4.4	4.1	3.7	96.3**	1.1	0.05	22.0

		sand (%)	*silt (%)*	*clay (%)*
* Particle size distribution	G1:	83.6	10.6	4.8
	G2:	90.9	6.6	1.6
** Particle size distribution	A11:	6.6	63.8	29.6
	A12:	4.0	61.1	34.9
	C1:	4.1	48.2	42.7
	G1:	21.8	52.9	25.3
	G2:	82.5	10.0	2.5

larger bacillocylindrical excrements originate from earthworms (probably *Dendrobaena* species). The ellipsoids embedded in the o-matrix may indicate their passing through the earthworm alimentary canal (Bal, 1970). Schuster (1956) provides information about the role of Oribatid mites in the decomposition of organic matter in soils. The o-matrix in the C12 is derived from strongly welded earthworm excrements. Jongerius & Pons (1926b) mention the activity of *Dendrobaena octaedra* in acid peat without clay.

The welding of the excrements of Oribated mites and earthworms reflects the process of ageing, indicative for unfavourable conditions for decomposition (Bal, 1970, 1973). In general the decomposition of the organic material in this soil can be characterized by an oligotrophic moder formation towards raw humus (Jongerius

& Pons, 1962a; Pons, 1960; Bal, 1970). Fungal activity is a characteristic phenomenon in this soil.

The decomposition of the organic material in Soil 2 has somewhat more proceeded in comparison with Soil 1, although varying amounts of histons are present throughout the soil. Plasma formed by biochemical processes occurs as a yellowish substance impregnating cell walls (coniatic internal arrangement) and as a brown substance covering histons (pleistoplasmatic internal arrangement). Small part of the o-matrix (particularly in the A) is formed by disintegration of histons by biochemical processes. This is especially observable on the individual cells coming off histons with a phellemic internal arrangement.

Recent and fossil fungal activity occurs throughout the soil at a rather low level as can be seen from the presence of fungal hyphae, spores and sclerotia. These occur especially in the C12 horizon. The opaque o-plasma within melanons, occurring throughout the profile, is presumably also due to fungal activity.

Faunal activity is very high in the A12 where ellipsoidal excrements of Oribatid mites, forming modexotubules within histons, are numerous. In the C12 the faunal activity is low, but in the C13 strongly welded excrements from Oribated mites sometimes in modexotubules occur together with strongly welded bacillocylindrical earthworm excrements, thus forming an o-matrix with diffuse boundaries between the composing elements. Pedotubules containing fine (50-60 μm) organic bacillocylindrical excrements indicate some activity of Enchytraeidae.

This soil is likewise characterized by an oligotrophic moder formation, in which the welding of the excrements is illustrative for an unfavourable environment for decomposition of the organic material.

Both soils show rather high amounts of histons indicating that only part of the organic material has been decomposed by animal species indicative for unfavourable environments, which is also evident from the clearly expressed ageing and the fungal activity. The better drainage of Soil 2 is illustrated by a higher recent activity of the fauna penetrating to greater depths.

Contrary to these two soils the amount of histons in Soil 3 is much less and features of recent and fossil fungal activity are almost absent.

To 18 cm from the soil surface the histons have largely been transformed into strongly welded cylindrical excrements from small sized Dipterous larvae. Some ellipsoidal excrements from Oribatid mites are also present but these are less significant. Ageing of the excrements from Dipterous larvae can be seen in various stages in the A12 and C1. Strikingly are the completely welded excrements forming yellowish units in the o-matrix due to decomposition of specific types of histons without significant biochemical change (Bal, 1970). In the C1 also some modexotubules formed by Oribated mites and Dipterous larvae are found in histons. Weakly to strongly welded bacillocylindrical excrements from earthworm species (*Dendrobaena* species and/or *Lumbricus rubellus*), locally with embedded excrements from Oribatid mites, occur in high amounts in the A12 and C1. The stability of excrements of Oribated mites has been mentioned by Bal (1970).

This mesotrophic peat with some mineral material provides conditions for decompositions of the organic material in this moderately well drained soil, which are

Table 2. Soil morphologically characteristic fauna (Bal, 1970) per soil.

	Oligotrophic Soil 1	Oligotrophic Soil 2	Mesotrophic Soil 3
Oribatid mites	xx	xxx	x
Earthworms	x	xx	xxx
Dipterous larvae			xxx
Enchytraeidae		(x)	
Fungal activity	xxx	x	

x = not characteristic; xx = moderately characteristic; xxx = strongly characteristic.

much more favourable compared with Soils 1 and 2, shown by high activities of earthworm species and larvae of a Dipteron species. Bal (1970) also found a predominance of Diptera larvae and earthworms on the richer litter of the red oak compared to the litter of the Douglas fir. Therefore in Soil 3 excrements of Oribated mites were present to a small extent and fungal activity was almost absent. The decomposition of organic material and the morphologically characteristic fauna (Table 2) are strongly correlated with the oligotrophic (Soils 1 and 2) or mesotrophic (Soil 3) character of the peat (Jongerius & Pons, 1962b; Bal, 1970).

The data of Table 1 show that Soils 1 (till 120 cm depth) and 2 are purely organic with negligible amounts of mineral material (less than 5 %). The organic material in both soils has high to very high C/N ratios, due to low total N contents (0.7 - 1.2 %). The pH-H_2O in both soils is very low (3.0 - 3.5). This also illustrates clearly the unfavourable conditions and little proceeded decomposition in Soils 1 and 2.

Soil 3 has a considerable mineral admixture (15 - 20 %) of silty clay and consequently somewhat lower organic carbon contents, and relatively high total N contents (2.5 - 3 %) resulting in rather low C/N ratios (15 - 20). The pH-H_2O is around 5.0 except for the A11 where due to leaching more acid conditions prevail with a pH-H_2O of 3.5. In Soil 3 decomposition has taken place under favourable conditions and has much proceeded.

Decomposition can also be illustrated when the data of Table 1 and the profile descriptions are interpreted following the division in sapric, hemic and fibric soil material (Soil Survey Staff, 1970), which defines well decomposed, moderately decomposed and weakly to non-decomposed material. Criteria for this division are mentioned in Table 3 together with the relevant data of Soils 1, 2 and 3.

The maximum water content is calculated from the bulk density and the loss on ignition ($\approx$percentage organic matter), assuming specific weight of 1.4 g/cm^3 for organic matter and 2.7 g/cm^3 for mineral material, according to the formula: max.

$$\text{water content } (\%) = \frac{100}{\text{B.D.}} - \left(\frac{\%\,\text{o.m.}}{1.4} + \frac{\%\,\text{min.} = 100 - \%\,\text{o.m.}}{2.7} \right).$$

It follows from Table 3 that in all soils the maximum water content and the rubbed fibre content generally speaking increase with depth, whilst the dry bulk density decreases with depth.

Table 3. Criteria for sapric, hemic and fibric soil material (Soil Survey Staff, 1970) and relevant data of Soils 1, 2 and 3.

	Rubbed fibre (%)	Colour sodium-pyrophosphate extract (Munsell)	Max. sat. water content (%)	Dry bulk density (G/cm^3)	Horizon classification
Sapric(S)	< 10	5/2,4/2,4/1,3/2, 3/1,2/2,2/1	average < 450	> 0.2	
Hemic(H)	10–40	value < 7; chroma > 3	average 450–850	0.1–0.2	
Fibric(F)	> 40	7/1,7/2,8/1,8/2, 8/3	850–> 3000	< 0.1	
Soil 1					
A1 (0– 7 cm)	30–40(H)	5 YR 4/6(H)	430(S)	0.20(S/H)	Hemic
C11 (7– 18 cm)	30–50(H/F)	5 YR 3/3(H)	645(H)	0.14(H)	Hemic
C12 (18– 92 cm)	40–50(F)	10 YR 5/4(H)	765(H)	0.12(H)	Fibric
C13 (92–117 cm)	60–70(F)	10 YR 5/4(H)	930(F)	0.10(H/F)	Fibric
G1 (117–127 cm)					Non-organic
G2 (127–150 cm)					Non-organic
Soil 2					
A11 (0– 7 cm)	10–15(H)	10 YR 3/3(H)	345(S)	0.24(S)	Hemic (Sapric)
A12 (7– 24 cm)	15–25(H)	10 YR 5/4(H)	600(H)	0.15(H)	Hemic
A13 (24– 35 cm)	10–20(H)	10 YR 5/6(H)	645(H)	0.14(H)	Hemic
C11 (35– 55 cm)	40–50(F)	10 YR 7/4(H)	700(H)	0.13(H)	Fibric
C12 (55– 86 cm)	90–95(F)	10 YR 7/4(H)	930(F)	0.10(H/F)	Fibric
C13 (86–120 cm)	80–90(F)	10 YR 7/3(H)	700(H)	0.13(H)	Fibric
G1 (120–142 cm)	70–80(F)	10 YR 8/3(F)	930(F)	0.10(H/F)	Fibric
G2 (> 142 cm)	80–90(F)	10 YR 8/2(F)	—	—	Fibric
Soil 3					
A11 (0– 18 cm)	10–15(H)	5 YR 2/2(S)	390(S)	0.22(S)	Hemic (Sapric)
A12 (18– 51 cm)	< 10(S)	5 YR 3/3(H)	305(S)	0.27(S)	Sapric
C1 (51– 78 cm)	30–40(H)	5 YR 3/3(H)	560(H)	0.16(H)	Hemic
G1 (78–100 cm)	–	5 YR 6/4(H)	670(H)	0.14(H)	Hemic
G2 (> 100 cm)					Non-organic

Soil 1 has a hemic A1 although maximum water content and dry bulk density already point to some sapric characteristics. The C11 is hemic although the rubbed fibre content tends to be slightly too high. The C12 has a rubbed fibre content high enough to quality for fibric soil material although all other characteristics point to a hemic character. Because rubbed fibre content is the diagnostic criterion and the other characteristics are only illustrative in such cases we are choosing the classification according to the rubbed fibre content. The C13 is fibric except for the colour of the sodium pyrophosphate extract which points to hemic. The conclusions concerning decomposition are in agreement with the conclusions drawn from its micromorphology.

Soil 2 has a hemic (to sapric) A11 with hemic characteristics in case of the rubbed fibre content and colour of the sodium pyrophosphate extract whereas maximum water content and dry bulk density are sapric but close to hemic. The A12 and A13 are hemic with rather low rubbed fibre contents. The C11 has a rubbed fibre content high enough to qualify for fibric although all other characteristics point to hemic. The C12 is clearly fibric (colour sodium pyrophosphate extract not completely matching) whilst the C13 is clearly fibric on the basis of rubbed fibre content although all other characteristics point to hemic.

The micromorphological description of a sample in a more decomposed part of the C13 also points to the hemic character of the more decomposed parts. Finally the G1 and G2 horizons fully qualify for fibric. In this soils the slightly further and deeper proceeded decomposition read from the physico-chemical data also agrees with the conclusions drawn from its micromorphology.

Soil 3 has a hemic (to sapric) A11 because the rubbed fibre content is slightly too high, but all other characteristics point to sapric. The A12 is sapric but in this case the colour of the sodium pyrophosphate extract is not exactly matching. The C1 fulfils all requirements of hemic soil material. The stage of decomposition based on physico-chemical data again agrees very well with the one concluded from the micromorphological study. The classification of the soil materials as discussed above is also shown in Table 3, which is used to classify the soils according to the Soil Taxonomy (Soil Survey Staff, 1970).

The order of the Histosols includes soils that consist for more than half of the upper 80 cm of organic material unless rock or rubble are shallower than this depth. Organic soil material if saturated with water for prolonged periods or artificially drained is defined to contain more than 30 % organic matter if the mineral fraction is 50 % or more clay; or 20 % or more organic matter when the mineral fraction has no clay and proportional amounts of organic matter if the clay content of the mineral fraction is intermediate. All three soils meet the requirements of the *Histosols*. For the classification on lower levels within the control section (to a depth of 130 cm) three tiers are distinguished. The surface tier normally consists of the top 30 cm, is more unstable and most readily altered by cultivation and is used in case of thick organic materials as differentiating at soil series or soil phase level. The subsurface tier is normally 60 cm thick and generally the kind of materials in this tier are the basis for differentiation at suborder level. The bottom tier is 40 cm thick unless the control section ends shallower. This tier is normally used to differentiate at subgroup level.

On suborder level Soils 1 and 2 may be classified as *Fibrists* and Soil 3 as a *Hemist* according to the kind of organic material of the subsurface tier. Although the soil materials of the subsurface tiers of Soils 1 and 2 show many characteristics that point to hemic we have considered the rubbed fibre content as decisive.

On the level of the Great Soil Groups, the classification of the Fibrists differs from that of the Hemists. The Fibrists are classified according to mean annual soil temperatures, the difference between mean summer and mean winter temperatures, the kind of plant remains in the upper 90 cm of the soil and the presence of humilluvic materials. Soils 1 and 2 developed in Sphagnum peat may both be classified as *Sphagnofibrists* (Soil Survey Staff, 1970). Soil 3 is classified according to the key as a *Medihemist* because its presence in mid-latitudes, having mean soil temperatures higher than 8 °C and differences between mean summer and winter temperatures of more than 5 °C.

The classification of the two Sphagnofibrists (Soils 1 and 2) provides some difficulties. Although they have to be classified as Typic Sphagnofibrists according to the rules, this is not satisfying. The composition of the organic soil material in the subsurface and bottom tiers in both soils is on the boundary between fibric and hemic, and although only in Soil 2 a layer of hemic material with a thickness less than one-third of the thickness of both tiers is occurring we would like to express this charicteristic in the classification on subgroup level. For this reason we are classifying both soils as *Hemic Sphagnofibrists.*

In classifying Soil 3, the Medihemist on subgrouplevel the depth of the mineral subsoil has to be considered. As a result of the presence of continuous mineral material, 30 cm or more thick, with an upper boundary within the control section below the surface tier, in this case at a depth of 100 cm, the classification would read: Terric Medihemist. In this name the rather strong sapric character of the organic soil layers is not expressed. The organic material in the subsurface and bottom tiers shows a composition which in this case is on the boundary between sapric and hemic.

Although only a layer of 21 cm (30 - 51 cm) is classified as sapric, and this layer is slightly less than one-third of the thickness of the organic layer of the subsurface and bottom tiers (30 - 100 cm = 70 cm) we would like to consider this enough for the adjective sapric, mainly because the hemic material of the A11 horizon is very near to sapric. As a result of these considerations we are classifying soil 3 as a *Sapric Terric Medihemist.*

In classifying organic soils very different criteria are used in the current classification systems (Farnham & Finney, 1965). In the Soil Taxonomy (Soil Survey Staff, 1970) only the subsurface and bottom tiers are completely diagnostic for the classification of organic soils on the higher levels. From a genetical as well as from an ecological point of view and also in relation to agricultural practises, e.g. the use of machinery and the supporting capacity of the soil for cattle, however, the character of the topsoil is much more important than subsurface layers. For these reasons and also because we do not see why organic soils can not be classified on higher levels according to the characteristics of their upper soil horizons just like mineral soils we consider the classification system of the Soil Taxonomy for the Histosols very unsatisfactory.

The argument that topsoils of organic soils are disappearing rapidly under modern agricultural practises is not realistic because in that case also when erosion occurs in mineral soils main emphasis should be laid on subsurface horizons. Moreover the disappearance of top soil material does not mean that also top soil horizons are disappearing when part of the organic matter oxidizes, as progressively again hemic and sapric surface horizons are gradually developing even from fibric soil material. In such cases a kind of mobile equilibrium exists in which the upper soil layers are rather stable in properties. With progressive disappearing of the subsurface horizons especially these are the only horizons that are changing in thickness.

In the present study it is shown that the investigated soils are strongly differing in degree of development and properties of the organic A horizons (Pons, 1960) which are of great practical importance.

In this respect, in classifying organic soils we prefer the use of the Dutch Soil Classification System for the higher levels (de Bakker & Schelling, 1966) because, in this system, main emphasis is laid on the kind and characteristics of the upper soil horizons. All three soils are classified as *'Veengronden' (Organic Soils)*, more or less in the same way as the subdivision of the Histosols from mineral soils in the Soil Taxonomy. The diagnostic criterion on suborder level is the presence of a well developed moulded surface horizon so called peaty earthy layers. Peaty earthy layers are peaty A1 horizons thicker than 15 cm or Ap horizons which contain not more than 10 - 15 % (v/v) of recognizable plant remains.

In terms of the Soil Taxonomy this means that the 'peaty earthy layer' has to show a sapric or a hemic to sapric character. The A1 horizon of Soil 1 does not meet the requirements of a peaty earthy layer, and this soil would be classified within the suborder of the *Raw Peat Soils*. Soils 2 and 3 both are possessing a peaty earthy layer and are classified in the suborder of the *Earthy Peat Soils*.

On group level the Raw Peat Soils are subdivided according to the state of physical ripening, the presence of humilluvic layers and the presence of sand or clay layers on top of the peat. Soil 1 has to be classified together with the *Ordinary Raw Peat Soils* in relation with the more or less ripened character of the horizons below a depth of 20 cm. On subgroup level we include Soil 1 with the *'Vlier' Peat Soils* because the absence of organic B horizons comparable with humilluvic materials of the Soil Taxonomy, and clay or sandy layers on top of the soil.

The subdivision on group level of the Earthy Peat Soils to which both Soils 2 and 3 belong is based on the presence or absence of an organic B horizon and on the clayey or non-clayey character of the peaty A1 horizon.

The top layers of both Soils 2 and 3 showing 91.2 % and 78.6 % organic matter, respectively, are classified as 'peat' (de Bakker & Schelling, 1966). This property, together with the absence of organic B layers in the subsoil, is diagnostic for the classification of both Soils 2 and 3 with the group of *Clay-poor Earthy Peat Soils*.

On subgroup level a distinction is made between Clay-poor Earthy Peat Soils with a thick A1 horizon (>50 cm), to which Soil 3 belongs, and Clay-poor Earthy

Table 4. The classification of Soils 1, 2 and 3 in the various classification systems.

	Soil 1	Soil 2	Soil 3
Soil Taxonomy	Hemic Sphagno-fibrist	Hemic Sphagno-fibrist	Sapric Terric Medihemist
Dutch Soil Classification system	Ordinary Raw Peat Soil with peaty A1 (Vlier Peat Soil)	Clay-poor Earthy Peat Soil with A1 thinner than 50 cm ('Made' Peat Soil)	Clay-poor Earthy Peat Soil with thick A1 (> 50 cm) ('Bo' Peat Soil)
FAO-UNESCO Soil Map of the World	Dystric Histosol	Dystric Histosol	Dystric Histosol

Peat Soil with an A1 horizon thinner than 50 cm, to which Soil 2 belongs. The corresponding names are respectively *'Bo' Peat Soils* (Soil 3) and *'Made' Peat Soils* (Soil 2).

According to the FAO classification all three soils are classified as *Histosols* (O). Following the subdivision of the Histosols the three soils are belonging to the *Dystric Histosols (Od)* because they all have pH values of less than 5.5. in some part of the soil between 20 and 50 cm from the surface.

To our opinion this criterion is not correct because nearly all very fertile soils developed in eutrophic peats must then also be classified as Dystric Histosols (Od).

In Table 4 the classification of the three soils in the three classification systems is compared. We can conclude, that in the Dutch classification system, already on the higher levels, pedo-genetical as well as ecological and agricultural characteristics are taken into consideration. The classification according to the Soil Taxonomy fails because it does not lay emphasis on these properties; on the contrary it is merely based on subsoil characteristics that are of minor significance both in relation to pedogenetical and ecological-agricultural aspects of the soil. The FAO-UNESCO subdivision also fails to express the important differences between the three organic soils studied.

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