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DETERMINING THE DEGREE OF PEAT DECOMPOSITION FOR PEAT-BASED PALAEOCLIMATIC STUDIES

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SUMMARY

Different methods of determining the degree of peat decomposition are reviewed, showing fibre content and alkali-extraction as suitable methods. The NaOH extraction technique is tested, with different alkali concentrations, timing, inorganic contaminant and evaporation rates. The results show that the colorimetric measurements of continuous samples can provide a robust and replicable record. Experiments should take account of the inorganic content of the peat samples, and keep to a strict time schedule. However, transformation of recorded measurements into the form of percentage humification is questionable, because of the variable nature of humic acids. Data can be best represented as percentage light transmission or optical density.

Alkali-extraction of humic acids appears to be more suitable than fibre content in peat-based climatic studies because of the differential response of the latter technique to changing species composition.

INTRODUCTION

Mires have been used as sources of proxy climatic data since the peat-stratigraphic studies conducted in the nineteenth century, and the advent of pollen analysis in the early twentieth. Both lines of enquiry led to descriptions of Holocene climatic change, within a broader context of environmental change. Examples are the divisions of post-glacial times into broad climatic and chronostratigraphic units, such as the Blytt-Sernander scheme (Sernander, 1908) and various pollen-zone sequences (Godwin, 1940). The incorporation of radiometric dating into palaeoecological studies, as well as other changes in methodology (Blackford, 1993) enabled a movement towards the detailed reconstruction of climatic changes from data obtained from mires (Barber, 1981a; 1985). Pollen data from many sites can now be combined on a regional basis to reconstruct past climates (Huntley, 1990; MacDonald & Edwards, 1991); macrofossil analyses, particularly of Sphagna, can show changes in past peat-surface wetness (Barber, 1985; Haslam, 1987), and the two techniques can be combined to infer climate and vegetation history (Barber, 1981b; Barber et al., 1993).

As well as specific subfossils contained within it, properties of the peat matrix itself can provide proxy climatic information (eg. Aaby, 1976; Dupont and Brenninkmeijer, 1984). One such property is the extent to which the peat has decomposed, as shown by the degree of peat humification, which is linked to surface wetness at the time of peat deposition (Aaby & Tauber, 1975). Measurement of the degree of humification at different levels within a peat profile can therefore give an indication of changes in surface wetness at a certain location. Local reconstructions of peat-surface wetness can then be combined to reconstruct regional changes in peat hydrology, and by inference, changes in climate (Blackford & Chambers, 1991; Blackford, 1993). Ombrotrophic mires, including raised bogs and the watershedding parts of blanket bogs are most useful in this context, as at these locations surface wetness is most closely linked to precipitation and evaporation, rather than to other site characteristics (Haslam, 1987; Blackford, 1990; Chambers, 1988 - published 1991).

This paper aims to determine how the degree of peat humification might best be assessed in studies of peat and climate. A review of techniques used is followed by a comparison of the two methods most suitable for palaeoclimatic studies.

TECHNIQUES USED TO MEASURE DEGREE OF DECOMPOSITION

Techniques for estimating the degree of decomposition and humification of humic soil and peat can be grouped into four categories: visual examination and classification, measurement of physical properties, measurement of chemical properties, and the chemical extraction of soluble material.

Visual examination

Stratigraphic studies of peat humification changes led the way to theories regarding mire hydrology and ecology (Osvald, 1923), as well as the broad climatic divisions of the post-glacial (Sernander, 1908). The data used were based primarily on the colour of the different peat horizons, their content in terms of constituent plant material and their state of preservation. Troels-Smith (1955), for example, described how by squeezing peat and examining the colour of the extracted water, humification degree could be estimated on a five-class scale. Von Post's (1924) 10-point scale (Table 1) used variables of texture and physical deterioration as well as colour.

Table 1. The 10-class scale of peat humification (after von Post 1924; Aaby 1986)

Type and colour of peat	Humification value
Yellow-light brown, often with undamaged *Sphagnum* leaves.	
Yellow, pale and whitish,	1
Yellow,	2
Light brown,	3
Brown, with *Sphagnum* leaves more or less damaged.	
Milk chocolate-brown,	4
Brown,	5
Dark chocolate brown,	6
Dark brown, *Sphagnum* leaves badly damaged.	
Dark brown, plant structures can still be observed in the matrix, wood remains, seeds etc. determinable,	7
Dark coffee-brown, macrofossils disintegrated and hard to determine,	8
Plant structures rarely observed and indeterminable,	9
Blackish-brown peat.	
Totally destroyed organic material,	10

The von Post humification scale has been widely used in subsequent studies, often alongside measures of other peat properties. For instance, Haslam (1987; see also Twigger & Haslam, 1992) described vegetational changes across recurrence surfaces using both the 1-10 scale and plant macrofossil analysis. There are several distinct drawbacks with the scheme, one of which is that it is by nature a classification. Measurements on a continuous numeric scale, not possible using von Post's method, are more accurate for the detection of small-scale or cyclic changes. The use of the state of Sphagnum remains is an important element of the classification, and makes it invalid in peat where Sphagna are rare or absent. The technique is of limited use in many blanket peats, where profiles fall entirely into classes 8-10.

Casparie (1972) estimated the degree of humification by observing the colour of freshly exposed peat. The quicker the colour changed, the more humified the peat. This method is, however, unquantified, and difficult to compare between different peat types.

Indeed, all colour-based visual examination methods are beset by problems involving the condition of natural light and the effect of colour change through oxidation.

In a study of the recurrence surfaces in a raised bog, Dickinson (1975) used a classification that included observing the degree of disintegration. She identified Sphagnum peat in which plants were in a whole state, consisting of stems, branches and leaves. This was distinguished from an intermediate stage where branches had become detached, and a more humified type in which leaves were separated from branches. When combined with colour observations this method worked well, except where Sphagnum cuspidatum was present, as it was always found with separated leaves. For widespread use in the study of peat and climate, however, this method is again unsuitable in samples where Sphagna are not frequent enough, or are decomposed beyond recognition.

A simple visual assessment of humification was devised at Southampton University, whereby a suspension of disaggregated peat was poured into a large measuring cylinder until a mark on its base was obscured (cf. Stoneman, 1993). The quantity of suspension required to obscure the mark was taken as a surrogate measure of peat humification. The reliability of this 'turbidity' method is unquantified.

Physical properties

As decomposition of plant matter proceeds, quantifiable changes occur to peat deposits. The proportion of mineral matter increases, as does bulk density (Zoltai, 1991). Large fibres are broken down, leading to an increase in the proportion of fine material. Pore space between particles is reduced, and water holding properties change. Measurement of these properties might indirectly measure the degree of humification.

A comprehensive comparison of the properties of peat materials has been carried out by Levesque & Mathur (1979) and Levesque et al. (1980). They measured bulk density, mineral content, proportions of different plant types, percentages of fine and coarse particles and water holding capacity, and correlated each variable against all the others. The maximum number of significant correlations were with fibre content, which led Levesque & Mathur (1979) to conclude that fibre content determination was the most suitable way of measuring the extent of decomposition in peats.

Chemical properties

The chemical transformations that occur as plant matter decomposes are extremely complex and are far from being fully understood. Certain chemical properties may be expected to increase and others to decrease, although the initial content will depend on plant type.

Humus has a higher cation exchange capacity, a higher nitrogen content and greater calorific value than undecomposed plant material (Mathur & Farnham, 1985). However, these variables are particularly species dependent, and so changes in the principal peat-forming species would restrict their use in a palaeoclimatic context. Assessing the calorific content of peat has been the subject of studies concerned with finding mire horizons suitable for fuel (Tolonen, 1982). The calorific content may be of use in this field when either a rapid and cheap means of measuring it is developed, or some reliable indirect measure is found, and when the effects of different parent material (plant matter), which may overwhelm the subsequent effects of decompositional processes, can be compensated for.

Hemicellulose and cellulose decompose, and would therefore become less abundant in more humified peat, whereas some polysaccharides are by-products of decomposition, and would therefore become more concentrated. Mathur & Farnham (1985) concluded, however, that these properties vary widely according to different botanical composition.

As biodegradation proceeds, the biodegradable proportion of the remaining peat decreases. As such, respiration rates should decrease through time. Levesque & Mathur (1979) measured the rates of respiration of peats when allowed to decompose in ideal conditions. More humified peat would theoretically decompose more slowly than would fresh plant matter. Results from a variety of different samples correlated well with fibre content data, suggesting that respiration rate could be a useful measure of degree of decomposition, and adding credibility to the use of measurements of fibre content.

Chemical extraction of soluble material

Humic acids are produced by the decomposition of organic material. They are dark brown in solution, giving humus its colour. As peat decomposes, the proportion of humic acid increases, and attempts have been made to estimate the quantities of humic acid in peat and organic soil. The extractant most widely used in both palaeoecology and soil chemistry has been sodium hydroxide. Studies by Aaby (1976), Chambers (1984), Rowell & Turner (1985) and Blackford & Chambers (1991) have assumed that the colour of NaOH extracts are indicative of the degree of humification, and therefore of the extent of decomposition.

The use of NaOH extracts as humic-acid indicators has not, however, been universally accepted. Kaila (1956) noted that NaOH solutions of peat also contain high levels of contaminant, non-humic material, and Hayes (1985) noted that additional compounds are produced by the extraction procedure. Kaila (1956) developed a "pyrophosphate index", whereby sodium pyrophosphate was used instead of alkali. Although this reduced the quantity of contaminants, it also reduced the humic acid yield.

Hayes et al. (1975) tested different solvents in order to extract humic acids as efficiently as possible. The solvents used could be divided into two groups: those that did not alter the molecules but are relatively inefficient extractants, and those that extract efficiently but cause structural alterations (Table 2). Of the reagents tested, significant yields were only obtained by EDA and NaOH, both of which extract the more complex and less water-soluble components of humus (Hayes et al., 1975, p. 244). NaOH is a more reliable single-process reagent, as EDA appreciably alters the humic compounds extracted.

Table 2. Yields of Humic and Fulvic fractions extracted with different solvent systems (after Hayes et al. 1975, p. 236)

Extractant	Humic acid yield (%)	Fulvic acid yield (%)
DMF	16	2.0
Sulpholane	10	12.0
DMSO	17	6.0
Pyridine	34	2.0
EDA-HCL	5	7.8
EDA (Anhydrous)	2	3.0
Sodium Pyrophosphate	13.7	1.6
Dowex A-1	17.8	1.6
EDTA	12.5	3.8
EDA	**49.0**	14.0
Sodium Hydroxide	**58.0**	2.0

Abbreviations: DMF, Dimethylformamide; DMSO, Dimethyl sulphoxide; EDA, Ethylene diamine; EDTA, Ethylene diamine tetraacetic acid.

Conclusion

From the physical properties group of measures of decomposition, fibre content appears to be the most reliable. Estimates of humic acid content, based on impure extracts in NaOH should also provide an indication of the degree of humification. After a review of the precise nature of the extraction technique, these two methods are compared.

TESTING THE NaOH EXTRACTION PROCEDURE

In previous palaeoecological studies an alkali extraction method has been used, with the optical absorbtion of the resulting solution being measured by colorimetry (Aaby, 1986). The basis of the method was that used by Overbeck (1947), modified by Bahnson (1968) and translated by Aaby (1986, p. 151). Various aspects of this method have been tested.

To eliminate differences between samples, all tests were performed on material from a bulk sample that had been dried, ground and mixed for 20 minutes in an automatic homogenizer. A batch of 12 homogenized samples produced optical densities with a mean value of 0.440 (sd 0.06), and a range of 1.3 % from the mean, showing the internal consistency of the technique.

Mineral content

Chambers (1984) referred to the possibility that inorganic material incorporated in the peat matrix might cause a distorting effect on humification results. In order to test this effect, a batch of samples was deliberately contaminated with varying quantities of clay. These samples were then remixed and divided, with one part tested for humification and the other incinerated. Results were thus obtained for optical density and percentage mass-loss on ignition.

The linear relationship shown in Figure 1a is caused by the mineral matter reducing the amount of organic matter in the original 0.2 g sample. This can be corrected for, either by increasing the original sample size, so that 0.2g of organic material is boiled in NaOH, or by correcting the final result using the following equation:

$$t = r / LOI,$$

where t = corrected result, r = percentage transmission reading (prefered to optical density readings, see section 3.6), LOI = loss on ignition expressed as a proportion (for instance for 60 % loss on ignition, LOI = 0.6).

Schnitzer (1967) suggested that clay particles in a humic soil can gather around humic molecules in such a way as to prevent their solubility in alkali, so it is possible that not all of the distorting effect is accounted for by the reduction in organic material. Schnitzer found a considerably increased yield, especially of fulvic, but also of humic acids, after a pre-wash treatment of HF-HCL. Although mineral contents are low in most ombrotrophic peats, a pre-wash may be useful in some circumstances.

Evaporation

Haslam (1987; personal communication) noted that while boiling the samples a different amount of evaporation occurs from each one. To quantify the effect of differential evaporation a batch of twelve similar samples was used, six samples being covered through the boiling time and six remaining uncovered. Figure 1b shows that the uncovered samples have slightly higher values of optical density than the others, possibly due to the effect of increasing concentration as water is lost. The loss is, however, statistically insignificant to the end result; a t-test shows no significant difference between the means of covered and uncovered samples (df=10, p=0.05, T[calc]=1.01, T[crit]=2.18).

Extraction time

A group of homogenized samples was allowed to boil for different time periods in otherwise similar conditions. The results show (Figure 1c) that no further extraction occurred when the samples were boiled for longer, suggesting that one hour is adequate.

Alkali concentration

Aaby (1986) recommended that 5 % NaOH solution should be used. Tests have been conducted using a range of NaOH concentrations on identical samples (Figure 1d). The results showed that not all the possible extraction is achieved at 5 % concentration; a slightly darker solute was produced using 8 % NaOH. Although the variation is less than that shown between the samples in the initial control experiment, the 5 % solution used in previous studies may be too weak. The pattern beyond 8 % suggests that absorbance, and therefore extraction, is reduced when 10 % or 12 % NaOH solutions are used.

Colorimeter filter wavelength

Aaby (1986) and previous authors used a colorimeter filter wavelength of 540 *n*m to test the transmission or absorbance of solute. A study by Sapek et al. (1980), however, showed the potential of using a sequence of wavelengths. Figure 2 shows the results of a multi-wavelength colorimetry test on extracts of peat from an Irish mire. Low wavelengths appear to show less variability in transmission in the lower part of the profile than higher wavelengths, with the maximum range of transmission being detected by wavelengths between 520 and 590 *n*m. As maximum variability is desirable for sensitivity to hydrological changes, this range appears best suited to peat-based climatic studies, and so a wavelength of 540 *n*m or 550 *n*m is recommended.

Discussion

These tests have quantified the tolerances of some aspects of the NaOH extraction procedure. It has been shown to be replicable, and the data can be used more accurately, especially where peats contain inorganic material. Variations in peat humification measured this way do not, it seems, arise from experimental sources.

*Figure 1. Graphs showing the effect of **A**, mineral material in the peat; **B**, evaporation; **C**, extraction time; and **D**, alkali concentration, on the optical density of alkali-soluble peat extracts.*

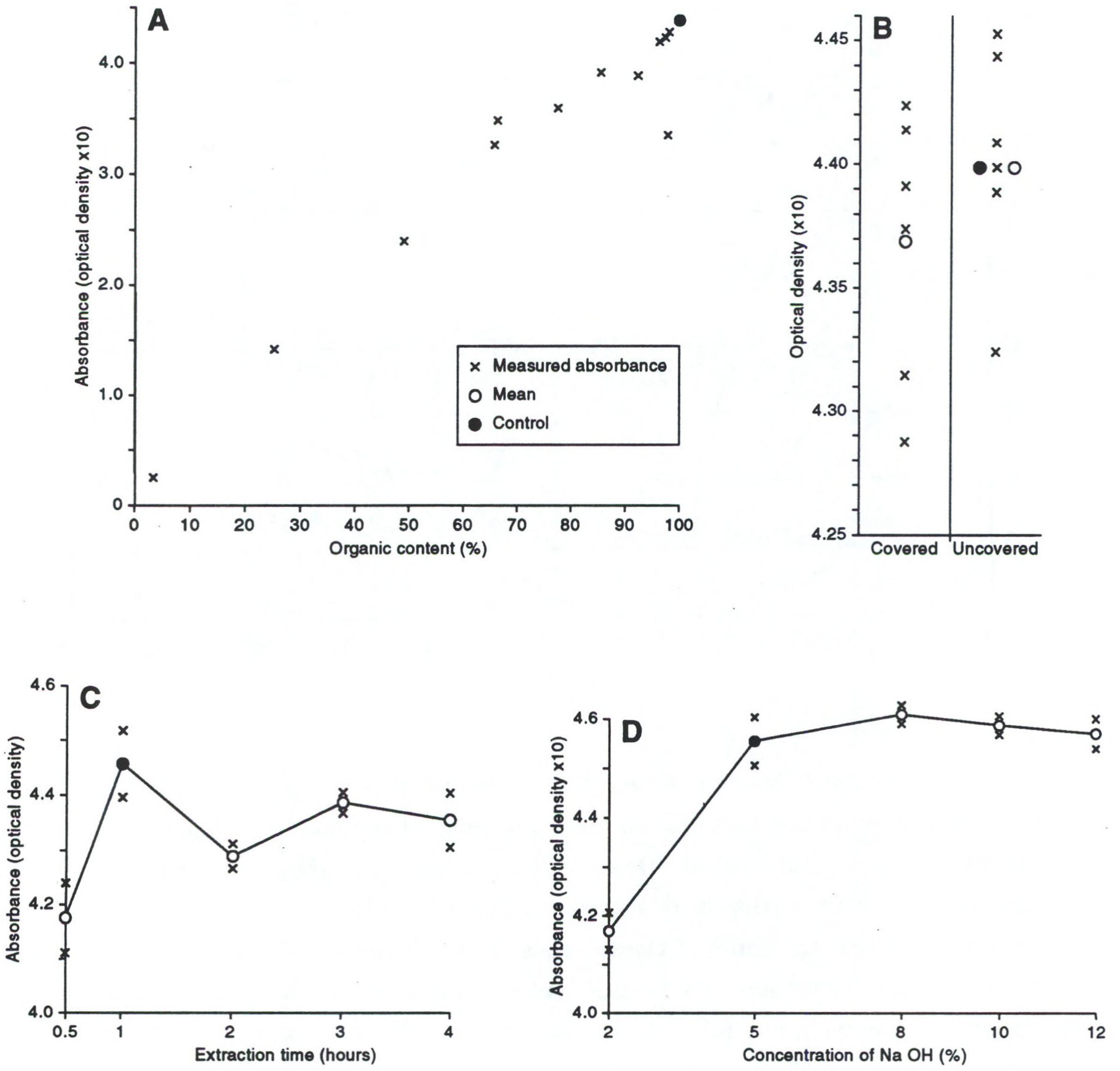
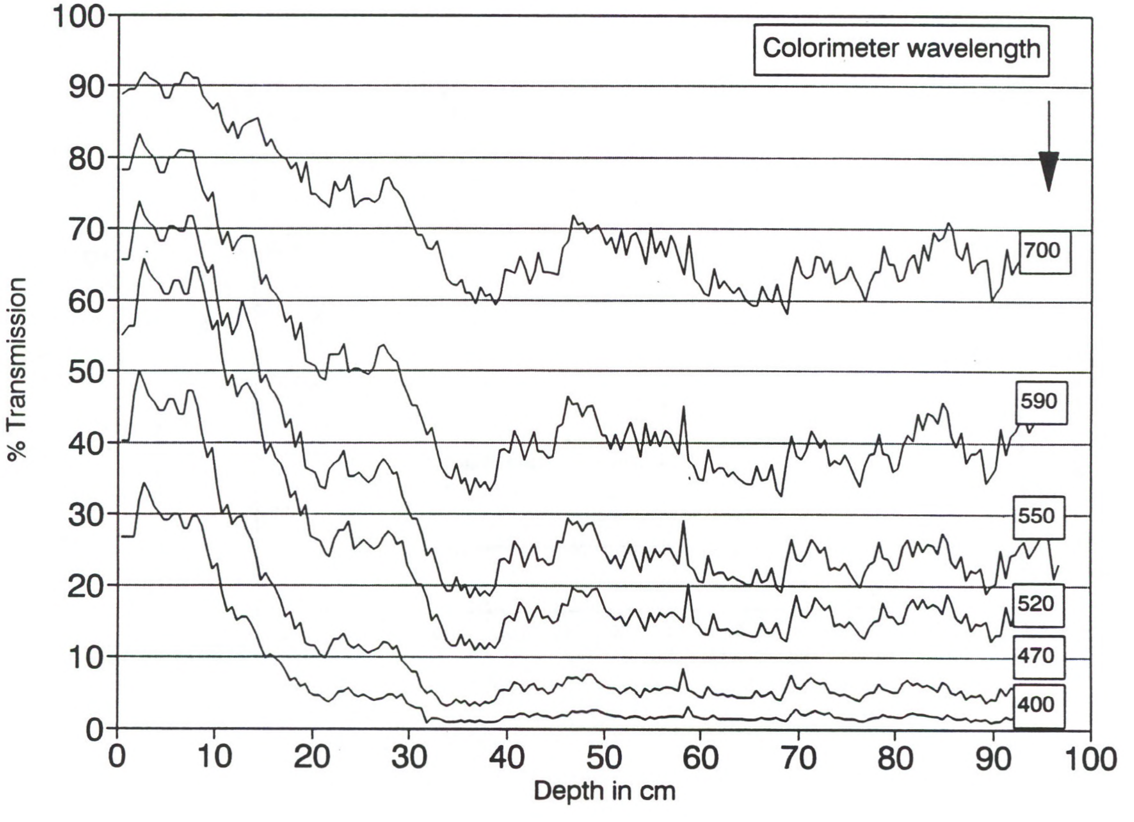


Figure 2. Percentage transmission of light of different wavelengths through alkali-soluble peat extracts from a peat profile in western Ireland, using 0.5 cm thick contiguous samples.



Aaby (1986) recommended that absorption values from the colorimeter be converted into a figure of percentage humification, calculated using an equation derived from experiments with humic acid standards. However, there are distinct problems with this conversion, not least that the existence of a standard humic acid is dubious. Humic acid is a variable and complex **"...mixture of closely related macromolecules, and the composition is determined by the source of the acid and the method employed in its isolation"** (Haworth & Atherton, 1965, p.57). Techniques of electron spin resonance and NMR spectroscopy have still left gaps in the description and explanation of humic substances (Wershaw & Mikita, 1987). What is clear is that each sample of humic acid is to some extent unique, with differences depending on the material from which the humic acids are derived and conditions of decomposition. The calculation of 'percentage' humification is therefore an unnecessary transformation of the data. Measurements of percentage light transmission are preferable to those of absorbance as the former are on a linear scale.

Previously published humification curves showing percentage humification (Aaby, 1976; Chambers, 1984; Rowell & Turner, 1985) are no less valid, but the humification data shown should be considered as a semi-quantitative estimate. Profiles of percentage transmission are preferable, with higher transmission values being indicative of and proportional to, but not an exact measure of, lower degrees of humification.

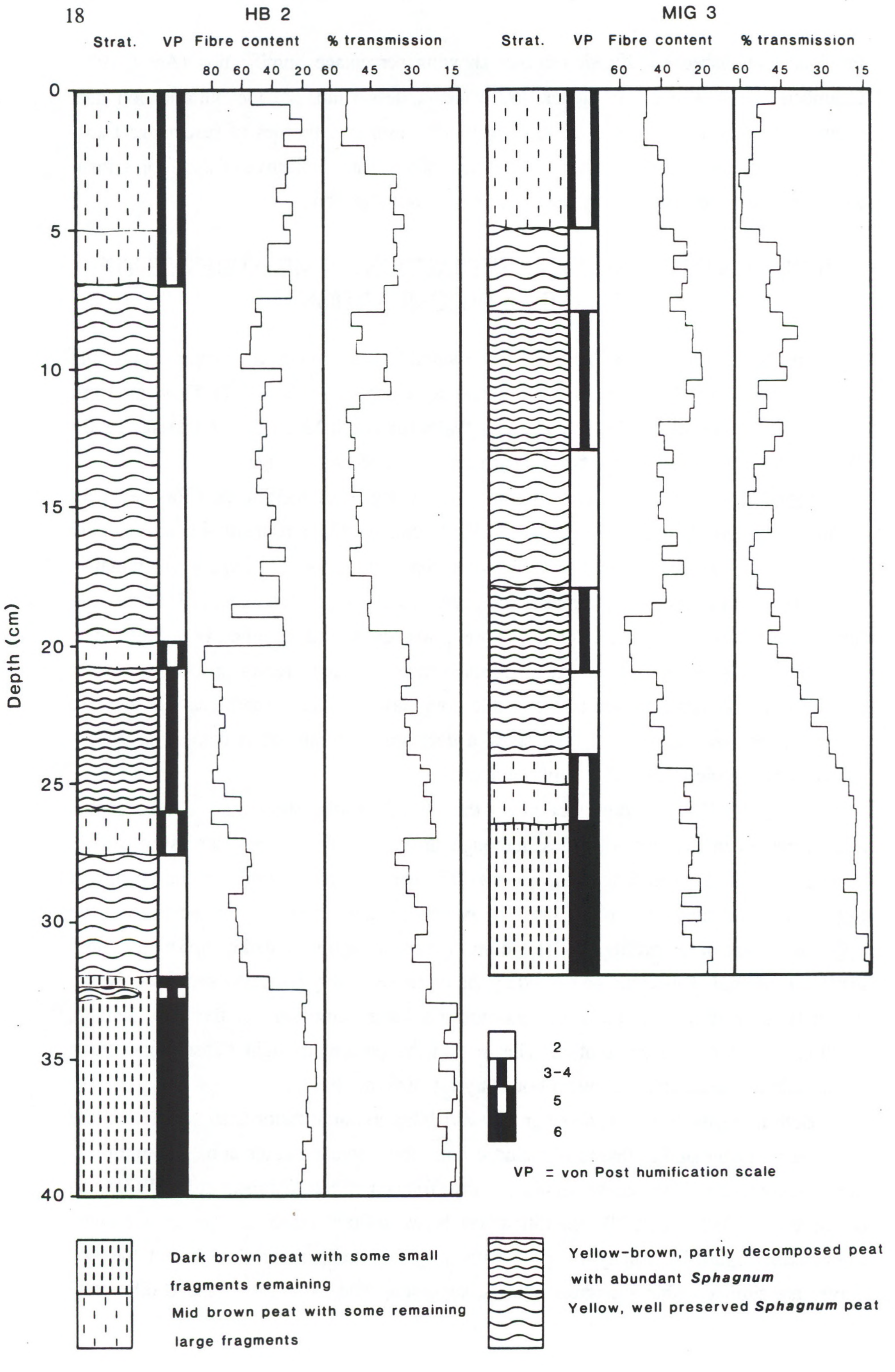
FIBRE CONTENT AND NaOH EXTRACTION AS MEASURES OF THE DEGREE OF DECOMPOSITION

The upper sections of two blanket-peat monoliths were chosen to compare the NaOH extraction method and the fibre content method (after Sneddon et al., 1971). These are from North Yorkshire (monolith HB 2) and North Wales (monolith MIG 3, cf. Blackford, 1990). The results from consecutive 0.5 cm thick samples are shown in Figure 3.

Monolith HB 2. Both variables show a high degree of humification for the lower section of the profile, recording changes at 32-33 cm. At 27.5 cm, there is a stratigraphic change to slightly darker, more humified peat containing abundant Cyperaceae remains. This is shown in the percentage transmission curve as a change to more humified peat. The fibre-content curve, however, increases, seeming to indicate less humified peat. At the upper limit of this horizon at 20 cm, percentage transmission increases, and fibre content decreases. In the upper section of the profile both variables record more changes than are visible in the stratigraphy, and both show a decrease in humification coinciding with a visible stratigraphic change at a depth of 7 cm.

Monolith MIG 3. Some sections of the MIG 3 profiles show coinciding increases and decreases in the two variables, although differences do occur where stratigraphic changes are visible. The fibre content curve falls abruptly, for example, at the change to Sphagnum-dominated peat at 12.5 cm. The percentage transmission curve increases in the uppermost 5 cm of the profile, despite the peat matrix consisting of darker, apparently more humified material. This could be caused by the presence of very recent root material, which would be unhumified and be a disproportionately large component of the dried sample, resulting in a less opaque solution. This rise in the percentage light transmission curve might delimit the acrotelm/catotelm boundary (cf. Ingram, 1983).

Both methods, therefore, show greater variability in humification than is visible in the stratigraphy. Other studies that have included both fibre content and alkali-extract humification determinations have shown similar results (Tolonen, 1982; Wijmstra et al., 1971; van der Molen & Hoekstra, 1988). The differences between fibre content and percentage transmission (in Figure 3) usually coincide with a visible stratigraphic change, but the two curves are similar within stratigraphic units, suggesting that the curves respond differently


HB 2
MIG 3
Strat.
VP
Fibre content
% transmission
80 60 40 20
60 45 30 15
Depth (cm)
0
5
10
15
20
25
30
35
40
2
3-4
5
6
VP = von Post humification scale
Dark brown peat with some small fragments remaining
Mid brown peat with some remaining large fragments
Yellow-brown, partly decomposed peat with abundant Sphagnum
Yellow, well preserved Sphagnum peat

to changes in the source material. This is because different plants, whose fragments start at different sizes, have different decompositional characteristics when subjected to the same decompositional environment. Most Sphagna are prone to breakage on decomposition, but with leaves remaining intact and identifiable. Eriophorum remains preserved in a matrix of well-decomposed peat often occur in a matted form, with large fibres surrounded by dark, amorphous material. Ericaceous remains, however, and the roots and leaves of Gramineae species, appear to decompose to smaller particles under the same conditions, or break up more readily in the acrotelm.

The results of the alkali-extraction method are also distorted by changes in the peat-forming plants. Different chemical and structural properties cause a different rate of humification, and a different end-product. However, the directional response of these changes makes this method preferable for palaeoclimatic studies. For instance, if a 'dry' assemblage of mire plants dominated by Calluna vulgaris gives way to a Sphagnum-dominated 'wetter' community, the degree of humification recorded would be reduced, as the Sphagnum decays at a lesser rate under the same conditions. Coulson & Butterfield (1978) present figures of mass-loss during the first year of decomposition of 16.2% for Sphagnum recurvum and 25.6% for Calluna vulgaris. Heal et al. (1978) showed a marked difference between the decomposition of Calluna shoots and stems, and their results were appreciably lower than those of Coulson & Butterfield (1978). However, their Calluna decomposition rates were faster than those recorded for Sphagnum species by Clymo (1965; 1978) from similar sites. A change to wetter conditions, then, should have an exaggerated effect on the extract colour when species composition changes. The direction of response of fibre content, however, to a change in species composition, may contradict that caused by a change in the decompositional environment, making the technique less useful in this context.

CONCLUSIONS

1. From a range of possibilities, fibre content and alkali-extraction appear to be the more suitable methods of determining the degree of peat decomposition.
2. Alkali extraction of continuous samples of peat can be measured colorimetrically to provide a robust, replicable and continuous record. However, transformation of the recorded measurements to produce data in the form of percentage humification is questionable, because of the variety of humic acids produced by different peats under

Figure 3. Comparison of fibre content and percentage transmission curves as measures of degree of humification from two short peat profiles.

different conditions. Data can be best represented as percentage light transmission or optical density.

3. Experiments should include, and take into account, measurements of the inorganic content of the peat, and be kept to a strict time schedule to avoid errors through 'fading' (see Appendix 1).
4. Alkali-extraction of humic acids appears to be more suitable than fibre content in peat-based climatic studies because of the differential response of the latter technique to changing species composition. Although the degree of humification as measured colorimetrically is also to some extent dependant on the plant material, the response of mire floras to climatic changes should enhance, rather than confuse, the proxy palaeohydrological record obtained.

Appendix 1. Experimental procedure for the NaOH extraction technique

This section describes a procedure to arrive at replicable measurements of percentage transmission, as a semi-quantitative estimate of degree of peat humification, and is derived from Aaby (1986) and altered on the basis of experiments described in this paper.

Dry contiguous samples of peat under an infra-red lamp. Matted sedge peat can be cut with scissors to prevent it forming a felty mass. Grind the dry peat with a pestle and mortar and if necessary dry again until no further mass loss occurs. Weigh 0.2 g of powdered peat into a 150 ml beaker, add 100 ml of freshly mixed 8 % NaOH, and note the time of mixing. The remaining portion of each sample should be weighed, burned, and reweighed to calculate loss-on-ignition. Heat the beaker on a hot plate (in a fume cupboard) until the solution boils. The temperature of the plate can then be lowered, and the samples simmered very gently for 1 hour, minimizing evaporation. After cooling, transfer the contents of the beaker into a 200 ml flask, top up to the mark, and shake well. Filter samples through Whatman Qualitative 1 paper. Dilute 50 ml of the solution 1:1 with water into a 100 ml flask, and shake well. Measure the percentage transmission on a colorimeter at a wavelength of 540 or 550 *n*m, or at a series of wavelengths. Measure a number of samples from the same flask, and ensure that if different colorimeter tubes are used, they all record zero when filled with distilled water. Record each set of measurements at an equal time interval after the initial mixing (4 hours is a suitable period). Results of percentage transmission can be corrected for mineral content when necessary.

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GEOLOGY AND PALAEOECOLOGY OF THE KALODIKI PEATLAND, WESTERN GREECE

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SUMMARY

The Kalodiki fen is a 195 ha topogenous mire located in a small basin representing a tectonic depression in Epirus, western Greece. During the Late Glacial, the greatest part of the basin was occupied by a fresh-water lake supplied mainly by karstic springwater. At the beginning of the Holocene, the southern-southeastern part of the basin was converted into a fen, since when peat of a limnotelmatic type has accumulated up to a depth of 7 metres.

INTRODUCTION

The trapezoid-shaped basin of Kalodiki, located approximately 10 km east-northeast of the small city of Parga, Epirus (western Greece), occupies an area of 4 km^2. The long axis of the basin, approximately 3.5 km, runs NW-SE, and the mean width is ~1 km (Fig. 1). The surface of the basin has an altitude of between 106 and 113 m above sea level while the surrounding mountains rise up to 550 m. A reed and shrub fen has formed on the basin surface (Broussoulis & Giakkoupis, 1985).

We visited the area in the autumn of 1992 and found a peat formation up to 7 m thick, with reserves of some 5.5x10^6 m^3 peat.

GEOLOGICAL AND GEOMORPHOLOGICAL SETTING

Geologically, the study area belongs to the external Ionian geotectonic zone. Lower to Middle Liassic light-coloured limestones and karstified dolomites, derived by dolomitization of the former, constitute the greatest part of the basinal margins (Fig. 1). An underlying Triassic breccia that consists of dark dolomite and limestone fragments bound in altered gypsum, occurs only at the southeastern margins of the basin (I.G.S.R.-I.F.P., 1966; Perrier & Koukouzas, 1969).

Field observations and aerophotographs of the greater area indicate the presence of three groups of faults trending NNE, EW and NW. Some of the faults were active till

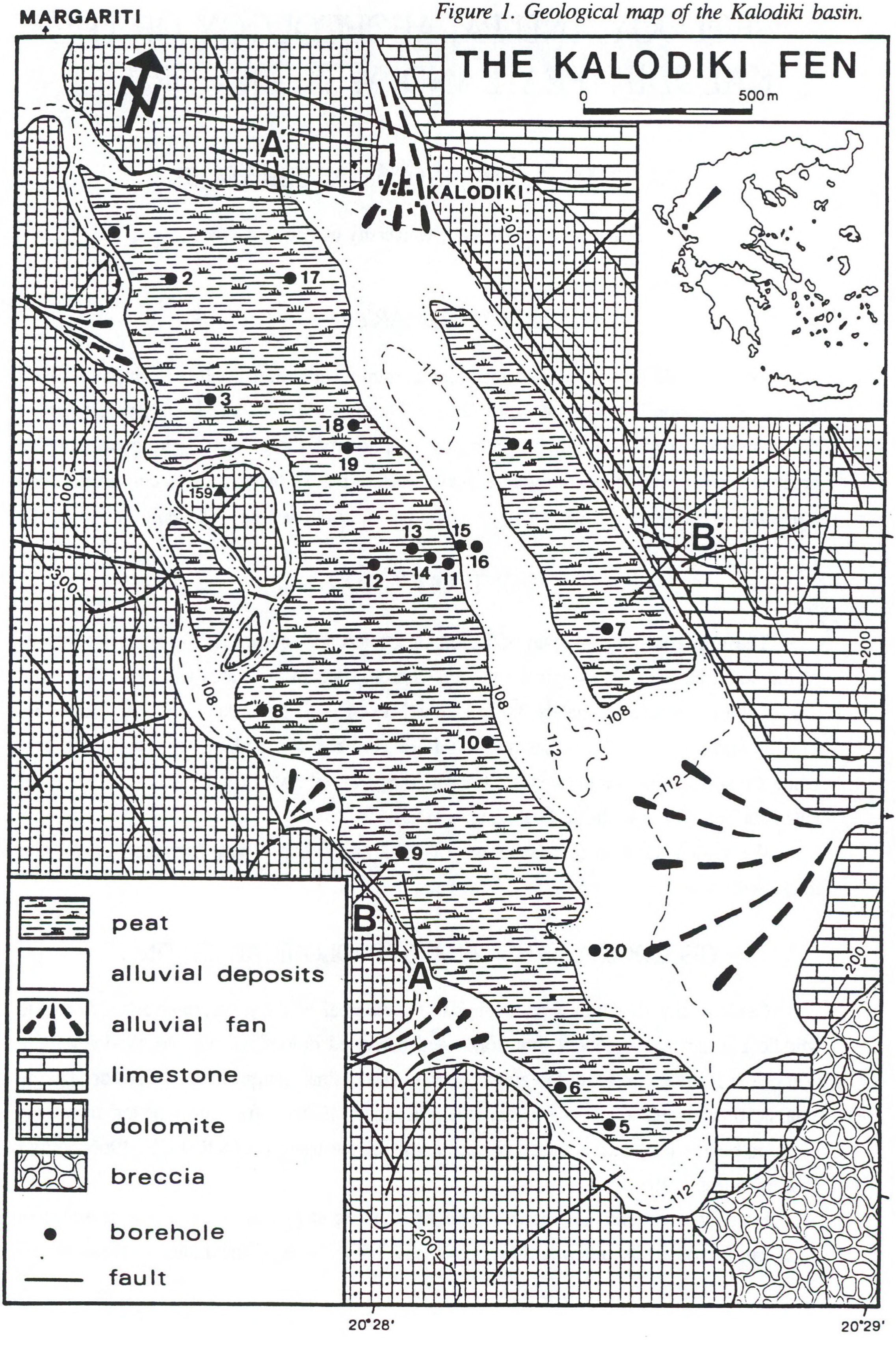


Figure 1. Geological map of the Kalodiki basin.

Holocene times and resulted in basin formation and peat accumulation. The basin studied is a small, NW-SE oriented graben. No data exist concerning the thickness and stratigraphy of the sediments filling the basin, but a Late Pliocene to Quaternary age may be suggested for its formation. The basin seems to have been isolated from the sea at least since the Late Pleistocene; therefore an intramontane regime has dominated, and the type of sedimentation has been controlled by the relationship between the rate of deposition and the rate of basin subsidence (Lüttig, 1971, 1991; Teichmüller & Teichmüller, 1982).

Alluvial fans running centripetal and emanating from side valleys tend to flush the basin with inorganic material of fluviatile-detritic origin. The most extensive fans are those of Morphi in the east and of Kalodiki in the north (Fig. 1).

The topographically lower areas of the basin are nearly flat, ranging in altitude between 106-108 m above sea level and hosting the fen. A longitudinal ridge (1.5 km long and 120 m wide), consisting of fine alluvial sediments (mainly brown silty clay), rises to altitudes of up to 113 m above sea level. It runs parallel to the long axis of the basin (NW-SE) and divides the whole basinal area into two sectors referred to later as the "big" and the "small" fen. The former occupies an area of 165 ha on the west side of the ridge, while the latter covers 30 ha to the east.

Kolovos et al. (1992) consider the ridge to be a Pleistocene fold. However, we believe that it was formed by differential basement subsidence caused by neotectonic block-faulting activity. In order to answer this question detailed geophysical and borehole data are required to establish the tectonics and morphology of the crystalline basement - a task beyond the scope of the present study.

The aquifer is fed by karstic waters which are derived from springs, mainly lying close to the southwestern and northeastern edge of the fen, as well as by irregular run-off from the surrounding drainage area. The basin overflows through a narrow channel towards the neighbouring basin of Margariti to the northwest. Due to the general aridity of the last few years, as well as to the intensive pumping of water from a well drilled at the southern dolomitic margins to supply water to Parga, the greatest part of the fen has dried out. At the time of the visit, the groundwater table was 1.5-2.5 m below the fen surface.

FIELD AND LABORATORY PROCEDURES

The stratigraphy of the uppermost sediments filling the basin was determined by coring. About 20 boreholes were made with an Edelmann hand-driven corer, up to a maximal depth of 10 m. The cores were examined macroscopically and logged on site (Merkt et al., 1971), and the degree of peat decomposition was estimated according to the von Post method (Schneekloth, 1981).

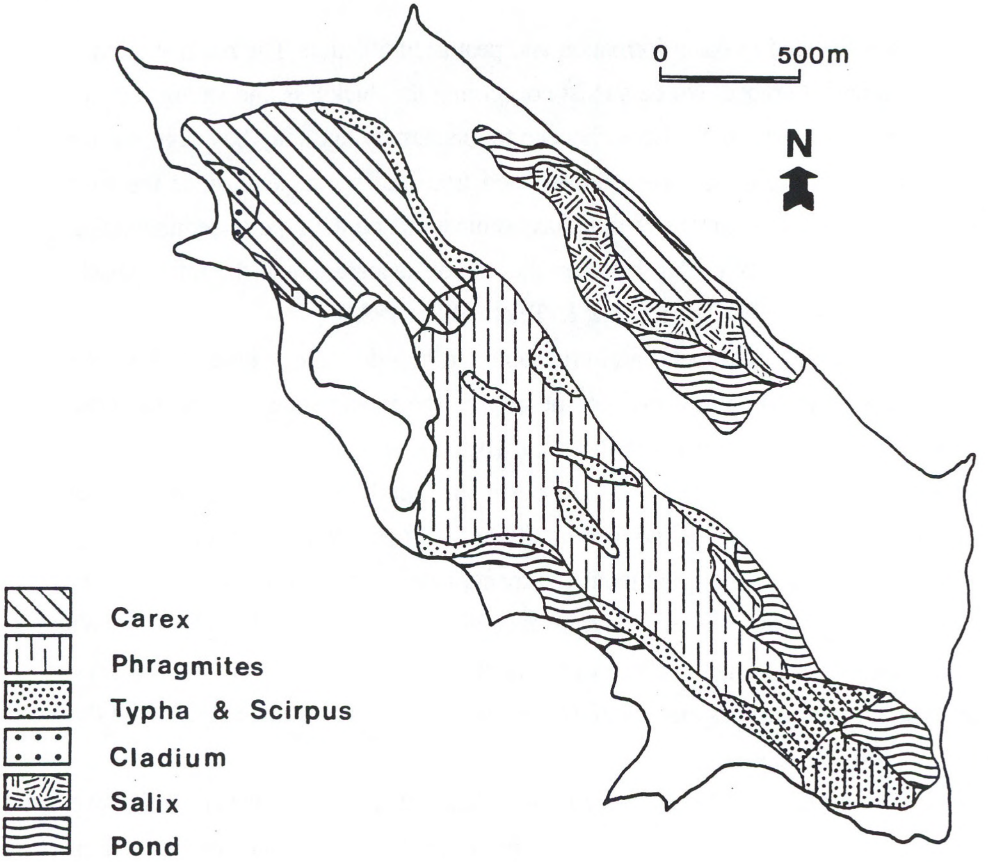
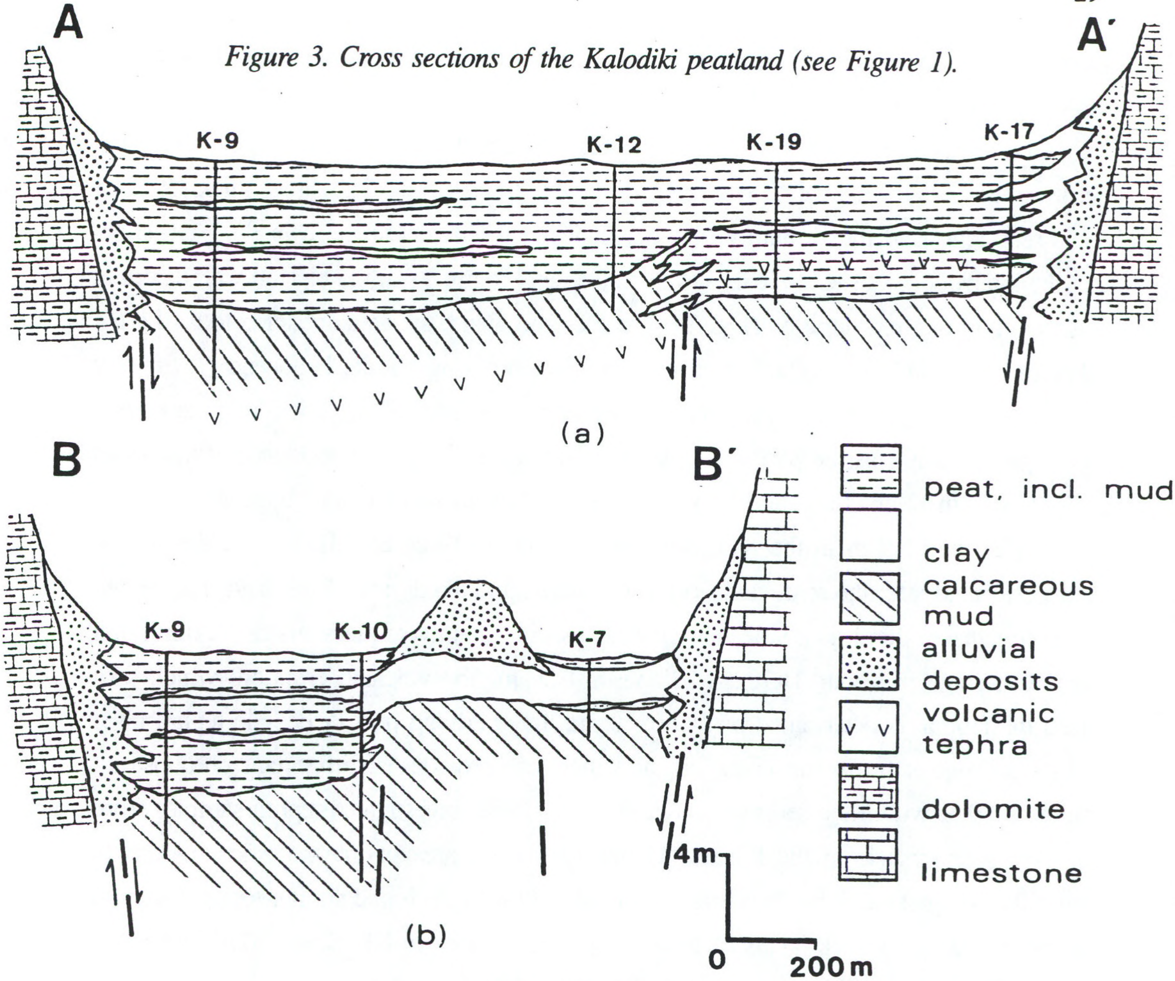


Figure 2. Vegetation map of the Kalodiki fen (after Kolovos et al., 1992).

Moisture and ash contents of samples, taken from boreholes K-9 and K-19, each representing depth intervals of 20 cm, were determined firstly by oven drying at 105°C for 48 hours and then by ignition in a muffle furnace at 550°C for 4 hours. Additionally, pH (in H_2O) and electrical conductivity measurements were carried out. The procedures used followed the guidelines given by the Peat Institute of the Lower Saxonian Geological Survey, Germany (Goetzke, 1974).

Five peat samples of the K-9 core, taken from different depths (1.5, 2.5, 3.5, 5.5, 6.5 m), each representing a 30 cm thick layer, were examined palaeobotanically for plant macro- remains by Dr. J. Schwaar of the Soil Technological Institute, Bremen, Germany. Two peat samples obtained at depths of 5.5 m from the K-17 borehole (just above a volcanic tephra layer) and at 6.9 m from the K-9 borehole (i.e. near the base of the peat sequence) were dated with ^{14}C by Dr. Y. Maniatis and G. Fakorellis, N.C.S.R.-Demokritos, Athens, Greece.

Figure 3. Cross sections of the Kalodiki peatland (see Figure 1).



RESULTS

The dominant helophytes growing on the fen surface are *Carex* spp. (mainly *C. flacca*) forming typical phytogenous hummocks up to a height of 2 m. Additionally, *Phragmites australis, Typha latifolia, Scirpus lacustris* and *Cladium mariscus* are found in the big fen and pond vegetation and shrubs (*Salix* spp.) in the small fen.

According to Kolovos et al. (1992), *Carex* species dominate the northern and southern parts of the big fen and *Phragmites* the central part (Fig. 2). *Typha* forms small clusters in the central and southern parts of the big fen, as well as narrow zones on the periphery. *Cladium* together with *Carex* is confined to a small area close to the northwestern dolomitic foothill, an indication of the prevalence of karstic springwater in this area.

In the big fen, the average peat thickness is 3.5 m; the thickest peat, reaching 7 m, was formed in the southern part of the fen. The reserves estimated according to the Thiessen method reach some 5.5x10^{6} m^{3}. In the small fen, the mean peat thickness is only 0.5 m.

The peat displays a relative homogenous matrix consisting mainly of roots, and has a light to dark brown colour often with a grey hue. No wood or charcoal horizons were recorded. The degree of humification estimated after the field method of von Post ranges between 4 and 6 and does not vary with depth.

Sediments mainly of limnic (clay, calcareous mud) and limno-telmatic (clay mud, detritic mud) origin intercalate with peat up to the cored depth. The small thicknesses of these sediments and the similarity of their plant macroremains to those in the peat, show that the interruptions of telmatic by limnic palaeo-environments in the big fen were laterally restricted and of short duration (Fig. 3a). On the other hand, the area occupied today by the ridge and the small fen appears to have been covered during middle Holocene (?) time by a lake, in which a layer of grey-bluish clay approximately 1.2 m thick was deposited. Consequently, this was the part of the basin experiencing the most subsidence at that time.

A 10 cm thick, fine sandy layer of light brown to olive colour appears at depths between 2.9 and 5.7 m in the K-3, K-8, K-14, K-17, K-19 cores. Microscopical observations performed after the removal of organic material and the drying of the sand fraction led to the conclusion that it is a volcanic tephra consisting mainly of glass shards. A minimum radiocarbon age of about 31,782±1,228 years B.P. for the volcanic eruption, which produced the tephra, is determined by ^{14}C dating in the overlying peat layer. The tephra layer is an isochronous formation (Fig. 3a), and therefore provides an important chronostratigraphic marker within the sediments. Keller et al. (1978) investigated tephra samples from deep sea sediments from the Eastern Mediterranean, an area of intense volcanic activity during the Neogene and the Quaternary. Christanis (1983a, b) found similar tephra layers in the uppermost 15 m thick layers of the Philippi peat deposit in NE Greece. The subject of the Kalodiki tephra will be discussed in detail in a future paper.

The inorganic sediment underlying the peat formation is a calcareous mud found almost all over the fen area. It comprises shells of molluscs and has a beige-whitish colour often of grey, pink or olive hues. The top of the calcareous mud in the big fen lies at depths between 3.2 m (in the northwestern part) and 7 m (in the southern part) while in the small fen it lies at 1.8-2.3 m under the present surface. Its thickness remains unknown, exceeding in any case 5 m. In the cores of boreholes K-5 and K-20 the calcareous mud was not intercepted up to the drilled depths (10 and 8.1 m, respectively). This is an indication that at the time of mud deposition in the lake, terrestrialization and paludification were proceeding on its southeastern shore resulting in peat accumulation. Furthermore, in the northwestern part of the big fen, the limnocalcareous conditions had not been stable. The intercalation of calcareous mud, detritic mud, clay and peat reveals rapid alternations of the dominant depositional palaeoenvironments. According to the radiocarbon dating, the end of the limnocalcareous regime and the beginning of the terrestrialization process in the centre of the big fen occured about 11,049±144 years B.P. This corresponds to an average rate of peat accumulation of almost 0.6 mm per year in borehole K-9 where the thickest peat formation occurs. This value is similar to those found in the Philippi fen (Christanis, 1983a), as well as to values in many fens of the temperate zone (Teichmüller & Teichmüller, 1982).

According to data obtained from the palaeobotanical determinations, pollen of *Cladium mariscus* occur in all the samples, while tissues, fruits and seeds of this species were found in the deepest peat samples (at depths of 3.5, 5.5, 6.5 m). The occurrence of fruits and seeds of submerged living (*Potamogeton obtusifolius*) and floating aquatic plants (*Nymphea alba*), as well as the plethora of oogonia of Characeae, suggest that a limnotelmatic environment dominated during the formation of the whole peat sequence, i.e. on the fen surface many ponds and pools existed between which *Cladium* peat accumulated. On the other hand, the existence of many hydrophilous terrestrial and semiterrestrial species in the peat, such as *Euphorbia palustris, Carex pseudocyperus* and *Polygonum lapathifolium*, indicates that probably the fen was often flooded by surface waters provided mainly by the alluvial fans after high rainfall. As a result, the fruits and seeds of the above species, sited on drier locations, were transported fenwards. Finally, the occurrence of *Cladium* and oogonia of Characeae in almost all the peat samples indicates calcium-rich conditions, obviously due to karstic water that flushed into the fen.

The preliminary determinations of the physical and chemical properties of the peat and the other organogenic sediments can be summarized as follows: The moisture content of the K-9 samples ranges between 80-90% and that of the K-19 between 75-86% of mass. The ash content of the K-9 and K-19 samples lies between 20 and 30% and 20 and 50% of mass, respectively (the latter being out with the range for peat) without showing any trend with increasing depth. On the contrary, the pH and the electrical conductivity values in samples from both boreholes show variations which probable reflect differences in the palaeo-ecological conditions dominant during peat formation. Samples from the uppermost 2 m thick peat layer have pH values between 5.6 and 6.7 and electrical conductivity values < 350 μS/cm, while in the deeper layers pH and conductivity values are between 5.0 and 5.7 and > 400μS/cm, respectively. The generally high ash content indicates that a considerable supply of inorganic material has been transported fenwards by surface waters. Thus a disturbed peat-forming environment is indicated in which mineralization of the organic matter also took place. The K-19 samples are more affected by the mineralization than those of the K-9 borehole.

Further determinations such as those of the chemical composition of the peat ash are the subject of future research, which may provide more data concerning peat-forming conditions and explain the aforementioned differentiation.

CONCLUSIONS

Considering the data obtained in this study, the development of peat formation in the Kalodiki basin is reconstructed as follows:

During the Late Glacial period (Weichsel) almost the whole Kalodiki basin was occupied by a shallow fresh-water lake, fed by karstic springwater. Calcareous mud was deposited over the greatest part of the basin. Peat accumulated only in the southeastern edge of the big fen (K-5, K-20), at least during the Late Glacial, while on the northwestern edge, in the area between K-1 and K-19, unstable palaeoenvironmental conditions prevailed, resulting in the temporary extension or contraction of the lake and consequently the deposition of intercalated limnic and telmatic sediments. This means that the deepest parts of the former lake were located in the area occupied today by the small fen, the ridge, and the central part of the big fen, while in the remaining parts of the basin, at least temporarily, the process of filling in the lake predominated. The alluvial fans of both Kalodiki and Morphi were active and reduced the lake area by flushing inorganic clastic material into the basin. On the contrary, the alluvial fans on the southern margins did not affect the lake considerably.

Around 11,000 years B.P., the groundwater table in the basin fell drastically. This could have been due to: a) The climate changing the water flow into the basin; b) The tectonics, probably causing the opening of the channel to the NW towards the Margariti basin; c) The activation of the karstic system, through which seepage out of the basin increased.

The date of the lowering of the groundwater level coincides with the Pleistocene/ Holocene boundary. However, we do not suggest that the climate was the controlling factor, since climatic amelioration marking the end of the Late Glacial and the beginning of the Post Glacial could not have been so sudden, although Bottema (1978) has suggested an abrupt climatic change at that time, marked by rapid tree expansion. The lack of transitional sediments in the Kalodiki fen, such as gyttja, interbedded between the pure limnic calcareous mud and the overlying telmatic peat suggests that the fall in water level may have happened relatively rapidly, so that tectonism and/or activation of the karstic system may have been the cause.

In any case, the lake drained and the central and south-eastern areas of the big fen were converted into a topogenous mire where peat started accumulating. On the mire surface, many pools and ponds existed; thus *Cladium mariscus*, aquatic and subaquatic plants lived, died and accumulated in close proximity. In the northwestern part of the big fen, as well as in the small fen, subsidence was very limited, so that during early Holocene only thin peat layers could accumulate. The karstic water supply, if any existed, was reduced and the basin was often partly or totally flooded by surface waters, provided mainly by the alluvial fans of Morphi and Kalodiki. The alluvial fans on the southern margins of the basin did not have a great effect on the peat accumulation.

If a mean rate of peat accumulation of 0.6 mm per year at the centre of the big fen (at K-9 borehole) is projected, then in the approximate time span between 6,000 and 3,000 years B.P., the area of the small fen and the ridge was occupied by a lake marked by clay deposition. During this period, in the central and south- eastern parts of the big fen, peat was continuously accumulating and only twice for a short period did the lake almost completely cover this area. Subsequent initiation of the growth of the ridge area resulted from the rapid subsidence of the longitudinal fault-bound terrain between the two fens (Courel, 1989). Continued growth of the ridge was assured by the influx of clastic material from the Morphi and Kalodiki alluvial fans, and by the growth of a dense barrier of helophytes in both fens.

Considering the lithofacies and their vertical and lateral extension in the cored deposits of the Kalodiki basin, we conclude that:

The whole basin was a tectonically labile area where relatively high rates of subsidence occured, at least during the period studied. During Late Glacial, the greatest subsidence in the basin occured in the area presently occupied by the ridge, whilst in the Post Glacial period the ridge and, for part of the time, the small fen were subjected to the highest amount of subsidence. Limnotelmatic peat accumulation, however, was restricted to the remaining parts of the basin where subsidence was slower but constant and continuous.

It is very likely that at greater depths the sedimentary strata of the Kalodiki basin may comprise a sequence of peat or peaty lignite, indicating that it has experienced previously equilibria between the rate of sedimentation and the rate of basin subsidence. On these grounds we would suggest some exploratory drilling, although no large reserves, or good quality, of peat/lignite are expected.

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ESTIMATION OF SURFACE MOISTURE VARIATION IN MILLED PEAT FIELDS USING INFRA-RED METHODS

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SUMMARY

It is well-known from practice that the initial moisture level of peat production areas has large variations. Areas with the highest initial moisture content require the longest drying times and thus limit production efficiency.

The phenomenon of field drying of milled peat is complex to model because both the moisture and temperature distribution are dependent on peat quality and particle size distribution and also on external weather factors. In order to estimate the initial moisture distribution on large areas, aerial infra-red thermography has been tested.

Tests under field conditions illustrate the possibilities to utilize aerial infra-red thermography for determining the initial moisture distribution of large peat production areas. This requires the systematic development of rules for the interpretation of aerial thermograms.

INTRODUCTION

The moisture profiles of peat production fields usually show large variations. In milled peat production, the initial moisture content of the uppermost milled layer also varies considerably even on one field sector, depending on basic field conditions.

There can be many reasons for such variations in initial moisture content. Peat quality may change, depending for example on the humification degree and the particle size distribution. The operation and efficiency of the drainage system may vary from one point to another and the effect of working machines may form, for example, rain collecting 'pockets' or depressions on the fields. Therefore a number of factors either alone or in combination determine the measurable and observable initial surface moisture conditions.

In order to maintain the highest production efficiency, the initial moisture profile of the field has to be kept as low and regular as possible. The first task is to characterize existing moisture profiles using direct or indirect methods of measurement. The moisture profiles can then be adjusted and improved by smoothing out depressions in the fields, in order to minimize the effects of rain, by improving the open ditch system and by using mole drains (Klemetti & Sänkiaho,1992).

The practical experience of the field operators can obviously provide preliminary treatment where the slowly drying - or fast drying - areas are located.

However, a comprehensive knowledge of the initial moisture distribution can be obtained only by aerial photographic or thermographic methods, because of the large areas concerned (Schwidefsky & Ackermann, 1978). Calibration of this data is achieved by ground truth spot measurements for temperature and by peat sampling for moisture determinations.

THE SURFACE MOISTURE AND TEMPERATURE OF THE PEAT PRODUCTION FIELD

The basic physical phenomenon on the peat production field is evaporation of water from porous material in which the water has several types of physical bonds (Leinonen & Marttila, 1976). The particle size distribution determines the actual rate of evaporation from peat particles deep in the surface layer. The development of the moisture content and temperature in the milled peat layer as a function of time is illustrated in Figure 1. By increasing time the moisture content of the peat layer decreases, most efficiently on the surface, and the temperature of the layer rises.

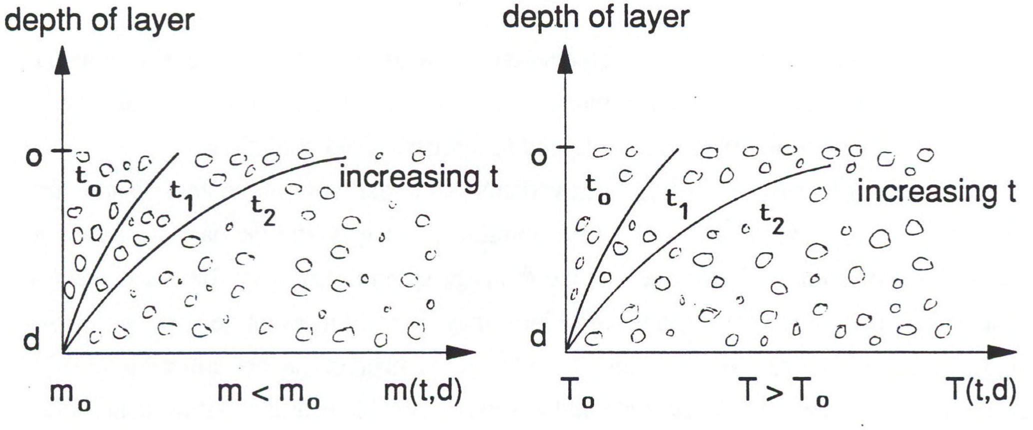

Figure 1. Development of the moisture content and temperature in a milled peat layer

The actual rate of drying depends on factors of the weather, the field and the production methods. Measurement of the time development of both the moisture content and the temperature distribution of the drying layer is quite a complex task in practice. Taking representative samples from a surface layer of given depth is difficult as is the measurement of representative temperatures from the same layer using thermocouples.

The indirect measurement of surface temperature distribution by infra-red methods therefore provides an interesting alternative to obtain such information simultaneously from large areas. The aerial thermography methods have been tested for different ground materials by Lunden, 1977. This report shows the importance of the thermal inertia in the thermal behaviour of different terrain features. Thermal inertia is defined as follows:

I = sqrt(d x c x k), where

I = thermal inertia
d = density of the material
c = spesific heat of the material
k = thermal conductivity of the material

The dependence of thermal inertia on the volumetric moisture content of peat is shown in Figure 2.

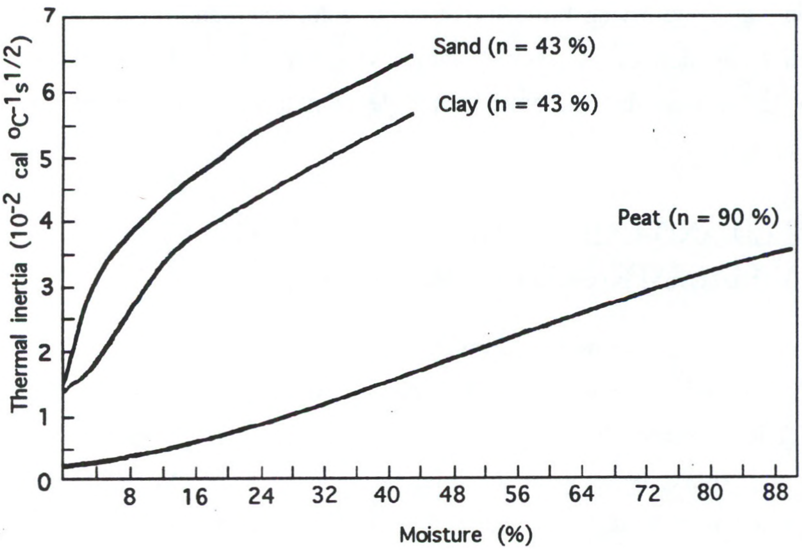

Figure 2. Thermal inertia as a function of water content for sand, clay and peat according to Lunden (1977).

The changes in surface moisture and temperature thus apparently follow the principle of thermal inertia; moist areas are warmed up and also cooled more slowly than dry areas or materials. This basic phenomenon forms the actual background for aerial infra-red thermography of peat fields.

THE ECONOMIC EFFECT OF CORRECTING THE INITIAL MOISTURE PROFILE OF THE FIELD

The main advantage of smoothing out the initial moisture profile of the peat field is the acceleration of the production cycles as the wet sectors of the field are eliminated. In practical terms, the drying times required to dry milled peat layers to 'collecting moisture' give comparative values which can be used to estimate the advantage of smoothing out the moisture profile. It is estimated that a 5% decrease in the initial moisture content of the peat field may decrease the drying time by 15 to 20 %.

The actual method of smoothing the moisture profile is by adjusting the level of the ground water table by open ditching or by using mole drains. By these methods, the amplitude of the initial variations in field moisture content can be narrowed.

The actual economic advantage of correcting the moisture profile of the field can be calculated using corresponding shortened drying times for single harvests and by comparing seasons' harvests with and without the corrections in the initial moisture distribution.

A practical demonstration of the importance of moisture profile correction would require at least simulation of the drying times for fields with corrected and non-corrected moisture profiles and estimation of the corresponding seasonal yields. An alternative method would be to demonstrate the economic advantage of moisture profile correction under field conditions.

FIELD AND LABORATORY TESTS USING AERIAL INFRA-RED THERMOGRAPHY

Field and laboratory tests can be used to show the capability and validity of the aerial infra-red thermography method. These tests have been carried out within the framework of the Finnish OPTIMITURVE-project. It has been shown that on a normal peat production field on a sunny day the observable temperature differences, between a fresh milled peat surface and a dried surface may be about 8 degrees Celsius. This shows that the range in surface temperature is large enough for observable differencies (Tervo, 1993). These differencies can be detected by thermography from an aeroplane.

In field thermography, the aerial observations are used to demonstrate the main differencies in surface drying rates. The main conclusion is here that small differencies in surface temperature may reveal the location of dry or wet areas of the field. The absolute values for moisture content of the surface should be obtained by careful field sampling and measurement but for information on fast drying or slowly drying areas, absolute values are not necessary.

Figure 3. shows the relationship between initial moisture contents and corresponding surface temperatures measured by an infra-red camera on a peat production field on a sunny day. Although based on a small number of samples the figure shows that there is a fairly clear correlation between the observable surface temperature and the initial moisture conditions on the peat field. The thermographs were in this case recorded on the ground but other tests show that larger areas can be thermographed from an aeroplane.

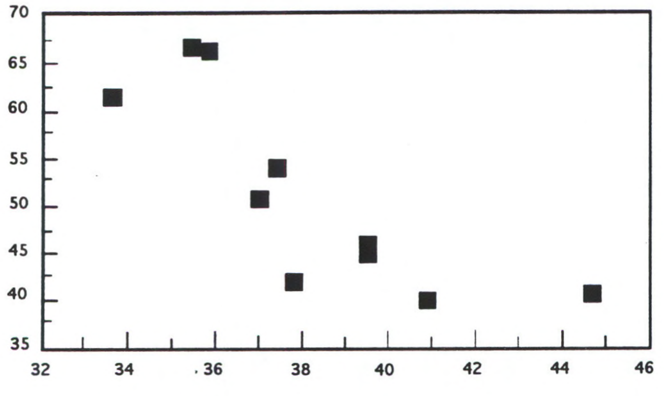

Figure 3. Relationship between initial moisture content in weight percents on a peat field and corresponding surface temperatures (Tervo, 1993).

CONCLUSIONS

For peat production fields, the principle of aerial thermography seems to apply well because of large variations in the initial moisture content. The thermal inertia of the field surface is high for moist peat particles both when heating or cooling the surface.

In the present paper, the possibility of using aerial thermography to study moisture conditions in peat production fields has been discussed. It appears that the detection of large differences in the rate of peat field drying is technically possible. The economic importance of this information is evident. The practical procedure of carrying out even more extensive mapping of field surface temperatures and related moisture conditions still requires additional testing and development.

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THE AGRICULTURAL AND HORTICULTURAL VALUE OF TROPICAL PEATLAND A CASE STUDY

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SUMMARY

After 15 years of cultivation, the peatland near Pontianak, West-Kalimantan, Indonesia has changed considerably in its physical and chemical properties. One can observe a decrease in waterholding capacity, an increase in bulk density and in pH. Total and exchangeable nutrients are increasing with a subsequent increase in base saturation. This resulted in higher yields, especially when growing vegetables. The peat soils are originally acid and chemically poor. The local situation and the findings of a pot experiment show that for the improvement of the nutrient status a careful exploitation and an intensive fertilizing program is required. The fertilizers used consist mainly of wood ash or agricultural waste ash. They release nutrients resulting in a decrease of the acidity. The nutrient cations may form complexes with the organic matter, which prevent them from leaching. Due to the higher pH, even phosphorus deficiency seems to have been overcome by the formation of stable organic Fe-phosphate complexes. In this particular case study, the farmer first applied a dressing of 60 tons of ash per hectare, followed by an additional application of 10 tons of ash per hectare for every new crop.

INTRODUCTION

The cultivation of tropical peatland

Normally, the first step in the reclamation of tropical peatland is drainage. A shallow drainage system should be established in order to avoid irreversible drying and subsidence. At first the original vegetation should not be removed, since evapotranspiration will speed up the dewatering process. After a couple of months most of the bush vegetation is cut and burnt. A major risk during the reclamation of peatland is subsidence of the land, caused by the combination of shrinkage, compaction, biochemical oxidation and burning of the material. Driessen & Soepraptohardjo (1977) mention a subsidence of 0.15 to 0.25 m per year during the first years of cultivation. The rate of compaction during drainage is influenced by several factors, such as the weight of the drained layer and the capillary forces. As a result, the total volume available for the root growth decreases. Mineralization of peat occurs by microbial activity, being low at the pH of the freshly reclaimed peat, and by burning the land. If not followed by vegetation, the released nutrients should be lost either by volatilization (N) or by leaching (P).

During the first year after reclamation good yields can be achieved for maize, cassava, pineapple and several vegetables. These so-called pioneer crops take up the required nutrients from the ash. Driessen & Soepraptohardjo (1977) propose a sequence of cassava as the pioneer crop, replaced after 2 years by pineapple and cocos, and by vegetables and fruit crops after 4 years. Tree crops are discouraged on deep peat soils because of the low bearing capacity of the peat and the risk of toppling over.

Before, Indonesian agronomists stated that peatland could be converted into agricultural land if the peat depth did not exceed 1.5 m. However, in the region of Pontianak, profitable traditional farming systems exist on peat with a depth of 3.5 m. These are the traditional mixed farms with pig breeding and dryland crops, especially leaf onion, brassica and spinach (Lambert *et al.*, 1990).

Case study on a mixed farm

The farm under study is located in Siantar Hilir, Sungai Slamet area, near Pontianak, West-Kalimantan. The farmer has been cultivating the peatland for 15 years. At present, he cultivates 7 ha of land, growing vegetables such as spinach, celery and kangkung (*Ipomoea aquatica* POIR.) as well as papaya, maize, cassava and banana. The farmer reclaims the peatland in the following way: wood is removed and the top soil layer is aerated. Beds (1.5 m x 10 m) are constructed, surrounded by small and shallow drainage canals. Fertilization follows with 6 kg wood ash per m^2, spread out over the surface. Finally, crops are sowed.

The second application of wood ash depends on the yield of the pioneer crop. When the application of 6 kg wood ash proves ineffective, the peatland is abandoned. This kind of peat is still too acid and not well enough decomposed to be suitable for any type of agricultural activity. When the pioneer crop gives a satisfactory yield, the dressing for the next crop is based on the yield of the previous one, with a maximum rate of 1.25 kg ash per m^2. Vegetables, maize or papaya are the main second crops. During the growth period of vegetables, ash is applied every 20 days, starting from planting time onwards. Maize receives this fertilization twice, once before sowing and again in the middle of the growth period. Papaya is fertilized every 2 months. The different ameliorants used are wood ash, agricultural waste ash, peat ash, decayed fish, and pig and chicken manure (Suryanto & Lambert, 1992).

The yields are high, although problems occur with maize lodging due to the uptake of too much N. Keeping in mind that only ash was added, this excess of available N might result from the high mineralization rate at the prevailing temperature and humidity. Today, after 15 years of cultivation, the farmer achieves nowadays an average yield of 3 to 5 kg spinach per m^2. Maize yields 3 kg fresh cobs per m^2. While the relative yield is sufficient, there is still on occasion a lack of quality. Problems still occur due to nematodes on kangkung and to grasshoppers on spinach. Pesticides are not applied since the return is uneconomic.

MATERIALS & METHODS

Material

The peat at the farm described was sampled in May 1991. Samples were taken under different crops from 3 layers (0-10 cm, 10-25 cm, and 25-40 cm). The groundwater table was at 40 cm depth. In addition to secondary forest and rubber, the different crops under which peat material was sampled were sawi (*Brassica juncea* CZERN.), kangkung (*Ipomoea aquatica* POIR.), maize (*Zea mays* L.), spinach (*Amaranthus hybridus* L.), soybean (*Glycine max* MERR.) and papaya (*Carica papaya* L.). They can be grouped according to the intensity of the fertilization:

- no application : rubber and secondary bush
- low application: papaya and cassava
- high application: maize, soybean, spinach, brassica and kangkung.

We selected out of this three types of cultivation, four crops for our experiments. In October 1991 at the same location additional peat was sampled under the spinach and from newly reclaimed or prepared peatland (0-20 cm). This was used in a comparative pot experiment.

Methods for soil analysis

Physical parameters, such as pore volumes, bulk density and particle density were determined using the methods described for horticulture substrates (Hartman & Michiels, 1991). Moisture and ash contents were determined according to Thomas (1970). Total element analysis for P (colorimetry) and Ca, K, Na (flame photometry) were conducted after digestion with 18 % $HClO_4$. Total contents of Mg, Fe, Cu, and Mn were determined by atomic absorption spectrophotometry after digestion of the ash with 1 M HNO_3. Ammonium-lactate and ammonium-acetate-EDTA were used for soil extractions (2 g wet peat + 40 ml extractant). Cation exchange capacity was determined as described by Lambert et al. (1988) and exchangeable acidity with 1 M KCl using an automatic titrator (end point at pH 8.25).

Pot experiment

The purpose was to make a comparative study between newly reclaimed peat and peat after 15 years of cultivation. The peat sampled in October 1991 was air-dried to a moisture content of up to 65-70%. Knowing the low pH of the original peat, the influence of different rates of lime on the yield of spinach was investigated. The rates applied were: 0, 2, 5, 10 tons of lime per hectare or 0, 0.25, 0.625, 1.25 g $CaCO_3$ per 50 g fresh peat. The basal fertilizer was a solution composed of NH_4NO_3 (an amount equal to 175 kg N per ha), KH_2PO_4 (150 kg P per ha), KCl (350 kg K per ha), $MgSO_4.7H_2O$ (20 kg Mg per ha), $MnSO_4.H_2O$ (20 kg Mn per ha), $CuSO_4.5H_2O$ (20 kg Cu per ha), $ZnSO_4.7H_2O$ (20 kg Zn per ha), MoO_3 (0.8 kg Mo per ha), $CoCl_2$ (0.38 kg Co per ha). Micronutrients were applied before sowing and macronutrients 10 days after germination. The different treatments were:

- blank (= newly reclaimed peat, without any application)
- blank + basal treatment (= without liming)
- blank + basal treatment + 2 ton $CaCO_3$/ha
- blank + basal treatment + 5 ton $CaCO_3$/ha
- blank + basal treatment + 10 ton $CaCO_3$/ha
- blank + 60 ton wood ash/ha (= without basal treatment)
- peat under spinach (= without any addition or treatment)

The pot experiment lasted 57 days during which the moisture content was kept constant. After harvest, plant material was dried at 60C, pre-ashed at 600C and digested with 1 M HNO_3 for total analysis of P (colorimetry) and Ca, K, Na (flame photometry).

RESULTS AND DISCUSSION

The influence of cultivation on different soil characteristics

Some physical parameters

Bulk density, particle density and total volume of the pores were determined for the top layer under secondary forest and spinach. The impact of cultivation on the physical condition of the peat is obvious (Table 1). After reclamation of the peatland, the peat is compacted. This leads to a decrease in porosity and waterholding capacity, and to an increase in bulk density.

Table 1. Bulk Density (BD), Particle Density (PD), Total Volume of the Pores (TVP) for two top layers under different vegetation.

Vegetation	BD (g/cm^3)	PD (g/cm^3)	TVP (%)
Sec. forest	0.17	1.25	86.4
Spinach	0.26	1.66	84.3

Moisture and ash content

Moisture and ash contents were determined at 4 different depths for each type of crop (Table 2). It is clear that the moisture content increases with depth, since the groundwater table is found at 40 cm. Unreclaimed peat is much more moist than cultivated peat. On the other hand the compaction after drainage results in a decrease in the porosity of the peat (see Table 1). However, peat under cultivation and in dry conditions could hold water stronger than virgin peat, reducing the possibility of irreversible shrinking and drying.

The ash content of fresh peat is very low. This peat can be classified as oligotrophic. As a result of a long term application of ash, the ash content in the top layer of the peat under cultivation increased markedly from 1 % to 15-20 % (on a dry weight basis). The ash content also decreases with depth. Under spinach and papaya, the high ash contents are limited to the uppermost layer. Under maize the ash content remains high in 10-25cm layers because of deeper soil tillage and root proliferation.

Nutrient content

Air-dried peat was used for the total analysis of macronutrients and micronutrients. Wet peat was used for the extractions. The moisture content is given in Table 2 and 3 respectively. The results presented in Tables 4 to 8 are the average of 3 determinations.

Peat under cultivation contains up to 100 times more calcium than unreclaimed peat under secondary forest (Table 4). Under cultivation, the Ca-content sharply decreases with depth, mainly under spinach, but remains low and more or less constant throughout the profile of virgin peat. The values for ammonium-lactate-extractable Ca show that for peat under cultivation about 30 % of the total Ca is plant available, whereas for virgin peat, it is 80 to 90 %.

Table 2. Moisture and ash content for peat under different vegetation.

Vegetation	Depth (cm)	Moisture content (% w/w) (wet basis)	(dry basis)	Ash content (% w/w) (wet basis)	(dry basis)
Spinach	0-10	52.0	108.3	9.3	19.3
	10-25	79.1	379.7	1.8	8.4
	25-40	80.6	415.3	1.8	8.9
Maize	0-10	56.5	130.2	8.6	19.9
	10-25	60.6	154.8	6.1	15.6
	25-40	87.6	705.5	0.9	7.0
Papaya	0-10	56.6	130.4	6.3	14.6
	10-25	83.0	489.0	1.2	7.0
	25-40	87.7	713.3	0.5	4.3
Sec. forest	0-10	77.8	349.3	0.2	1.0
	10-25	84.1	527.4	0.2	0.9
	25-40	84.9	562.5	0.2	1.3

Table 3. Moisture content of air-dry peat, used for total analysis and C.E.C. determinations.

Vegetation	Depth (cm)	Moisture content % w/w (wet)	% w/w (dry)
Spinach	0-10	25.1	33.6
	10-25	55.6	125.4
	25-40	49.7	98.9
Maize	0-10	31.2	45.3
	10-25	16.2	19.3
	25-40	62.9	169.2
Papaya	0-10	22.6	29.2
	10-25	58.2	139.4
	25-40	61.4	159.1
Sec. forest	0-10	59.0	143.7
	10-25	38.3	62.1
	25-40	22.6	29.1

Results for K are shown in Table 5. The top layer under papaya and maize contains 3 to 8 times more K than under secondary forest. The total K-content decreases with depth for peat under cultivation but is constant through the profile under secondary forest. Ammonium-acetate-EDTA extractable K amounts 20 to 30 %. Cultivated peat contains 3 to 8 times more sodium than virgin peat, except under papaya (Table 6).

Table 4. Total and extractable Ca-content in peat under different vegetation.

Vegetation	Depth (cm)	Total Ca mg/100g dry peat	Total Ca meq/100g dry peat	Extractable Ca mg/100g dry peat	Extractable Ca meq/100g dry peat
Spinach	0-10	4985.1	248.8	1533.3	76.5
	10-25	1730.9	86.4	634.9	31.7
	25-40	629.8	31.4	179.7	8.9
Maize	0-10	5185.2	258.7	1716.3	85.6
	10-25	4315.1	215.3	1327.2	66.2
	25-40	1943.5	96.9	479.6	23.9
Papaya	0-10	3734.9	186.4	1229.5	61.4
	10-25	2036.3	101.6	744.3	37.1
	25-40	980.1	48.9	379.2	18.9
Sec. forest	0-10	57.8	2.9	44.4	2.2
	10-25	56.5	2.8	n.d.	2.7
	25-40	45.4	2.3	n.d.	2.9

Table 5. Total and extractable K-content in peat under different vegetation.

Vegetation	Depth (cm)	Total K mg/100g dry peat	Total K meq/100g dry peat	Extractable K mg/100g dry peat	Extractable K meq/100g dry peat
Spinach	0-10	92.8	2.4	32.9	0.6
	10-25	35.9	0.9	5.4	0.1
	25-40	43.0	1.1	13.5	0.4
Maize	0-10	145.2	3.7	56.3	1.4
	10-25	96.9	2.5	21.1	0.5
	25-40	56.8	1.5	19.1	0.5
Papaya	0-10	59.1	1.5	7.8	0.2
	10-25	27.8	0.7	5.9	0.2
	25-40	35.1	0.9	7.1	0.2
Sec. forest	0-10	18.1	0.5	3.9	0.1
	10-25	36.2	0.9	3.9	0.1
	25-40	26.5	0.7	1.7	0.04

Virgin peat has a more or less constant Na-concentration throughout the profile, whereas under cultivation the total Na-content decreases sharply below 10 cm. Sodium is not extractable in virgin peat, but very high under cultivated peat. The figures for extractability often exceed those for total Na-content in virgin peat. This might be due to the different moisture content of the material used (see Table 2 and 3).

Table 6. Total and extractable Na-content in peat under different vegetation.

Vegetation	Depth (cm)	Total Na mg/100g dry peat	Total Na meq/100g dry peat	Extractable Na mg/100g dry peat	Extractable Na meq/100g dry peat
Spinach	0-10	42.4	1.8	28.1	1.2
	10-25	22.9	1.0	23.2	1.0
	25-40	23.5	1.0	19.9	0.9
Maize	0-10	46.5	2.0	29.4	1.3
	10-25	40.0	1.7	22.6	1.0
	25-40	26.6	1.2	17.6	0.8
Papaya	0-10	29.4	1.3	17.9	0.8
	10-25	14.8	0.6	16.2	0.7
	25-40	13.9	0.6	15.2	0.7
Sec. forest	0-10	5.0	0.2	0	0
	10-25	5.2	0.2	0	0
	25-40	2.8	0.1	0	0

The P-content in peat under cultivation is 2 to 4 times higher than in peat under secondary forest (Table 7). The P-content in peat under cultivation decreases sharply with depth. In virgin peat only 10 to 20% of the total P is extractable and is mostly present in organic form. In cultivated peat, 50 to 60% of the phosphorus is extractable.

Maize and spinach received the same amount of ash and were growing on peatland with a similar fertilisation history. Still, the total P-content is up to 3 times higher under maize than under spinach, while for the 1st layers extractable P is equal. The difference can be explained by the fact that fast-growing leafy vegetables such as spinach require large amounts of P throughout the growing period, whereas crops such as corn are more able to utilise labile soil P forms (Sanchez *et al.*, 1991).

The micronutrient content increases after peat has been reclaimed (Table 8). The top layer under spinach contains 29 times more Mg, 7 times more Fe and 12 times more Mn than the top layer under secondary forest. Virgin peat does not contain any Cu. The content of all micronutrients decreases with depth for peat under cultivation, whereas it slightly increases with depth for peat under secondary forest.

Table 7. Total and extractable P-content in peat under different vegetation.

Vegetation	Depth (cm)	Total P (mg P/100g d.m.)	Extractable P (mg P/100g d.m.)
Spinach	0-10	165.5	99.0
	10-25	42.5	27.4
	25-40	31.6	8.2
Maize	0-10	195.5	98.2
	10-25	129.8	68.8
	25-40	69.2	32.7
Papaya	0-10	163.2	65.9
	10-25	50.4	24.8
	25-40	38.6	12.5
Sec. forest	0-10	59.0	5.9
	10-25	28.0	4.6
	25-40	27.6	5.8

Table 8. Total analysis of 4 micronutrients (in ppm on dry weight basis) in peat under different vegetation.

Vegetation	Depth (cm)	Mg	Fe	Cu	Mn
Spinach	0-10	4084	7669	19.8	150.8
	10-25	2945	1005	7.1	88.5
	25-40	1281	1161	5.1	80.0
Maize	0-10	5009	11821	12.7	155.3
	10-25	9462	5130	6.9	121.2
	25-40	2974	3497	0.0	69.8
Papaya	0-10	2818	6583	18.3	143.7
	10-25	2107	4907	3.5	52.4
	25-40	1379	2157	0.0	32.4
Sec. forest	0-10	139	1140	0.0	12.8
	10-25	182	2013	0.0	18.5
	25-40	212	1833	0.0	19.7

pH and exchangeable acidity

The pH(H_2O) was measured after an equilibration time of 10 minutes. The high pH values of peat under cultivation are caused by the application of ash (pH = 8.6) as an ameliorant. The pH decreases with depth, with a gradient depending on shallow or deep tillage. Unreclaimed peat has a very low pH and is classified as acid oligotrophic peat (Table 9).

Exchangeable aluminum is negligible, exchangeable protons were determined by titrating the 1n KCl-extraction solution with NaOH (endpoint pH = 8.25). Only the layers with pH lower than 8.25 were analyzed. The results are presented in Table 10. It is clear that, under such a high pH and after years of cultivation, the exchange complex is occupied by basic cations, removing all protons and diminishing acidity, even at a greater depth.

Table 9. The pH (pH-H_2O) of the peat under different vegetation and for 3 layers.

Vegetation	0-10 cm	10-20 cm	25-40 cm
Spinach	7.6	5.5	4.7
Maize	8.0	7.5	6.2
Papaya	6.7	5.6	4.9
Sec.forest	3.1	3.1	3.3

Cation exchange capacity and base saturation

The method used for the determination of the cation exchange capacity (C.E.C.) (Lambert *et al.*, 1988) includes the estimation of the base saturation and the exchange-pH. The pH of the filtrate, obtained by filtration of the peat-$BaCl_2$-suspension after 3 hours shaking, is called the exchange-pH. An advantage of the method is that the exchange processes occur at the "natural pH", in contrast with the common NH_4OAc(pH 7)-method. NH_4OAc at pH 7 creates new exchange sites on the peat, resulting in higher C.E.C.-values which do not reflect the real situation in the field. Using the NH_4OAc-method, Suhardjo & Widjaja-Adhi (1977) found C.E.C. values of 125 to 140 meq per 100 gram dry peat for peat from Riau, Sumatra, while Driessen (1978) even records values up to 270 meq per 100 gram for deep peat soils under forest. Table 11 clearly shows these high values will never be reached, not even for the peat at high pH.

Base saturation is estimated by the ratio of the sum (Na + K + Ca) in the extraction solution (0.1 m $BaCl_2$) to the C.E.C. The results for the different top layers are given in Table 12, together with the figures for exchangeable cations, taken from Table 4, 5 and 6 respectively. Base saturation for the top layer is over 80 % for all three crops.

Table 10. Exchangeable acidity (EA) in some peat profiles.

Vegetation	Depth (cm)	EA (meq/100 g dry peat)
Spinach	25-40	4.1
Maize	25-40	3.6
Papaya	25-40	2.8
Sec. forest	0-10	14.7
	10-25	21.8
	25-40	24.7

Table 11. Exchange-pH and C.E.C. (meq/100 g dry peat) for the top layer under different vegetation.

Vegetation	pH	C.E.C.
Spinach	7.1	93.2
Maize	7.2	106.4
Papaya	6.0	100.8
Sec. forest	2.4	22.9

Table 12. Extractable Ca, K, Na (meq/100g dry peat) and base saturation (%) after extraction with $BaCl_2$, NH_4-lactate and NH_4-acetate-EDTA.

Veget.	Ca		K		Na		EA	CEC	BS(%)
	$BaCl_2$	Am-lac	$BaCl_2$	Am-ac	$BaCl_2$	Am-ac			
Spinach	84.7	76.5	1.4	0.6	1.9	1.2	-	93.2	94.4
Maize	81.7	85.6	1.8	1.4	2.1	1.3	-	106.4	80.5
Papaya	81.2	61.4	1.2	0.2	1.7	0.8	-	100.8	83.4
Forest	-	2.2	-	0.1	-	0.0	14.7	22.9	(10.0)

Summary and evaluation of the nutrient status

The nutrient status of the upper layers (0-40 cm) of a cultivated peat soil under three different crops was investigated and compared with that of a non-cultivated profile under secondary forest. Some very clear trends are apparent from the results given in the preceding tables. These are summarized and evaluated below.

Peat under secondary forest contains 0.08 % CaO, 0.04 % K_2O and 0.06 % P_2O_5 on average. It can be classified as oligotrophic peat (Driessen & Soepraptohardjo, 1977). Due to the intensive fertilizer applications, peat under cultivation becomes enriched in nutrients. The ash, very regularly applied in high amounts contains 112 mg Ca, 1 mg Na, 8 mg K and 5 mg P per gram dry matter. The pH is 8.6 and the moisture content is 2.9 %. Suryanto & Lambert (1992) analyzed other ameliorants used on the farm. The figures are similar and are presented in Table 13. The ash being applied is very rich in calcium (10-20%) and this explains the high increase in pH after cultivation.

As a result of shallow tillage, leaching of the elements is nearly inhibited, and the concentration of nutrients and the pH sharply decrease with depth. Peat under maize with a deeper root proliferation, shows a more homogenous distribution through the profile.

Table 13. pH, moisture content and composition of some ameliorants used in Pontianak, Kalimantan (Suryanto & Lambert, 1992).

Type	pH	Moisture (% w/w)	P (ug P/g)	Ca	K (mg/g)	Na	Fe
Lime	8.7	0.17	0.28	450	-	0.6	0.5
Wood ash	9.0	2.29	12.88	185	0.7	6.4	19.8
Agricult. waste ash	10.5	28.60	3.59	143	0.7	6.9	4.2

The relative higher extractability of Ca in virgin peat can be explained by the low pH, resulting in a much higher solubility of Ca than in cultivated conditions. Besides this, the total Ca-concentration in peat under cultivation is nearly 100 times higher than under secondary forest. Thus the amount of Ca to be extracted is also 100 times higher. The maximum extraction capacity of 40 ml NH_4-lactate might be insufficient to remove all of the Ca from the cultivated peat. On the other hand, K and Na are more readily extractable from cultivated peat than from virgin peat. However, these results cannot be compared with Ca, since two different extraction solutions have been used. The total K- and Na-concentration is much lower than for Ca and the amount of extraction solution should have been sufficient here.

A comparison of the total and extractable amount of nutrients present in peat soils is not always possible or reliable. There is an urgent need for more specific and more appropriate analysis and extraction methods for peat soils, in which the elements behave rather differently than in mineral soils.

When phosphorus is incorporated in organic molekules, it will not be extractable anymore. Phosphate can also be bound onto organic material with Fe- or Ca-bridges, which connect negatively charged $H_2PO_4^-$ and HPO_4^{2-} with negatively charged functional groups of the organic matter. In the pH range studied, $H_2PO_4^-$ is the dominant phosphate ion in solution. The reactions with the Fe-peat can result in the precipitation of a strengite-like amorphous product or in the formation of Fe-peat-phosphate-complexes. Due to the application of ash, phosphorus can occur in its inorganic from. Because of the high pH, Ca-phosphate will dominate. After 15 years of cultivation the portion of P bound as inorganic phosphate increased, as did its extractability. For the case study here, leaching of phosphate did not occur, although it is often a serious problem in peat soils (Ahti, 1984; Duxbury & Peverly, 1978; Cogger & Duxbury, 1984; Scheffer & Kuntze, 1989; Sanchez *et al.*, 1991).

The peat under secondary forest does not contain any copper. This would lead to Cu-deficiency in the cultivation of vegetables or rice. Peat under cultivation has a higher total Cu-content, but at the high pH, organo-metallic complexes become insoluble (Haynes & Swift, 1985). As such, the Cu-availability for the plant is low. Both problems, Cu-deficiency and low Cu-availability, result in the green-die-back disease and male sterility of rice plants (Soepraptohardjo & Driessen, 1977). Iron is present in high concentrations in the top layer. This explains further the high phosphate concentrations and the fact that there is no leaching of P throughout the profile. In addition, the phytotoxicity of aluminum and manganese is diminished by the chelating power of the organic material. The pH-limit (minimum value) for crop growth is lower for peat soils than for mineral soils (Mathur & Levesque, 1983).

Due to the application of high amounts of ash, the base saturation is very high for peat under cultivation. Even peat soils with a low base saturation contain a sufficient amount of plant available bases, due to the high cation exchange capacity.

Pot experiment

The growth of spinach

The influence of different doses of lime was investigated by setting up a small pot experiment. Based on the field observations, it was decided to use spinach as the test plant. Although spinach is not really suitable for an experiment with substrates over a wide range of pH, most of the treatments resulted in significant differences.

For the unlimed pots, germination started after 10 days but all seedlings died after a couple of days. The lime doses of 2 ton per ha gave a good germination, but seedlings also died later on. All other treatments with lime resulted in a good germination and reasonable growth. The peat, sampled at the field under spinach gave fewer and smaller plants than with limed peat. The residual effect of the ash applied by the farmer was thus lower than expected. Treatment 6 (virgin peat treated with 60 ton ash per ha) resulted in the best growth, although yellowing of the leaves occurred after 6 weeks, probably because of N-deficiency. At harvest treatment 5 (high level liming with basal treatment) gave the best results. The plants were dried and the dry matter yield was determined (Table 14).

Table 14. Dry matter (D.M.) yield of spinach and pH of the peat after harvest.

Treatment	pH peat at harvest	Yield (g D.M.)
Blanco	3.2	0
Blanco + bt[1] + 0[2]	2.8	0
Blanco + bt + 2	3.6	0.016 ± 0.006
Blanco + bt + 5	4.5	1.047 ± 0.343
Blanco + bt + 10	5.7	2.490 ± 0.469
Blanco + ash	7.1	2.028 ± 0.081
Spinach	8.1	0.220 ± 0.079

(1) = basal treatment (2) = ton $CaCO_3$/ha

Plant analysis

Plant material was pre-ashed and digested with HNO_3. Table 15 shows the total Ca, K-, Na- and P-content of the plants for the treatments which resulted in a pH higher than 4. For the highest addition of lime, the Ca-content in the plants is still low. So further increasing the amount of lime might increase the yield further. The higher Ca-uptake in peat treated only with ash also shows a potentially higher uptake for that element. As mentioned before, the ash applied contains 5 mg P, 8 mg K, 1 mg Na and 112 mg Ca per gram dry matter. The treatment of 60 ton ash per ha represents as such 270 kg P, 470 kg K, 64 kg Na and 6500 kg Ca, the latter being equal to more than 16 ton $CaCO_3$. Peat under spinach contains 1.5 g extractable Ca per 100 g dry peat (Table 4), equal to 6.75 g available Ca per pot, while the highest level of liming (12 g $CaCO_3$ per pot) represents only 4.8 g Ca. As such Ca-uptake is highest for cultivated peat (treatment "spinach").

Peat under spinach contains 33 mg extractable K per 100 g dry peat (Table 5), equal to 148.5 mg K per pot. The basal treatment and the application of ash both represents a dose of roughly 500 mg K. As such, the K-uptake from peat under spinach is 50% lower (Table 15).

The basal treatment does not include sodium and the ash contains 1 mg Na per g. Both applications resulted in a low Na-uptake. Peat sampled under spinach contains 30 mg extractable Na per 100 g dry peat (Table 6), equal to 135 mg Na per pot. But the Na-uptake is also for these pots relatively low.

The highest P-uptake was found for the treatments with basal fertilizer unless only 0.2 g P per pot was added. Although the peat sampled under spinach contains 0.5 g extractable P per pot, the P-uptake is very low. This can be explained by P being present under less soluble forms of phosphate.

Table 15. Total Ca-, K-, Na-, P-content (mg/g D.M.) in the plants (average of three repetitions).

Treatment	Ca	K	Na	P
Blanco + bt(1) + 5(2)	14.8	87.2	1.1	16.4
Blanco + bt + 10	15.7	97.3	0.7	12.5
Blanco + ash	19.2	93.3	1.1	9.8
Spinach	22.9	45.0	8.2	2.2

(1) = basal treatment (2) = ton $CaCO_3$/ha

Conclusions

The application of ash results in the best growth during the first 6 weeks. After that period, the plants are yellowing and flowering, suffering from N-deficiency. This deficiency is typical for peat soils, unless the total N-content is always high (1 to 2 % on dry weight basis). Driessen (1978) mentions that 50 to 70% of the total N is bound as stable ligno-proteins.

The low yield on peat sampled under spinach was unexpected, since a high yield was observed in the field. The high pH cannot be the reason for this low residual effect, because spinach likes neutral to alkaline conditions. It can be explained by a lack of available nitrogen. Polak (1951), as cited by Driessen & Soepraptohardjo (1977) never observed N-deficiency during a field experiment in Kalimantan, in contrast to a pot experiment with peat sampled from the same field.

The low residual effect also explains why the farmer applies ash in high amounts for every new culture. The ash is a slow-release product and its fertilisation scheme is intensive. Spinach is sensitive to low pH values and does not grow at a pH lower than 4. The Ca-uptake is still low for the treatments applied here. As such, higher levels of lime might increase the yield further more. However, a pH higher than 6 is not recommendable since mineralization will lead to the loss of peat. The uptake of the elements depends on the solubility of the forms under which they are applied. In view of this, ash has a disadvantage because in the pH range studied Ca and P do not occur in readily available forms.

CONCLUDING REMARKS

Tropical peat soils are not always the marginal soils as often reported. After fifteen years of cultivation, the peat soils change markedly in their physical as well as chemical properties. All these changes resulted in high yields, especially for vegetables. These high yields offer an enormous opportunity for the extension of agricultural land in Indonesia. The successful farmer from our case study in Pontianak obtains large amounts of ash from a sawmill in the neighbourhood. It is obvious that this practice is limited. The majority of the farmers will have to look for other ways of fertilizing.

The drawback is that the improvements are only achieved by addition of very high amounts of ash. The question rises whether the increase to pH 8 is necessary or can even be justified. As a result of the very high mineralization at this pH, in combination with a high temperature, the peat will finally disappear and leave an acidic, chemically poor podsol behind. For long term sustainable cropping we therefore suggest an initial increase in pH up to 5.5 using ash or lime and later on the addition of fertilizers just sufficient to maintain this pH and an adequate nutrient supply for plant growth. At this pH, the cations form stable complexes with the organic matter without being deficient.

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APPLICATION OF NEYDHARTINGER PEAT POTION IN PIGLETS

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SUMMARY

The investigations presented here have been initiated to examine if the usual intramuscular (IM) iron supply (Fe) and/or antibiotic growth promotor (Virginiamycin, VGN) can be replaced by "Neydhartinger Moor-Tränke" (NMT = Neydhartinger Peat Potion) without reduction in performance. In 58 litters with 590 piglets, divided into 4 groups (VGN+Fe, Fe, VGN+NMT, NMT), the usual performance parameters such as body weight gain, feed conversion and mortality have been determined. Groups provided with NMT showed partially significantly better performance then the Fe group and hemoglobin values and erythrocyte counts remained within the tolerable range even without IM application of iron.

INTRODUCTION

Neydhartinger Peat Potion ("Neyhartinger Moor-Tränke", NMT) is a suspension of high viscosity of very fine grained low-moss-peat and lacustrine mud in peat water (the normal humic water runoff from the peat-bog), found very efficient by the research governed by the late Prof. Otto Stöber, the father of the famous Bad Neydharting spa, Austria.

The therapeutic effect of balneological peat "Heilmoor" on several diseases of man is well documented with respect to the external application. Also for oral application of Peat Potion several indications are known in human medicine. Some older reports on positive effects after oral application in various animal species are known (dog, horse: Kostner & Silbert, 1954; pig: Heindl, 1966, 1986; Horváth, 1970; Jolink, 1977; Münchberg & Tschiderer, 1965; Tschiderer, 1958, 1976; hoofed game: Stöber, 1982; Tschiderer, 1974) without having cleared the mode of action.

Recently the humic substances which are present also in the NMT, and probably responsible for its effect, have met great interest in veterinary medicine (Kühnert et al., 1989). Most important indications are infectious gastro-intestinal diseases, especially with young animals, because humic substances have not only an antiphlogistic, adstringent, adsorbing, anti-bacterial and virucid effect, but can also provoke a general stimulation of the immune system. Peat substances have been found effective also for the treatment of anemia (Solovyeva & Lotosh, 1984).

In piglets intramuscular (IM) Fe-application is common practice to prevent iron deficiency anemia as well as antibiotic and probiotic performance enhancing stabilization of the intestinal flora and preventing intestinal complaints. With respect to the effects of humic substances mentioned, it is to be examined if Fe application and antibiotic growth promotion in piglets can be replaced by NMT without a diminution in growth.

MATERIAL AND METHODS

For the test 26 sows of the breed "Edelschwein" were at disposal, the majority of them having been covered by boars ("Pietrain"), the minor part by artificial insemination. The pregnant sows were tethered in pens with partially slotted floor and pushing-type dung floor cleaner. The farrowing unit consisted of 12 crates.

Thirty eight days after parturition the sows were brought to the breeding centre, the piglets remained in the farrowing unit until the 63rd day. Air was supplied by ventilation at the ceiling, air cleaning with fans.

The mixed feed for sows and piglets (Table 1) had been prepared at the farm. The pregnant sow received daily 1,7 kg during the first 12 weekes of pregnancy and 2,2 kg later on; in addition 4 and 3 kg fresh grass (summer), respectively, or 4 kg fodder beet (winter) daily, the lactating sow the respective mixed feed ad libitum from the automatic feeder.

Table 1. Composition of mixed feed (%) and calculated nutrient content per kg feed

Ingredients (%) Content/kg	Mixed feed for sows pregnant	lactating	Piglets' starter
Barley	67	42	40
Wheat	-	27	15
Maize	10	-	15
Oat	5	10	-
Wheat bran	3	-	-
Soybean meal	7	12	20
Field pea	5	-	-
Fish meal	-	3	-
Dried skim milk	-	-	3
Feeding yeast	-	-	3
Dehydrated alfalfa	-	3	-
Calcium carbonate	1	-	-
Mineral and vitamin premix	2	3	4[1)]
Metabolizable energy MJ	12.22	12.33	12.62
Digestible protein g	107.00	137.30	159.50
Ca g	8.90	9.22	9.10
P g	5.40	6.54	7.60
Na g	1.50	2.41	1.60
Lysine g	5.90	7.81	9.80
Methionine+Cystine g	4.60	5.47	6.20

[1)]Guaranteed content/kg

Ca min.	g	190	Vit. A	I.E.	500000
P min.	g	88	Vit. D_3	I.E.	60000
Na min.	g	30	Vit. E	mg	1800
Fe	mg	3000	Vit. B_1	mg	120
Zn	mg	2400	Vit. B_2	mg	180
Cu	mg	640	Vit. B_6	mg	120
Mn	mg	960	Vit. B_{12}	µg	800
J	mg	6	Vit. K_3	mg	60
Se	mg	8	Cholinchlorid	mg	15.000
Co	mg	4	Nicotinic acid	mg	1.000
Lysine	g	30	Ca-Pantothenat	mg	540
Methionine	g	10	Biotin	µg	800
(Virginiamycin	mg	600)	Folic acid	mg	16
LBC	mg	700			

The analysis of two feed samples are shown in Table 2. Water was supplied through nippels.

Table 2. Analyzed nutrients per kg feed for piglets (A: without, B: with Virginiamycin)

Sample		A_1	A_2	Mean A	B_1	B_2	Mean B
Dry matter	g	881.4	875.6	878.5	882.0	881.7	881.8
Crude ash	g	71.8	57.1	64.4	55.7	79.7	67.7
Crude protein	g	220.8	177.6	199.2	204.4	212.7	208.5
Ether extract	g	19.9	19.5	19.7	20.5	23.1	21.8
Crude fiber	g	37.9	46.4	42.1	44.5	42.7	43.6
N-free extract	g	531.0	575.0	553.0	556.9	523.5	540.2
Ca	g	14.28	6.53	10.40	9.44	14.76	12.10
P	g	8.21	6.84	7.52	8.31	7.77	8.04
Mg	g	2.01	1.55	1.78	1.79	2.01	1.90
Na	g	2.66	0.82	1.74	1.48	3.58	2.53
K	g	6.78	6.29	6.53	6.78	6.78	6.78
Cu	mg	75	30	52	34	68	51
Mn	mg	168	70	119	70	152	111
Zn	mg	326	169	247	194	266	230

For the experiment 58 litters with 590 piglets have been checked; the sows have been well divided into the groups shown in Table 3, concerning frequency of gestation.

Table 3. Design of the trial

Treatment	VGN	Fe	NMT
Group I	+	+	-
Group II	-	+	-
Group III	+	-	+
Group IV	-	-	+

VGN: + piglet starter with 24 ppm Virginiamycin

- piglet starter without Virginiamycin

Fe: + 100 mg Fe IM on day 2 as iron dextran (Myofer®, Ducrofer®)

- no iron application

NMT: + 150 ml Neydhartinger Moor-Tränke two times daily per litter, up to 3 weeks of age in plastic bowls, from day 22 to 63 in flat concrete trough, 1 m in length

- no Neydhartinger Moortränke

Table 4 illustrates the appertaining of the litters to the various groups, and the number of live birth piglets per litter. One day after the birth some of the piglets from larger litters have been put to smaller litters, and have therefore changed group. As a result, the number of piglets of day 1 is not the same as the number of piglets per litter.

Table 4. Number of birth and number of piglets per litter

Sow No.	Group I birth	Group I piglets	Group II birth	Group II piglets	Group III birth	Group III piglets	Group IV birth	Group IV piglet
40			10.	8	11.	12		
43			10.	11	9.	10		
45	10.	7	11.	7			9.	12
48	7.	8			9.	10	8.	13
51	6.	4	8.	13			7.	15
52			6.	9	7.	11	8.	7
53	7.	8					8.	12
54	6.	7			7.	10	5.	11
56			5.	6				
57	5.	11	6.	16			4.	14
58			5.	13	4.	12	6.	11
59	4.	11					5.	14
63			4.	3	3.	10		
65	4.	11	3.	15	2.	11		
66	4.	5	2.	8	3.	11		
67			3.	15	4.	12	2.	14
67/0	3.	13	2.	13	1.	11		
68	1.	6						
69			1.	8	2.	8		
70					1.	7	2.	13
71	1.	8						
72	2.	7					1.	9
73	1.	8					2.	14
74							1.	4
77			1.	11				
80			1.	8	2.	14		
N	14	14	16	16	14	14	14	14
Mean	4.36	8.14^{a}	4.88	10.25^{a,b}	4.64	10.64^{b}	4.86	11.64^{b}
SD	0.72	2.54	0.85	3.70	0.89	1.74	0.77	3.10

Trial parameters are:

(1) Number of piglets per litter

(2) Body weight (BW) of piglet

- after birth
- after weaning (day 38)
- after end of test (day 63)

Trial parameters are:

(1) Number of piglets per litter

(2) Body weight (BW) of piglet
- after birth
- after weaning (day 38)
- after end of test (day 63)

(3) Feed intake per litter
- from birth to weaning
- from weaning to end of test

(4) Feed conversion (kg feed/kg BW gain) per litter from weaning to end of test

(5) Hemoglobin concentration day 2 and day 21 (g/L)

(6) Erythrocytes count on day 2 and day 21 (T/L blood)

(7) Mortality (number and cause)

(8) Parasitological examination of feces (Flotation method with saturated solution of sodium chloride and zinc chloride, centrifugation, microscopical examination), day 21 and 63.

The statistical evaluation resulted by way of multiple ANOVA and Multiple Range-Test, and H-Test after Kruskal-Wallis with unequal variances. Different superscript letters with the mean values indicate significant differences ($p < 0.05$) between groups.

RESULTS

Number of piglets per litter

The sows were divided into groups following the number of birth, therefore it came to an unexpected and significant difference in the number of piglets per litter, which led also to a difference in body weight of the new born piglets. On average group I had 2.1, 2.5 and 3.5 less piglets, respectively, than groups II, III, IV. The difference was significant between I and III and between I and IV (Table 5).

Table 5. Number of piglets per litter

Group		birth	day 1	day 38	day 63
	N	14	14	14	14
I	Mean	8.14[a]	9.07	8.43	8.21
	SD	2.54	2.30	1.95	2.19
	N	16	16	16	16
II	Mean	10.25[a.b]	9.81	8.00	7.94
	SD	3.70	3.08	2.61	2.62
	N	14	14	14	14
III	Mean	10.64[b]	10.50	8.86	8.50
	SD	1.74	1.70	2.21	2.35
	N	14	14	14	14
IV	Mean	11.64[b]	11.29	9.07	8.93
	SD	3.10	2.23	2.53	2.59

Consequently the body weight of the piglets was in average higher in group I for 200, 170 and 260 g, respectively, than in groups II, III, IV, these differences being significant (Table 6). Undoubtedly these differences mean advantages for the development of some of the relevant test parameters such as body weight gain and mortality. This fact has to be considered during the valuation of these parameters.

Table 6. Body weight (kg)

Group		after birth	day 38	day 63
	N	14	14	14
I	Mean	1.48^{a}	10.81^{a}	21.47^{a}
	SD	0.25	1.00	1.68
	N	16	16	16
II	Mean	1.28^{b}	9.71^{b}	18.34^{b}
	SD	0.21	1.52	2.78
	N	14	14	14
III	Mean	1.31^{b}	$10.14^{a,b}$	$19.98^{a,b}$
	SD	0.17	1.32	2.96
	N	14	14	14
IV	Mean	1.22^{b}	9.27^{b}	19.51^{b}
	SD	0.18	1.22	2.87

Body weight gain

The relation of body weight (BW) remains unchanged from birth to weaning (Table 6), the difference between group I and III (VGN + Fe: VGN+NMT) was not significant any more. The average daily BW gain was 245 g (group I), 222 g (group II), 232 g (group III), and 212 g (group IV), respectively. This indicates a growth promoting effect of virginiamycin, even if the feed intake in this period was low with 950 g (group I) and 840 g (group III), respectively.

After weaning (day 39 - day 63) the order of the groups concerning BW remained unchanged, group I being significantly higher than group II with 3.13 kg and group IV with 1.96 kg in average, but the last group gained by far, which is evident in the average BW gain during this period (group I: 426 g, group II: 245 g, group III: 394 g, group IV: 410). During the complete testing period (from birth to day 63) the average daily BW gain was in group I 317 g, in group II 217 g, in group III 296 g and in group IV 290 g. Altogether group I (VGN+Fe) had, therefore, showing the best growth rate, followed by group III and IV (NMT without Fe-application, with or without virginiamycin), group II (without VGN, with Fe) had the poorest results.

Feed intake

Table 7. Feed intake (kg)

Group		feed intake day 1-38	feed intake day 39-63	feed conversion day 39-63
	N	14	14	14
I	Mean	0.95	19.06[a]	1.79
	SD	0.61	2.30	0.15
	N	16	16	16
II	Mean	0.74	15.66[b]	1.87
	SD	0.46	3.08	0.30
	N	14	14	14
III	Mean	0.84	17.66[a,b,c]	1.80
	SD	0.54	3.48	0.11
	N	14	14	14
IV	Mean	0.83	18.18[a,c]	1.77
	SD	0.51	3.71	0.09

During suckling period (up to day 38) the feed intake per animal (group II: 740 g to group I: 950 g) was small as expected, and not significantly different between the groups (Table 7).

After weaning (day 39 - day 63) the piglets in group I took most of the feed (19,06 kg/animal), followed by group IV (18.18 kg/animal), group III (17.66 kg/animal), and group II (15.66 kg/animal) (Table 7). The difference between group I and IV to group II was significant. VGN+NMT increased, therefore, by far the feed intake in comparison with the group having received only Fe IM. It should be mentioned that after day 2 after birth, the piglets willingly accepted to take the NMT. As a result they seemed to be encouraged to suckle or take in feed and water.

Feed conversion

Group IV (NMT) came out top, concerning food conversion (1.77) followed by group I and III (1.79 and 1.80); group II was with 1.87 at a 0.1 higher level than group IV (Table 7). These differences are not significant.

Blood parameters

Hemoglobin (Hb) level and the count of erythrocytes on day 2 lay between 81.4 and 87.7 g/L blood, and between 3.53 and 3.72 x T/L, respectively, the Hb values in group III and the count of erythrocytes in group II being clearly lower than in group I and IV (Table 8). The cause for these differences, which are not relevant for the examination, is not known. The examination on day 21 showed that in group I and II (with Fe-application) the Hb and erythrocyte levels were by far higher than in both groups without Fe-application. In both groups, however, the level did not fall, as could be expected when Fe is not administered, but has slightly improved in these groups, too. From previous experience we know that such levels are sufficient for a normal growth and to maintain adequate immune response, as shown in these tests.

Table 8. Blood parameters

Group		Hemoglobin (g/l)		Erythrocytes (T/L)	
		day 2	day 21	day 2	day 21
	N	123	118	123	118
I	Mean	87,7[a]	100,9[a]	3,71[a]	4,42[a]
	SD	15,3	20,7	0,59	0,70
	N	152	132	152	132
II	Mean	84,9[a,b,c]	101,4[a]	3,53[b]	4,27[a]
	SD	15,8	17,5	0,67	0,58
	N	141	123	141	123
III	Mean	81,4[b]	90,1[b]	3,61[a,b,c]	3,92[b]
	s	13,4	21,7	0,60	0,73
	N	153	128	152	128
IV	Mean	87,4[a,c]	87,9[b]	3,72[a,c]	3,92[b]
	SD	16,0	22,3	0,65	0,81

Mortality

Altogether the mortality rate (Table 9) remained within a limit normal in daily practise. As had to be expected on account of statement 1., mortality was lower in group I during the suckling period than in the other groups. The most frequent causes were starvation and squeezing by the sow (Table 10). The piglets of group I, which in average had higher BW after birth were obviously stronger; so a lower number of them died due to starvation or squeezing. After weaning there were not noticeable differences between the groups.

Table 9. Number of piglets died per litter

Group		day 1-38	day 39-63	day 1-63
	N	14 (9)	14 (3)	14 (12)
I	Mean	0.64	0.21	0.86
	SD	0.81	0.43	0.95
	N	16 (29)	16 (1)	16 (30)
II	Mean	1.81	0.06	1.88
	SD	2.17	0.25	2.16
	N	14 (23)	14 (5)	14 (28)
III	Mean	1.64	0.36	2.00
	s	1.45	0.63	1.57
	N	14 (31)	14 (2)	14 (33)
IV	Mean	2.21	0.14	2.36
	SD	1.89	0.36	1.91

() = number of piglets died per group

Parasitological findings

In group I one case nematode infestation was stated. In all other groups no infestation with enteroparasites could be detected.

Table 10. Cause of death

Group	I		II		III		IV	
Cause	day 1-38	day 39-63	day 1-38	day 39-63	day 1-38	day 39-63	day 1-38	day 39-63
Starvation	5	-	14	-	8	-	15	-
Squeezing by sow	4	-	14	-	10	-	4	-
Injuries	-	-	-	-	1	-	2	-
Heart attack (after blood sampling)	-	-	-	-	-	-	2	-
Diarrhea	-	-	-	-	-	-	2	-
Ileus	-	-	-	-	1	-	1	1
Shock	-	-	-	-	2	-	-	-
Still birth	-	-	-	-	-	-	1	-
Pneumonia	-	-	1	-	-	1	-	-
Anemia	-	-	-	-	-	1	-	-
Swine influenza	-	1	-	-	-	1	-	-
Rupture of suture (postoperative)	-	1	-	-	-	-	-	-
Sold	-	-	-	-	-	-	1	-
No diagnosis	-	1	-	1	1	2	3	1
Total	9	3	29	1	23	5	31	2

DISCUSSION

Preparations containing humic acids (Kalumat, Sulumin,) have been used with good results as prophylaxis and also therapeutically in higher dosage with calfs (Kalich, 1977; Kühnert et al., 1980) and piglets (Golbs & Kühnert, 1986; Sachse, 1982) as growth promotor respectively in treatment of eneritis. Mayakova and Gavrilchik (1983) studied a considerable increase of body weight after administration of peat with bovine animals. These informations are in good accordance with the present results.

Even though the additional Fe-application with NMT was not too considerable, the decrease of Hb value and count of erythrocytes remained within tolerable limits. This may be due to an increase of Fe availability, as Kühnert et al. (1989) supposed it to be for Sulmin, +containing humic acid, or Visser (1973) for humic acid. The explanation for this better availability is the formation of complexes with humic acids on one hand, on the other hand the better membrane permeability caused by humic acids (Visser, 1988). This explains the successful treatment of anemia with peat (Solonyeva & Lotosh, 1984). Also Horváth (1970) found that NMT has an anti-anemic effect in piglets and, therefore, is able to increase body weight.

CONCLUSION

The application of 150 ml Neydhartinger Moor-Tränke (NMT) per litter twice a day to piglets without IM Fe administration showed a tendency to an improvement of body weight gain and feed intake in comparison with a control group without peat-application but with IM iron application. Hemoglobin value and count of erythrocytes remained within a tolerable limit, in spite of the lack of Fe-application. The use of NMT in raising piglets seems to be appropriate.

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NITROGEN TRANSFORMATIONS AND NITRATE CONTROL IN CULTIVATED ORGANIC SOILS A REVIEW

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SUMMARY

Nitrogen mineralized in organic soils between harvest and to late autumn is a potential pollutant. In this paper, published information on N transformations and measures taken to control inorganic N in the soils are reviewed and discussed. The relative importance of the different N transformation processes appears to be mineralization > denitrification > crop uptake > leaching > immobilization > NH_3 volatilization. The contribution to lowering inorganic N pools was greatest for denitrification, followed by crop uptake, leaching, immobilization and NH_3 volatilization. Dissimilatory reduction of NO_3-N to NH_4-N markedly contributed to NO_3-N disappearance; hence, it should receive more attention. Cultivation measures taken to decrease NO_3-N accumulation have mainly been sowing crops to increase uptake or saturating the soils with moisture to suppress nitrification.

Key words: Mineralization, immobilization, denitrification, NH_3 volatilization, assimilatory-dissimilatory NO_3-N reduction, NO_3-N control.

INTRODUCTION

Peatlands are unbalanced wetland ecosystems in which production of plant residues exceeds decomposition of organic matter, leading to the formation of "peats" (Moore & Bellamy, 1974; Williams & Crawford, 1983). In the present work the term "organic soils" refers to all types of peat soils. Of *ca.* 3 million ha total area of cultivated land in Sweden, 10% is organic soils (Jordbruksstatistisk årsbok, 1987; Lantbruksstyrelsen, 1988).

Cultivation of organic soils enhances loss of soil organic matter (SOM), with a concomitant mineralization of N (e.g. Osvald, 1937; Avnimelech *et al.*, 1978; Kuntze, 1992). Accumulation of inorganic N occurs in cultivated mineral soils of cool temperate

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regions up to late autumn (Wallgren & Lindén, 1991). A similar event could be expected to occur in cultivated organic soils. The accumulated N is subject to transformations and leaching. Gaseous losses of N as NH_3, NO, N_2O and N_2 ultimately contribute to the depletion of the stratospheric ozone layer, whereas leached NO_3 can contaminate surface and groundwater. Contamination of the Hjälmaren lake and groundwater in the Kvismar valley, both located in an agricultural district in Central Sweden, could, partly have occurred in this way. Moreover, excessively high NO_3-N levels in soils during the summer season may decrease yields of cereal crops and grasses due to lodging and reduce the quality of potatoes.

The objective of this paper was to collect and discuss published information on N transformations and control of excess NO_3-N in organic soils for safe cultivation of these soils.

MINERALIZATION

Ammonification and nitrification

Soil organic N is present mainly in large molecules in the form of amino ($-NH_2$), amide (=NH) and imide (N) groups. These groups are split, forming NH_3 by enzymes produced during the microbial breakdown of SOM. This process known as ammonification, is the primary stage of N transformation in soils, which can be summarized as follows:

Organic-N------------> NH_3--------> NH_4^+ ----------> NO_3^- -----------> NO, N_2O, N_2

Ammonification Hydrolysis Nitrification Denitrification

|----------------------Mineralization ----------------->|

|<--------------Immobilization ---------------|

Ammonification and nitrification are known as mineralization process in soils. Ammonification rates are rather difficult to estimate accurately in soils. Once released on the soil surface, NH_3 may be volatilized, whereas when released below the soil surface, NH_3 associates H^+, forming the NH_4^+ cation. In aerobic soil conditions, NH_4^+ can be rapidly oxidized to NO_3^-, depending on the acidity of the soil. In anaerobic soils, denitrification-induced losses of N take place, while at the same time, NH_4^+ accumulates as a result of the poor oxidizing conditions and assimilatory-dissimilatory reduction of NO_3-N to NH_4-N. Furthermore, a considerable amount of the released NH_3 is immobilized by certain humic compounds (Nömmik & Vhtras, 1982; Malh *et al.*, 1984). It should, however, be pointed out that N turnover in the SOM is often overestimated since the results are usually not adjusted for the weight losses that occur during decomposition (see later). This discrepancy can be a problem, particularly in warm regions where SOM decomposition rates are relatively high compared with the cool regions.

The factors that influence N mineralization in soils include moisture, temperature, pH, contents of nutrients and decomposable SOM and cultivation management.

Impact of water table and pH

Nitrogen mineralization is usually low in acid soils, many of which are organic, but it normally can be enhanced by liming. Williams and Wheatley (1988) determined ammonification rates in fresh peat samples (pH_{aq} 3.34 - 3.67) taken from a Scottish field experiment in which the water table in three plots had been maintained at 0, 20 and 50 cm below the soil surface for 14 years. The mean NH_4-N contents in the 0 - 60 cm profile were 0.99, 1.17 and 1.48 g m^{-2}, respectively, most of which was found in the 0 - 20 cm layer where 80-90% of the ammonifying bacteria resided. Regardless of the water table level, NH_4-N accounted for nearly all the inorganic N found in the soil samples.

In four Polish organic soils incubated by Maciak (1983) at 22 °C for 5 months, more NH_4-N accumulated in a strongly acid sedge-moss peat than in a weakly acid reed peat or in neutral alder and tall-sedge peats (Table 1). That pattern of events was reversed for NO_3-N accumulation. Working with a Canadian peat (pH_{aq} 3.5) in an incubation experiment, Rangeley and Knowley (1988) found a very low ammonification rate in the unlimed fractions, in which the mineralized NH_4-N was not nitrified owing to the absence of nitrifying bacteria (*Nitrosomonas*) in the soils.

Table 1. Mineralization rates (mg 100 g^{-1} dry weight) in four Polish organic soils

Parameter	Sedge-moss peat	Reed peat	Alder peat	Tall-sedge peat
Decomposition degree (%)	31	34	40	48
pH_{aq}	4.1	5.1	7.0	7.4
NH_4-N	74.1	53.8	53.8	48.7
NO_3-N	44.9	158.7	120.7	95.6
Total	119.0	212.5	174.5	144.3

They further noted that liming the soil to pH_{aq} 6.6 enhanced nitrification only when the soil had been inoculated with the bacteria. In contrast, nitrification takes place in cultivated organic soils whether or not they have been inoculated. Liming could have promoted nitrification in the experiment conducted by Rangeley and Knowley, but any such nitrified N was probably biologically immobilized.

Impact of nutrients

In the studies conducted by Maciack (1983) referred to earlier, the net mineralization rate was lowest in the sedge-moss peat which was inferior to the reed, alder and tall-sedge peat soils in terms of total contents of N, K and P. Total N amounts mineralized during a 6-month incubation in Dutch fens having small supplies of water-soluble N and P (pH_{aq} 6.6) were about twice as low as in other fens (pH_{aq} 6.6) having relatively large supplies of the two nutrients (Verhoeven & Arts, 1987). Similarly, Williams and Wheatley (1989) found that mineralization rates in peats containing larger amounts of inorganic N were higher than in those containing smaller amounts.

Liming not only increases soil pH, but may also increase the availability of N, P and S. Thus, using two *Carex* peat soils in laboratory and pot experiments, Otabbong (1981, 1984) noted that raising pH_{aq} from about 4.5 to 6.5 or 7.5 by liming increased soil contents of P extracted with ammonium lactate solution (pH 3.75) from 64 to 75 - 83 mg kg^{-1} (Otabbong, 1981) and significantly increased P and N uptake by barley (Otabbong, 1984) compared with controls. When studying a high moor soil, Kuntze (1991) found that soluble N contents were higher in plots treated with physiologically alkaline NPK-fertilizer than in those treated with physiologically acid NPK-fertilizer.

Impact of moisture

Of the total pore volume in poorly drained organic soils, *ca.* 90% may be occupied by water most of the year (Wheatley & Williams, 1989). This poor aeration depresses the mineralization process, while promoting NO_3-N reduction to NH_4-N and gaseous N. To successfully cultivate organic soils they must first be drained. Drainage accelerates decomposition of SOM, which in turn leads to soil compaction and an accumulation of inorganic N (Osvald, 1937; Lähde, 1969; Mishustin *et al.*, 1974; Avnimelech *et al.*, 1978; Piispanen & Lähdesmäki, 1983; Kuntze, 1992). For example, Piispanen and Lähdismäki (1983) reported that inorganic N in a Finnish organic soil increased from 5.6 ppm (on dry wt basis) before drying to 22.4 ppm after drying in the laboratory at 105 °C overnight.

In both inorganic soils (Stanford & Epstein, 1974) and organic soils (Scheffer, 1976; Virdung, 1982) mineralization rate maxima were found to be at 60 - 80% at the maximum water holding capacity (MWHC) of the soils, whereas below or above the maxima the rates were lower. Indeed, a high level of groundwater, which leads to saturating surface soils with moisture, reduced the N mineralization (Scheffer & Tóth, 1979) and the accumulation of NO_3-N in organic soils (Avnimelech *et al.*, 1978). At MWHC ranging from 120 % to 150 %, NO_3-N accumulation was nearly inhibited (Raveh & Avnimelech, 1973). By contrast, the flooding of organic soils enhanced NH_4-N accumulation (Avnimelech, 1971). Ammonification is enhanced by both aerobic and anaerobic bacteria, whereas nitrification is enhanced solely by aerobic bacteria. Both assimilatory-dissimilatory NO_3-N reduction and organic N mineralization should contribute to NH_4-N accumulation in the soils.

Impact of C/N ratios

Table 2. Total C and N contents (%), C/N ratios and N mineralization rates in cultivated organic soils of warm temperate regions

Location	Total C	Total N	C/N	Source
USA (Florida)				
Cultivated	23-65	2.1-3.8	11-17	Reddy (1982)
Fallow	44	2.0	22	Terry and Tate (1980a)
Grassland	48	2.1	23	Terry and Tate (1980a)
Israel[a]	17-35	1.7-2.3	10-15	Yaari Cohen 1972)
		kg ha^{-1} yr^{-1}		
a) Incubation experiments				
USA (Florida)[a]		1200-1400		Terry (1983)
		410-938		Reddy (1982)
		500-600		Gunthrie and Duxbury (1978)
		874-1250		Reddy (1982)
b) Field experiments				
Israel[a]		1000-2000		Raveh (1973)

[a] = cultivated.

Table 3. Total C and N contents, C/N ratios and N mineralization rates in organic soils of cool temperate regions

Region	Total C (%)	Total N (%)	C/N ratio	Source
Canada	12-17	0.5-2.5	23	Terry (1986)
Germany	44-50	1.4-1.9	23-36	Kuntze (1992)
Ireland				
Sphagnum	35	1.0	35	O'Toole (1975)
Carex	28	2.0	14	O'Toole (1975)
Russia	36	2.8	13	Mitshustin, *et al.* (1974)
		kg ha^{-1} yr^{-1}		
a) Incubation experiments				
Minnesota (USA)		480		Meyer *et al.* (1989)
Germany		34[a]		Scheffer (1976)
		290[b]		Scheffer (1976)
b) Field experiments				
Sweden		113-436		Sjögren (1987)
Poland		420		Gotkiewicz (1987)
		350[c]		Gotkiewicz (1987)

[a] = acid; [b] = calcareous; c = grassland.

Organic soils have high contents of total C and N, spanning a wide range of C/N ratios. A high C content generally results in a high C/N ratio and is usually lower in warm regions (Table 2) than in cooler ones (Table 3).

As shown in Tables 2 and 3, mineralization rates were greater in the warm regions, where microbial activity is relatively high the year round, than in cool regions where severe winters decrease or stop microbial activity. The corresponding SOM losses in the warm region must be high. N mineralization rates were higher in cropped soils than in fallow soils (Table 2), owing to differences in SOM decomposability (Terry, 1983) and fertilization. The mineralization rates should have been lower if SOM losses had been adjusted for and, hence, this is a general weakness noted in the papers reviewed in this work. For example, assume 1000 g organic soil containing 110 g inorganic N (NH_4-N + NO_3-N) weighed only 800 g and contained 160 g inorganic N kg^{-1} after incubation at 20 °C for one month. Thus, the initial sample was 1.25 (1000/800) times heavier than the incubated one. Dividing 160 g by 1.25 gives 128 g, which is the actual amount of inorganic N present in the incubated soil. This represents an increase of 18 g (128 - 110) or 16 %. In contrast, if this adjustment is not made, the increase would have been 50 g (160 - 110) or about 46 %; hence, N mineralization is over estimated about threefold. Admittedly, such adjustments cannot be carried out accurately in field experiments.

N mineralization during *in vitro* studies with 25 cultivated soils (C/N ratio range = 9 - 22, mean = 14) was significantly ($P = 0.001$) and positively correlated with C/N ratios (Jones & Parsons, 1970). With time, both amounts of decomposable SOM and inorganic N decline in drained organic soils, with a concomitant slowing down of mineralization.

Kuntze (1992) observed that liming in combination with N amendment markedly lowered the C/N ratio of a high moor organic soil to a much greater degree compared with liming alone. It is generally assumed for mineral soils that organic residues with C/N ratios of up to *ca.* 20 favour net N mineralization, whereas those with C/N ratios greater than 20 promote net N immobilization (Harmsen & van Schreven, 1955; Alexander, 1977). This general rule does not seem to apply in organic soils. For example, in an incubation experiment of peat fractions, net N mineralization occurred in samples having C/N ratios of up to 42 (Williams, 1983), possibly because the soil contained appreciable amounts of available N. It is more likely that the C/N ratio of the substrate decomposed is the important factor and not the overoll C/N ratio. In mineral soils, these are very similar, but not in organic soils.

The N amounts presented in Tables 2 and 3 sharply contrast with the values often obtained for mineral soils. For example, in Sweden they are *ca.* 10-110 kg N ha^{-1} yr^{-1} during the growing period of spring cereals (Lindén, 1986). High rates of N mineralization in organic soils could explain the low crop recovery of N applied to the soils (Farrell, 1985; Adams, 1986; Gotkiewicz, 1987; Sjögren, 1987). Moreover, as will be seen later, fertilizer N could have been leached, immobilized or volatilized.

The content of available N in a soil is determined partly by the balance between mineralization and immobilization. N immobilization is a prerequisite for mineralization in all soils (Jansson & Persson, 1982). In organic soils it is primarily due to microbial absorption of N. In addition, N can be fixed abiotically by mineral (expanding clay minerals) and organic (humins) components (Maciak, 1975; Nömmik & Vahtra, 1982; Malh *et al.*, 1984). Considerable amounts of inorganic N can be retained in these ways in organic soils (Malh *et al.*, 1984).

High C/N ratios were considered responsible for N deficiency in a well-established pasture which had not been fertilized with N (Rangeley, 1988). It was noted by

Williams (1983), however, that adequate N amounts can be mineralized in some organic soils even if their C/N ratios are high. Net N immobilization occurred during incubation of raised bog peat fractions having a C/N ratio of 30 (Williams, 1983). An equivalent of *ca.* 160 kg N ha^{-1} yr^{-1} was immobilized during incubation of a Minnesotan organic soil (Meyer *et al.*, 1989).

When a Scottish blanket peat was cleared of its original bog vegetation, limed, fertilized with P and K and sown with grasses, immobilization of ^{15}N applied in the form of NH_4NO_3 predominated (1.96 kg N ha^{-1} d^{-1}) over mineralization (0.63 kg N ha^{-1} d^{-1}) through the 29-day study (Williams, 1992). To explain why not all ^{15}N was recovered as either NH_4-N or NO_3-N within one day of N application, it was suggested that N was chemically converted into certain forms that had not been quantified in the study. The only compounds likely to have immobilized N in the organic soil are humic substances (Nömmik & Vhtras, 1982; Malh *et al.*, 1984). Furthermore, after only a few hours, some of the ^{15}N applied to a sterilized Californian mineral soil had become unavailable (Davidson *et al.*, 1991). NH_4^+ could have been fixed by expanding clays in that mineral soil, whereas in the organic soil, this fixation is negligible.

NITROGEN LEACHING AND RUNOFF

By comparing Table 4 with Table 5, it becomes clear that N losses due to leaching and surface runoff, are generally lower than N losses due to denitrification. A spring barley grain yield of 4 000 kg ha^{-1} removes about 80 kg N from soil, whereas a potato tuber yield of 50 000 kg ha^{-1} removes about 180 kg N. In most cases, the N losses through leaching were smaller than the N amounts removed from soils by the crop. Nevertheless, N leaching has been found to be higher in certain organic soils (Terry, 1986).

Fertilizer use in afforestation of organic soils may have an impact on mobility of elements in the soils. For example, N and P leaching rates in a Scottish peat limed to pH_{aq} 4.5 under young conifers increased with time and was greater in the treatment fertilized with $CaNH_4PO_4$ than in the unamended treatment, the N being leached mainly in the NH_4-N form (Malcolm *et al.*, 1977). The ambient acidic environment was apparently not suitable for nitrification and the binding capacity of peat for phosphate anions could have been very large.

Table 4. N leaching from incubation and field experiments

Region	N kg ha^{-1} yr^{-1}	Source
Incubation experiments		
Florida (USA)	37-245	Reddy (1982)
New York (USA)	40-90	Duxbury and Peverey (1978)
Field experiments		
Sweden	30-70	Gustafson and Hansson (1980) Brink and Gustafsson (1985)
Florida (USA)	20-40	Terry and Tate (1980b)
Florida (USA)	12-40	Terry (1983)
Ontario (USA)	91-196	Miller (1974)
Ontario (USA)	37-245	Niller (1979)
Russia	87-112	Mishustin *et al.* (1974)

DENITRIFICATION

Excess moisture, leading to anaerobic, and easily decomposable SOM enhance denitrification. Losses of N through denitrification are presented in Table 5. In general, organic soils have a high moisture retention capacity. As mentioned earlier, 90 % of the total pore volume in a poorly drained bog is occupied by water for most of the year (Wheatley and Williams, 1989), a situation that promotes denitrification losses of N.

Denitrification in a blanket peat was found to decrease in the order: early spring > autumn > summer (Wheatley & Williams, 1989).

Denitrification was reported to occur immediately following flooding of soils (Terry & Tate, 1980c). Verhoeven *et al.* (1983) found only traces of inorganic N in drainage welling from the bottom of a fen peat grassland, apparently due to denitrification. Scheffer (1976), Scheffer and Tóth (1979) and Virdung (1982) partly attributed declines in NO_3-N accumulation in soils saturated with water to denitrification.

The amounts of N lost through denitrification can vary greatly depending on the environment. Of 1200-1400 kg N ha^{-1} mineralized in a Florida cultivated organic soil, 80 % was lost through denitrification, 10% through leaching and 10% removed by crop uptake (Terry, 1983). By contrast, losses of N through denitrification in cultivated soils over a 28-

day incubation accounted for 2.5-9 % and 9-19 % of the mineralized 500-600 kg N ha^{-1} in unflooded and flooded samples, respectively (Gunthrie & Duxbury, 1978).

Table 5. Loss of N through denitrification

Soils	*Denitrification*	*Source*
Incubation experiments		
Cropped	6.7 (kg ha^{-1} d^{-1})[a]	Wheatley and Williams (1989)
Cropped	18 (g cm^{-3} d^{-1})[a]	Terry and Tate (1980c)
Cropped	4.2 (kg ha^{-1} d^{-1})[b]	Wheatley and Williams (1989)
Uncropped	6.8 (kg ha^{-1} d^{-1})[a]	Wheatley and Williams (1989)
Grassland	5.3 (kg ha^{-1} d^{-1})[a]	Wheatley and Williams (1989)
Field experiments		
Annual crops	960-1120 (kg ha^{-1} yr^{-1})	Terry (1983)
Fallow	165 (kg ha^{-1} yr^{-1})	Terry (1983)
Sugar cane	48 (kg ha^{-1} yr^{-1})	Terry (1983)
Grasses	97 (kg ha^{-1} yr^{-1})	Terry (1983)

[a] and [b] = anaerobically and aerobically incubated, respectively.

In a laboratory experiment in which a blanket peat was incubated with amounts equivalent to 112 kg N ha^{-1} applied in form of NH_4NO_3, 4.2 kg N ha^{-1} d^{-1} was denitrified under aerobic and 6.7 kg N under anaerobic conditions

(Wheatley & Williams, 1989). Possibly, some pockets in the aerobic samples were saturated with water, promoting denitrification. Because denitrification only occurs in anaerobic soil, the NO_3-N in the floodwater must diffuse to the soil layer before being denitrified (Reddy *et al.*, 1978). Diffusion was found to be higher in more humified organic soils than in less humified ones (Graham, 1989; Lindström, 1990). When organic soils were anaerobically incubated with 5 ppm NO_3-N, N_2 was volatilized, whereas when the soils were incubated with 50 - 2000 ppm NO_3-N, N_2O was volatilized (Blackmer & Bremner, 1978). Reduction of N_2O to N_2 occurred only when the soil NO_3-N supply had been depleted, with N_2O subsequently acting as electron acceptor (Terry & Tate, 1980b).

An abundant supply of easily decomposable SOM enhances the rate of denitrification. During the conversion of C to CO_2, O_2 is depleted, thereby creating favourable conditions for the onset of denitrification and a subsequent consumption of oxygen from nitrate. In a Florida organic soil, the denitrification rate increased with increasing supplies of both NO_3-N and available C. Denitrification of *ca.* 0.8 mole NO_3-N produced 1 mole CO_2, with a significant correlation ($P = 0.05$) being found between NO_3-N consumption and CO_2 production within 0.6 - 1.8 NO_3-N/CO_2 molar ratios. (Reddy *et al.*, 1980.) Similarly, incubation of an uncultivated Scottish peat (pH_{aq} 3.5) resulted in a discharge of 12 μg N_2O-N cm^{-3} soil from an anaerobic system not treated with glucose and 18 μg N-N_2O cm^{-3} soil in the system receiving glucose (Rangeley & Knowles, 1988).

At temperatures around freezing, depressed microbial activities were significantly depressed, but N transformations were not completely eliminated (Williams & Crawford, 1983). Denitrification rates measured at 27, 25 and 8 °C were highest at 27 °C and least at 8 °C (Reddy *et al.*, 1980).

AMMONIA VOLATILIZATION

Flooding soils enhances denitrification, with a concomitant increases in pH of acid soils and decreases in pH of alkaline soils (Ponnamperuma, 1972). High pH favours NH_3 volatilization. When an organic soil amended with 442 mg $^{15}NH_4$-N kg^{-1} (soil dry wt) was flooded, soil pH increased from an initial value of 6.9 to 9.2 during daylight and 8.6 at night, 1.2 and 2.1 mg N kg^{-1} day^{-1} were denitrified and 4 and 8 % of added N was volatilized in the form of NH_3 from the dark and illuminated soils, respectively (Meyer *et al.*, 1989). Hence, loss of gaseous N under those circumstances was predominantly in the form of NH_3.

ASSIMILATORY AND DISSIMILATORY NITRATE REDUCTION

In soils, NO_3-N can be reduced to NH_4-N (Nömmik, 1956; Fewson & Nicholas, 1961), often by incorporation into microbial cells (assimilatory reduction). Decomposition of microorganisms following their death leads to the mineralization of this N. Assimilatory, dissimilatory and denitrification transformations of NO_3-N occur simultaneously (Fewson & Nicholas, 1961) and this may be depicted (Campbell & Lees, 1967) as follows:

---> 2 NH_2OH---> 2 NH_4^+
[Dissimilatory pathway]

2 NO_3--------> 2 NO_2------->2 HNO

---> $H_2N_2O_2$---> N_2O and N_2
[Denitrification pathway]

[Assimilatory pathway]
(*Microbial biomass*) ----------> NH_4-N

The dissimilatory pathway is enhanced by specific anaerobes, i.e. *Bacillus lincheniformis* and *Clostridium tertium*, which cannot denitrify NO_3-N (Caskey & Tiedje, 1979; Verhoeven, 1956). Conversely, denitrifiers, i.e. *Microccus denitrificans* and *Pseudomonas aeruginosa* do not produce NH_4-N (Verhoeven, 1956). Dissimilatory NO_3-N reduction to NH_4-N occurs principally under highly reduced conditions, particularly when soils have high pH and contain large amounts of easily decomposable SOM (Nömmik, 1956; Buresh & Patrick, 1978), whereas denitrification occurs in acid soils as well. It seems, therefore, that the dissimilatory and volatilization processes can occur concurrently and quantifying each process accurately is difficult. Neither of the papers cited distinguish between dissimilatory reduction and denitrification.

Transformation of NO_3-N to NH_4-N and organic N has been studied by means of ^{15}N technique. Of 100 ppm $^{15}NO_3$-N incubated with soils, 9 and 19 % was recovered as $^{15}NH_4$-N and organic ^{15}N, respectively (Buresh & Patrick, 1978). In another similar experiment, Williams and Crowford (1983) recorded a significant conversion of 400 ppm $^{15}NO_3$-N to $^{15}NH_4$-N and organic ^{15}N. In both experiments, the reduction occurred instantly after the onset of anaerobiosis and the reduction increased in proportion to the increase in levels of easily decomposable organic C.

Terry and Tate (1980c) studied the effects of flooding on microbial activities in organic soils by monitoring N transformations. Denitrification rates increased as nitrification rates decreased and NH_4-N levels increased about fivefold during flooding. Reddy *et al.*(1980) determined the reduction of NO_3-N applied at rates of 27, 42, 60, 94 and 200 g cm^{-3} at 8, 18 and 28 °C. The portion of NO_3-N converted into NH_4-N and organic-N was greatest at 8 °C and the conversion was positively related to NO_3-N application rates.

MEASURES TO DECREASE NITRATE ACCUMULATION

The following measures can be useful in reducing water pollution.

Maintaining high soil moisture

N dynamics

By saturating an organic soil with water after harvesting crops one can reduce N nitrification and soil subsidence, while promoting NH_4-N accumulation (Avnimelech, 1971), denitrification (Rave & Avnimelech, 1973; Avnimelech *et al.*, 1978; Terry & Tate, 1980c), NH_3 volatilization (Meyer *et al.*, 1989), dissimilatory reduction of NO_3-N (Buresh & Patrick, 1978; Reddy *et al.*, 1980; Terry & Tate, 1980c) and N_2 fixation by blue-green algea (Wilson & Alexander, 1979). The extent to which these processes contribute to N dynamics in organic soils has not been investigated.

Impact on P mobility

The flooding of soils can mobilize P (Ponnamperuma, 1972). Relatively high rates of organic P leaching have been recorded from organic soils, e.g. 14 - 20 kg ha^{-1} yr^{-1} (Miller, 1974), 0.6 - 30.7 kg ha^{-1} yr^{-1} (Duxbury & Peverly, 1978), 3 - 10 kg P ha^{-1} yr^{-1} from grassland and 35 kg P ha^{-1} yr^{-1} from arable land (Scheffer & Kuntze, 1989). P leakage can result in deficiency in available P (Verhoeven *et al.*, 1983). Thus, in the long run, counter-acting NO_3-N accumulation by saturating soil with moisture may lead to plant nutrition problems. Moreover, soluble P escapes in the drainage, resulting in eutrophication of surface waters. Furthermore, subsequent to the drainage of soils in the spring, Mn^{2+} would be oxidized, leading to Mn deficiency. The NO_3-N influx that may occur in response to drainage can cause lodging in cereal and grass plants.

Sowing autumn-winter crops

The sowing of autumn-winter crops can be used to minimize NO_3-N leaching (Scheffer, 1976; Scheffer & Tóth, 1979; Nielsen & Jensen, 1985; Lantbruksstyrelsens rapport, 1990). The effectiveness of this measure depends on the magnitude of N uptake by the plants, which is usually low during the period of N accumulation. In Sweden and Denmark, the sowing of catch crops has been made compulsory in some cases, e.g. where less than 50 % of land cultivated by a farmer is covered by winter crops (Lantbruksstyrelsens rapport, 1990).

Sowing catch crops

Catch crops should include plants that can delay or inhibit NO_3-N accumulation. *Azadiracta indica* (Mengel & Kirby, 1987), *Medicago sativa* L., (Levin *et al.*, 1974; Levin & Leshem, 1978; Levanon *et al.*, 1979), *Brassica napus* L. and *Brassica campetris* L. (Mengel & Kirkby, 1987; Fridefors, 1991) are among the species suitable for use as catch crops. Their relative suitability depends on climatic conditions. These species do not only absorb N, but also inhibit its accumulation in form of NO_3-N, since they contain saponins and mono- and disaccharides which immobilize NH_4-N (Levanon *et al.*, 1978).

CONCLUSIONS

Based on the data presented in this review, the following conclusions pertaining to cultivated organic soils can be drawn:

1. N amounts mineralized annually often exceed the crop's requirement for N.
2. The N mineralized after crop harvest can trigger eutrophication.
3. More than half of the mineralized N can be denitrified.
4. Assimilatory-dissimilatory NO_3-N reduction and NH_3 volatilization contribute to the disappearance of NO_3-N from soil. Hence, denitrification is often overestimated.
5. Microorganisms that promote dissimilatory reduction should receive more attention.
6. Phosphorus tends to be mobilized to a large degree in anaerobic soils, from where it can easily be leached. Thus, some of it ends up in surface water where it contributes to eutrophication.
7. Of the measures proposed for counteracting NO_3-N accumulation, the sowing of winter and catch crops can be recommended.

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YIELD OPTIMISATION OF MILLED PEAT USING WEATHER FORECASTS

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SUMMARY

The potential impact of weather forecast technology on milled peat production under Irish conditions is analysed. Current estimates indicate that milled peat yield could be expected to increase by approximately 7%, with quite large year to year variations, and work carried out in the former USSR confirms these estimates.

INTRODUCTION

It is well documented that the drying rate of milled peat is highly dependent on actual evaporation (Luikov, 1935; Malkov et al., 1967; Derov, 1985). Derov (1985) states that predictions of wind speed, air temperature and precipitation are required in order to estimate the evaporation cycle. Work by Malkov et al. (1967) showed that the duration of the milled peat drying period (t,d) is dependent on both the after milling yield (Pc, kgd/m^2)* and the evaporation rate (i_{ev}, mm/d), and is given as:

$$t = C\,(Pc/D_{jw}\,d_{av})^{1.2}\,(D_{jw}\,d_{av}/i_{ev}) \quad d \tag{1}$$

where C = a constant, depending on the peat type

D_{jw} = bulk density (kgdm*/dm^3)

d_{av} = average particle diameter (mm).

If it is assumed, in a given situation, that D_{jw} and d_{av} are constants, then equation (1) simplifies to:

$$t = K\,Pc^{1.2}/i_{ev} \quad d \tag{2}$$

where K is a constant.

As in practice, t is fixed at a value between 3.5 and 4 d, depending on the bog, the only variables are Pc and i_{ev}. The standard yield of fresh millings under Irish conditions (Pc) is 0.84 kgdm/m^2. Therefore, in line with the recommendations of Malkov et al. (1967), the "optimum" milling yield is defined as

* kgdm = kg of dry matter

$$Pc = (K^{-1} \sum_{n=1}^{m} i_{ev_n})^{0.833} \text{ kgdm/m}^2 \quad (3)$$

where K = 14.793 (Irish conditions)
m = number of days per cycle.

Equation (3) offers a system whereby the optimum milling depth can be related to the cumulative evaporation in a milling cycle. If, however, this equation is to be implemented in practice, it is necessary to be able to predict the cumulative cycle evaporation, and this involves prediction of daily evaporation for 4 days ahead. Work by Yelnikov et al. (1986) indicates that daily evaporation is dependent on air temperature, wind speed and air humidity, and they developed empirical equations to predict cumulative cycle evaporation based on predictions of these parameters. They related the optimum milling yield (Pc) to the forecasted cycle evaporation (i_f) as follows:

$$Pc = 0.84 \, (i_f /12)^{0.75} \text{ kgdm/m}^2 \quad (4)$$

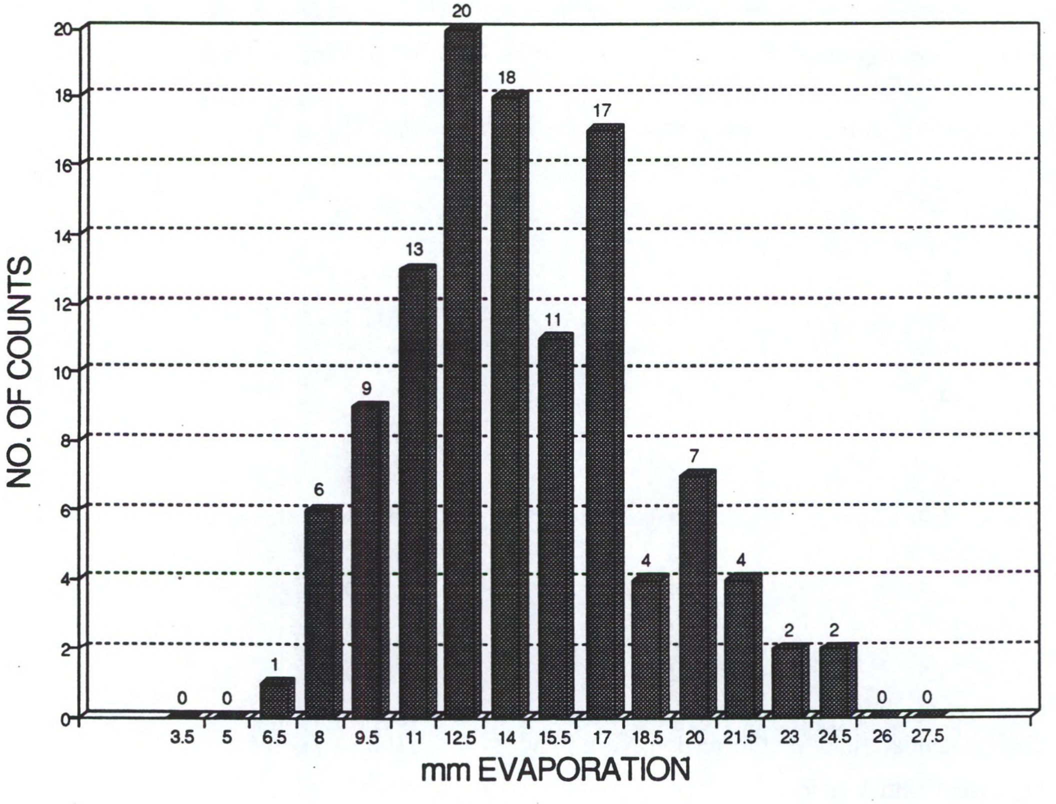
Using Equation (4), the respective optimum milling yields for cumulative cycle evaporations of 6 and 18 mm are 0.5 and 1.14 kgdm/m^2, which are in reasonable agreement with the values of Malkov et al. (1967) (viz 0.47 and 1.18 kgdm/m^2, respectively).

WEATHER PATTERN

A frequency distribution of the categories of 4-day drying cycles (based on cumulative cycle evaporation) for the Irish midlands (1976-1986) is given in Figure 1. This shows a mean cumulative cycle evaporation of just over 14 mm and a modal class of 12.5 mm. The Peco milled peat production system (Bórd na Móna, 1984) as practised in Ireland is geared to operate on a 3.5 to 4 day cycle, with a nominal cycle evaporation of 12 mm - this conforms with the data presented in Figure 1.

In the event of the 4-day cumulative cycle evaporation being less than 12 mm (which can be expected to occur approximately 25 % of the time) it is likely that the cycle duration will be extended and the machines will begin to queue in order to allow the peat to reach the target moisture content. If, on the other hand, the cycle evaporation is greater than 12 mm (which can be expected to occur more than 50 % of the time) the peat will dry down below the target moisture content. This latter situation, while adding value to the peat harvest in the form of higher quality produce, represents an inefficiency as valuable drying weather is lost. This is particularly so in view of the drying characteristics of peat, where the drying efficiency (i.e. actual evaporation/potential evaporation) drops off dramatically below the "target" moisture content (Luikov, 1935).

Clearly, if it was possible to predict the cycle evaporation then the milling depth could be adjusted accordingly, hence optimising available drying (Figure 2). Recent developments in weather forecasting technology (McGrath, 1986) offer considerable possibilities in this regard.



Mean 14.384 Std Dev 3.876 Minimum 5.900 Maximum 25.200
Valid Cases 114 Missing Cases 0

Figure 1. Frequency distribution of cumulative cycle evaporation for Irish midlands (May to August, inclusive) for the 11 years, 1976 to 1986.*

**A cycle is defined as a period of four consecutive days within which daily rainfall is less than 1mm.*

POTENTIAL YIELD

An assessment of the potential yield increase due to varying milling depth in response to cycle evaporation predictions is given in Table 1 - the potential increase is in the order of 20%. This analysis is based on the works of Malkov et al., (1967) and Yelnikov et al., (1986), and both show good agreement. Indeed the plot of "optimum" milling yield (and hence milling depth) versus cycle evaporation given in Figure 2 shows the nature of the relationships in Equations 3 and 4.

Table 1. Assessment of the potential yield increase due to varying milling depth in response to cycle evaporation, for the 11 years 1976 to 1986 in the Irish midlands.

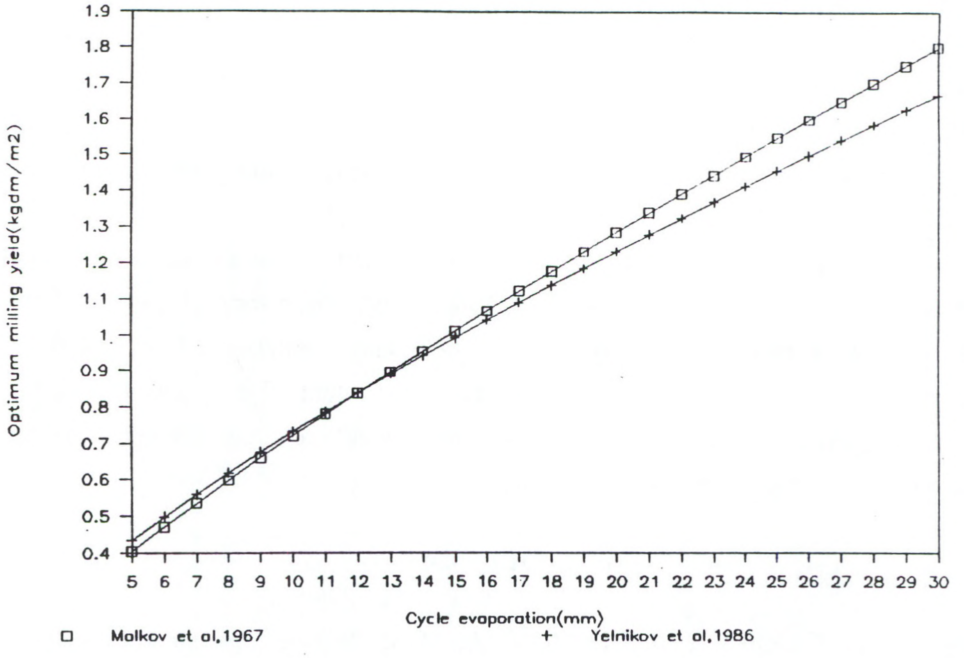
Cycle evaporation (mm)	Frequency	Potential Yield (kgdm/m^2)
6.5	1	0.53
8	6	3.71
9.5	9	6.34
11	13	10.23
12.5	20	17.32
14	18	16.97
15.5	11	11.19
17	17	18.54
18.5	4	4.64
20	7	8.62
21.5	4	5.20
23	2	2.73
24.5	2	2.86

Total potential yield, due to responsive milling	=	108.94 kgdm/m^2
Estimated actual yield	=	90.42 kgdm/m^2
Potential yield increase	=	20.5 %

DISCUSSION

The results given in Table 1. assume absolute prediction of cycle evaporation and absolute control of milling depth and system inefficiencies. The realities are less clear and the key success factors are evaporation predictions and milling depth control. In addition, losses of dried peat during the harvesting operation reduce drying efficiency. Work by McGrath (1986) indicates that certain weather parameters (viz. temperature at 2 m above

Figure 2. Optimum milling yield v. evaporation



the ground, and wind speeds at 10 m above the ground) can be forecast reasonably accurately up to approximately 3 days ahead, but cloud and precipitation amounts are more difficult to forecast. Nevertheless, tentative estimates by this author indicate that a suitable algorithm can be used approximately one third of the time (which, in general, amounts to settled weather periods when rainfall and cloudiness levels are low) in order to exploit the available drying. Such a system would offer a potential yield increase in the order of 7 %, but its effectiveness would vary from year to year and, in general, it would be most effective in good production years. For example, this author estimates that no improvement could have been achieved in 1986 (Table 2.). Clearly, the operation of such a system has to be carefully coupled with stock carryover and protection strategy.

Table 2. Percentage of total annual 4 day cycles with cumulative evaporation greater than 16 mm (May to August, inclusive)

1976	1977	1978	1979	1980	1981	1982	1983	1984	1985	1986
35	38	31	13	17	17	55	29	44	50	0

Mean = 30% Max. = 55% Min. = 0

The above estimate of a 7 % increase in yield due to milling depth control (in response to evaporation predictions) is in good agreement with the results of Lazeryev et al. (1986) who found that " ... using a mathematical model (to control the milling depth in response to weather predictions) improved average seasonal cycle yield by 7 % to 9 %". In contrast, Bogatov et al. (1985) achieved an increase of 16.8 % in seasonal yield per hectare, using such techniques, and the dispersion in the final moisture content of the peat was decreased by a factor of 3.

Finally, it must be pointed out that the current weather forecasts are based on sophisticated numerical prediction models (McGrath, 1986) coupled with some elements of local knowledge. These numerical models are being constantly upgraded and any biases or limitations of the models are likely to be reduced in the future. The quality of weather forecast can be expected to improve over the next decade and such improvements could be of major significance in milled peat production.

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ZUSAMMENFASSUNG IN DEUTSCH

Blackford J. J. & Chambers F. M.

DIE BESTIMMUNG DES HUMIFIZIERUNGSGRADES VON TORF FÜR PALÄOKLIMATOLOGISCHE STUDIEN

Verschiedene Methoden für die Bestimmung des Humifizierungsgrades von Torfen werden verglichen; dabei zeigt sich, daß die Bestimmung des Faseranteils und die Alkali-Extraktion brauchbar sind. Die NaOH-Extraktion wird bei unterschiedlichem Alkaligehalt, nach der Zeit, den anorganischen Bestandteilen und der Verdunstungsrate getestet. Die Ergebnisse zeigen, daß die kolorimetrische Messung robust und aussagekräftig ist. Die Berücksichtigung der anorganischen Bestandteile ist notwendig und die Einhaltung eines strengen Zeitplanes erforderlich. Fragwürdig ist die Umsetzung der Meßergebnisse in Prozentzahlen der Humifizierung, weil dabei die unterschiedliche Natur der Huminsäuren nicht berücksichtigt wird. Die Meßdaten sollten besser als prozentuale Licht-Transmission oder optische Dichte ausgedrückt werden.

Die Werte der Alkali-Extraktion sind aussagekräftiger als der Faseranteil, weil sich in ihnen die für paläoklimatologische Aussagen wichtige Veränderung der Zusammensetzung der Torfpflanzenarten besser ausdrückt.

Botis A., Bouzinos A. & Christanis K.

GEOLOGIE UND PALÄOÖKOLOGIE DER TORFLAGERSTÄTTE VON KALODIKI, WEST-GRIECHELAND

Das Moor von Kalodiki ist ein 195 ha großes Niedermoor in einem kleinen tektogenen intramontanen Becken im Epirus, West-Griechenland. Während des Spätglazials stand im Becken ein durch Karstwasserquellen ernährter See. Seit Beginn des Holozäns verlandete der S-SSE-Teil dieses Sees, und limnotelmatischer Torf wuchs zu einer Mächtigkeit bis zu 7 m auf.

Kiukaanniemi E. & Tervo M.

SCHÄTZEN VON VARIATION DER OBERFLÄCHENFEUCHTIGKEIT IN GEMAHLENEN TORFFELDERN MIT HILFE VON INFRAROT-METHODEN

Aus der Praxis ist wohlbekannt, daß der Original-Wassergehalt in Torflagerstätten sehr unterschiedlich ist. Die Gebiete mit den höchsten Wassergehalten erfordern zugleich die längste Trockenzeit und beschränken damit die Produktions-Effizienz.

Das Phänomen der Feldtrocknung von Frästorf hinwiederum läßt sich schwer modellieren, weil die Wassergehalts- und Temperaturverteilung stark von der Torfart, der Korngröße und auch von externen Wetterfaktoren abhängt. Um die primären Wassergehalte größerer Flächen zu bestimmen, wurde die Infrarot-Thermographie getestet.

Die Tests unter Feldbedingungen zeigten, daß die Aero-Infrarot-Thermographie geeignet ist, die Wassergehalte in größeren Abbauflächen zu bestimmen. Dazu ist aber die systematische Entwicklung von Interprätationsregeln für Aero-Thermogramme erforderlich.

Lambert K. & Staelens N.

DER LANDWIRTSCHAFTLICHE UND GARTENBAULICHE WERT VON TROPISCHEM MOOR. EINE FALLSTUDIE.

Nach 15jähriger Kultivation hat sich das Torfgebiet bei Pontianak, West-Kalimantan, Indonesien, in bemerkenswerter Weise verändert, sowohl was die physikalischen als auch die chemischen Parameter des Torfes anbelangt. Eine Abnahme des Wasserhaltevermögens, Zunahme der Raumdichte, Anstieg des pH-Wertes sowie Zunahme der Gesamt- und austauschbaren Nährstoffe mit entsprechender Anhebung der Basensättigung sind zu konstatieren. All' dieses hat die Bodenfruchtbarkeit erhöht, was besonders beim Anbau von Gemüse zu sehen ist. Die Einschätzung der Ortsverhältnisse und von Torfversuchen führt zum Schluß, daß, wenn man die Nährstoffzufuhr dieser ursprünglich sehr sauren und chemischer Hinsicht unterversorgten Bodenstandorte verbessern will, diese Maßnahme von sorgfältigen Geländeuntersuchungen und einem geschickten Düngemittel-Einsatzprogramm begleitet werden muß. Die örtlich eingesetzten Düngemittel bestehen aus Asche aus Holz bzw. landwirtschaftlichen Abfallstoffen, aus dieser Asche werden Nährstoffe freigesetzt und eine Steigerung des pH-Wertes bewirkt. Die Frage ist, ob das sinnvoll ist, v. a. wenn pH-Werte bis 8 erreicht werden.

Leibetseder J., Altrichter G. & Rosenmayr C.

EINSATZ VON NEYDHARTINGER MOORTRÄNKE BEIM FERKEL

Untersucht wurde, ob durch Neydhartinger Moortränke (NMT), welche Ferkeln verabreicht wurde, die übliche intramuskuläre Eisenversorgung (Fe) und/oder ein antibiotischer Leistungsförderer (Virginiamycin, VGN) ohne Leistungseinbußen ersetzt werden können. Bei 58 Würfen mit 590 Ferkeln, unterteilt in 4 Gruppen (VGN+Fe, Fe, VGN+NMT, NMT), wurden die üblichen Leistungsparameter Lebendmasse-Zunahme, Futteraufwand und Mortalität ermittelt. Die Gruppen VGN+NMT und NMT zeigten teilweise signifikant bessere Leistungen als die Gruppe Fe. In den Gruppen mit NMT blieben auch ohne intramuskuläre Eisenapplikation die Hämoglobinwerte und die Zahl der Erythrozyten im tolerierbaren Bereich.

Otabbong, E. & Lindén, B.

STICKSTOFFTRANSFORMATIONEN UND NITRATKONTROLLE IN KULTIVIERTEN ORGANISCHEN BÖDEN: EINE ÜBERSICHT

Der Stickstoff, der in organischen Böden nach der Ernte bis zum späten Herbst mineralisiert wird, ist ein potentieller Schadstoff. Wir haben die Veröffentlichungen über Stickstoff Transformationen und über Massnahmen zur Kontrolle des anorganischen Stickstoffs in Böden zusammengestellt und diskutiert. Die relative Bedeutung der verschiedenen Prozesse erscheint folgendermassen: Mineralisierung > Denitrifikation > Pflanzenaufnahme > Auswaschung > Immobilisierung > NH_3 Verdunstung. Der Beitrag zur Senkung des anorganischen Stickstoffmenge war am grössten für Denitrifikation, gefolgt von der Pflanzenaufnahme, Auswaschung, Immobilisierung und NH_3 Verdunstung. Die assimilatorische-dissimilatorische NO_3-N Reduktion trug markant zum Verschwinden des Nitrates bei, weshalb sie mehr Aufmerksamkeit erlangen sollte. Kulturmassnahmen um die NO_3-N Ackumulation zu begrenzen beschränken sich hauptsächlich auf den Pflanzenanbau und die Sättigung der Böden um die Mineralisierung und die Nitrifikation zu stoppen.

Ward S. M.

OPTIMALE AUSBEUTE VON GEMAHLENEM TORF DURCH VERWENDUNG VON WETTERVORHERSAGEN

Die möglichkeit der Nutzung von Wetterprognosen für die Frästorfgewinnung wird unter irischen Bedingungen diskutiert. Gegenwärtige Schätzungen gehen davon aus, daß mit einem jährlichen Anstieg der Frästorfproduktion um 7 % gerechnet werden kann. Dabei wird von starken jährlichen Schwankungen ausgegangen. Die Beobachtungen in den GUS-Staaten bestätigen diese Einschätzung.

Блэкфорд Дж.Дж.
ОПРЕДЕЛЕНИЕ СТЕПЕНИ РАЗЛОЖЕНИЯ ТОРФА В ОСНОВЫВАЮЩИХСЯ НА ИЗУЧЕНИИ ТОРФА ПАЛЕОКЛИМАТИЧЕСКИХ ИССЛЕДОВАНИЯХ

Рассмотрены различные методы определения степени разложения торфа и отмечено, что наиболее подходящими являются методы основанные на определении волокнистости и выделения щёлочи. Проверена методика выделения NaOH при различных концентрациях щёлочи, временых интервалах, неорганических примесях и скорости испарения. Полученные результаты показали, что использование колориметрических измерений на повторяющихся и многочисленных образцах обеспечивает, с хорошей повторяемостью, получение надежных данных. Эксперименты должны принимать во внимание содержание неорганических веществ в образцах торфа и проводится по строгому временному графику. Однако преобразование зарегистрированных данных измерений в проценты гумификации является не совсем достоверным, в связи с непостоянными свойствами гуминовых кислот. Лучше всего данные могут быть представлены в виде процентной светопрозрачности или оптической плотности.
Представляется, что в основаных на анализе торфа климатических наблюдениях щёлочное выделение гуминовой кислоты является более приемлемым методом, чем определение волокнистости. Это обясняется дифференцированной зависимостью волокнистости от изменяющегося набора различных видов растений.

Ботис А., Боузинос А. и Кристанис К.
ГЕОЛОГИЯ И ПАЛЕОЭКОЛОГИЯ ТОРФЯНИКА КАЛОДИКИ В ЗАПАДНОЙ ГРЕЦИИ

Низинный торфяник Калодики представляет собой топогенное болото площадью 195 га, которое расположено в небольшом бассейне, образованном на тектонической впадине в Эпирусе (Западная Греция). В течении позднеледникового периода бо̀льшая часть этого бассейна была занята пресноводным озером, которое получало питание в основном за счет карстовой ключевой воды. В начале голоцена южно-южновосточная часть бассейна трансформировалась в низинный торфяник, после чего образовался слой лимнотелматического торфа толщиной до 7 метров.

Киукааннииеми Е. и Терво М.
ОЦЕНКА КОЛЕБАНИЙ ПОВЕРХНОСТНОЙ ВЛАЖНОСТИ НА ФРЕЗЕРНЫХ ТОРФЯНИКАХ С ПОМОЩЬЮ ИНФРАКРАСНЫХ МЕТОДОВ

Как хорошо известно из практики, уровень начальной влажности имеет весьма значительный разброс в зависимости от зоны добычи торфа. Зоны в которых наблюдаются высокие значения этого уровня требуют наиболее продолжительного времени сушки, что приводит к снижению производительности.

Явление полевой сушки фрезерного торфа поддается моделированию с трудом, что объясняется тем фактом, что и распределение влажности и распределение температуры зависят от качественных параметров торфа, распределения размеров частиц и погодных факторов. Для того, чтобы определить распределение начальной влажности по большим зонам, было проведено испытание воздушной инфракрасной термографии.

Результаты испытаний в полевых условиях показали, что возможно использовать воздушную инфракрасную термографию для определения распределения начальной влажности в крупных районах добычи торфа. Этот метод требует систематическую разработку методики для расшифровки воздушных термограмм.

Ламберт К. и Стаеленс Н.
ЗНАЧЕНИЕ ТРОПИЧЕСКИХ ТОРФЯНИКОВ ДЛЯ СЕЛЬСКОГО ХОЗЯЙСТВА И САДОВОДСТВА. РАССМОТРЕНИЕ ОДНОГО СЛУЧАЯ.

После 15 лет культивации, торфяник в районе Понтианак (Западный Калимантан, Индонезия) значительно изменил свои физические и химические свойства. Отмечается снижение влагоудержающей способности торфяника, возрастание объемной плотности и pH. Наблюдается возрастание количества общих и обменных питательных веществ, с соответствующим ростом насыщенности основаниями. Результатом этого процесса является повышение урожайности, особенно при выращивании овощей. Торфянные почвы изначально являются кислотными и бедными по химическому составу. Локальная ситуация и данные полученные в вегетационном опыте показали, что для повышения питательности необходимо осуществлять тщательную эксплуатацию земель, с сопутствующим интенсивным внесением удобрений. Использованые удобрения представляли собой, в основном, древесную золу и зольные удобрения из отходов, питательные вещества которых приводят к снижению кислотности. Катионы питательных веществ могут образовывать комплексные соединения с органическими соединениями, что предотвращает вымывание последних. Благодаря наличию высоких значений pH, представляется, что даже недостаток фосфора был преодолен, за счет образования устойчивых органических феррум-фосфатных комплексов. В данном исследовании фермер сперва проводил обогащение в размере 60 тонн золы на один гектар, а затем вносил дополнительно 10 тонн золы на один гектар при каждом новом посеве.

Лейбетседер Ю., Альтрихтер Г. и Розенмайр Х.
ВОЗДЕЙСТВИЕ МИКСТУРЫ НЕЙДХАРТИНГЕРА НА ПОРОСЯТ

Представленное в данной работе исследование проводилось с целью определения возможности замены обычной внутримышечной (IM) подачи железа (Fe) и/или антибиотика-стимулятора роста (Virginiamycin, VGN) на "Neydhartinger Moor-Tränke" (NMT = Нейдхартингер торфянная микстура), без снижения эффективности процесса. Проводилось определение обычных параметров (таких, как прирост в весе тела, преобразование корма и смертность) в 58 пометах из 590 поросят, которые были разбиты на четыре группы (VGN+Fe, Fe, VGN+NMT, NMT). Было отмечено, что группы получившие NMT показали частично значительно лучшие параметры, чем группа Fe. Значения гемоглобина и эритроцитов оставались в рамках допуска даже без внутримышечного введения железа.

Отаббонг Э. и Линден Б.

ТРАНСФОРМАЦИИ АЗОТА И КОНТРОЛЬ КОНЦЕНТРАЦИИ НИТРАТОВ В ВОЗДЕЛАННЫХ ОРГАНИЧЕСКИХ ПОЧВАХ

Азот, который минерализируется в органических почвах в период после урожая и до поздней осени, представляет собой потенциальный источник загрязнений. В данной работе дается обзор и обсуждаются данные опубликованные по трансформациям азота, а также меры предпринятые для контроля неорганического азота в почвах. Представляется, что порядок относительной важности различных процессов трансформации азота может быть представлен следующим образом: минерализация > денитрификация > отбор азота растениями > вымывание > иммобилизация > летучесть NH_3. Наибольшее влияние на снижение количества неорганического азота оказали, по мере значимости: денитрификация, отбор азота растениями, вымывание, иммобилизация, летучесть NH_3. Ассимилиционное восстановление NO_3 - N до NH_4 - N существенно влияло на исчезновение NO_3 - N, в связи с чем этому процессу следует уделять больше внимания. Культивиционные меры предпринятые для того, чтобы снизить накопление NO_3 - N сводились в основном к проведению посевов, с целью увеличения отбора азота, или насыщения почвы влагой, с целью подавления нитрификации.

Ключевые слова: Минерализация, иммобилизация, денитрификация, летучесть NH_3, ассимилиционное-дессимилиционное восстановление NO_3 -N, контроль за NO_3 - N.

Ворд С.

ОПТИМИЗАЦИЯ ДОБЫЧИ ФРЕЗЕРНОГО ТОРФА С ПОМОЩЬЮ ПРОГНОЗОВ ПОГОДЫ

Проведен анализ возможного воздействия методов предсказания погоды на добычу фрезерного торфа в условиях Ирландии. Современные оценки свидетельствуют о том, что можно ожидать повышения выхода фрезерного торфа примерно на 7%, при наличии весьма значительных годовых колебаний. Исследования проведенные в бывшем СССР подтверждают такую оценку.