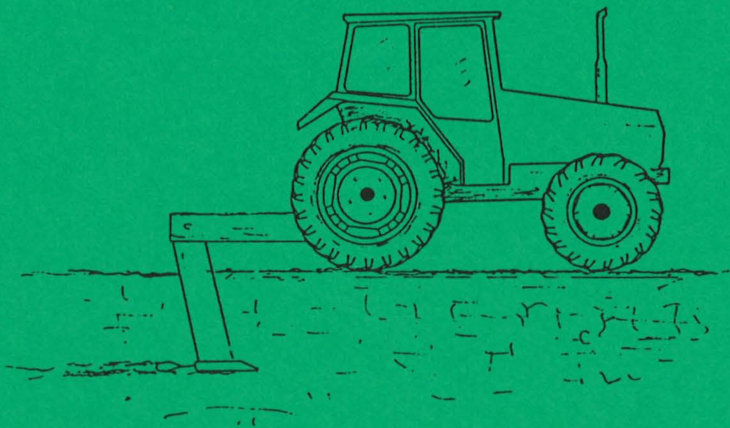
SVERIGES LANTBRUKSUNIVERSITET

DRAINAGE OF PEAT SOILS
A literature review

DRÄNERING AV TORVJORDAR
En litteraturöversikt

Mary Mc Afee



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Swedish University of Agricultural Sciences
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Rapport 143
Report

Uppsala 1984
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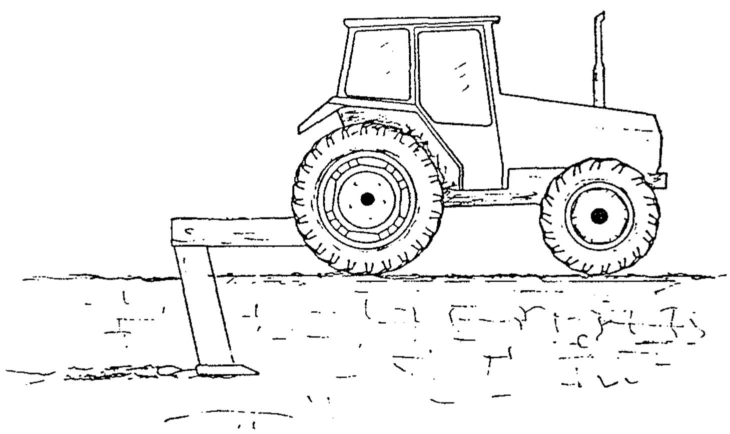

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PREFACE

Agricultural peat soils in Sweden, which were previously utilized chiefly for forage crop production, have in recent decades been tilled progressively for production of cereals and other arable crops. This change has often led to faster subsidence and drain depth of existing drainage systems is thus rapidly reduced. However, crop growth and surface trafficability requirements have increased the need for effective drainage. Drainage of peat soils has thus become increasingly significant.

Drainage of previously undrained peats is confined mainly to the coastal areas of Norrland. In other areas, existing drainage systems rendered ineffective by subsidence are the main focus of attention. Renovations required are often comprehensive and costly.

At present, drainage of peat soils follows a standard procedure despite differences due to peat type and the outcome of drainage is thus rather uncertain. There is a great need for drainage recommendations which differentiate between peat types.

Results and experiences from research into peat drainage are reviewed in this report, which was prepared as part of a Master of Science degree. The report provides background information for future research into physical properties and drainage function of peat soils. It also forms part of the work on organic soils carried out by the Division of Hydrotechnics during recent years.

FÖRORD

De odlade torvjordarna i Sverige, som tidigare främst utnyttjades för vallodling, har under senare årtionden allt mer tagits i anspråk för odling av stråsäd och andra grödor i öppet bruk. Denna utveckling har mångenstädes medfört snabbare ytsänkning och därmed snabbare minskning av djupet på befintliga dikessystem. Samtidigt har behovet av goda tillväxtbetingelser och bra markbärighet medfört ökade krav på dräneringens effektivitet. Dräneringen av torvjordarna har därför fått ökad betydelse. Nydikning av torvjordar sker numera huvudsakligen i Norrlands kustland. I övrigt är det främst gamla dikningsföretag som förnyas här ytsänkningen gjort dräneringen ineffektiv. Sådana omdikningar blir ofta mycket omfattande och kostsamma.

Dräneringen av torvjordar sker idag vanligen rutinmässigt och ofta med varierande resultat. Trots torvjordarnas mycket skiftande egenskaper behandlar vi dem i stort sett lika. Det finns därför ett stort behov av differentierade dräneringsrekommendationer för olika torvjordstyper.

I den rapport som här framlägges ges en översikt över resultat och erfarenheter från forskning och försök med dränering av torvjordar. Rapporten utgör en del i arbetet för en Master of Science examen och är avsedd att ligga till grund för mera ingående studier av fysikaliska egenskaper och dräneringsfunktionen hos olika typer av torvjordar. Den utgör samtidigt ett led i det arbete med organogena jordar, som under senare år bedrivits vid försöksavdelningen för hydroteknik.

Uppsala i november 1984

Waldemar Johansson

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INTRODUCTION

Current literature on drainage of peat soils is reviewed in this report. The objective of drainage in lowering watertable levels and improving peat surface conditions is related to crop needs. Peat properties before drainage and climatic factors which cause the need for drainage are discussed and hydrological studies on the wider effects of peat drainage are reviewed. Subsidence of peat is the subject of much research, especially in subsurface drainage plans. This report deals with its possible causes and its prediction from empirical formulae. Data from worldwide sources on actual amounts of subsidence are also summarised.

A range of drainage techniques are available at present. The main types are dealt with under three headings: open ditch methods, pipe subsurface drains and pipeless subsurface drains. The relative effectiveness of these techniques has been the subject of investigation in a wide range of peats and climates. Some of the main results are presented here. Conservation of natural ecosystems is a sensitive issue in the world and supply of energy to meet the present demand is an important consideration which can lead to a conflict of interests. The development of peat soils for forestry or food production leads to gradual wastage of the peat. Some current views on economic and efficient use of peat resources are described in the final section of this report.

GLOBAL IMPORTANCE OF PEAT

Peat soils, or the conditions which lead to peat formation, occur throughout the world though they are most typical of the boreal and arctic areas of the Northern Hemisphere.Some countries have peat soils as a sizeable fraction of their land area and for such countries the economic importance of peat resources can be significant. Estimates of total world area of peat vary from 150 million ha (Kivinen, 1968), 230.5 million ha (Moore & Bellamy, 1974) to 420-450 million ha (Holmen, 1982).

The national economic importance of peat drainage and land reclamation is stressed by various authors: Murashko (1969), Scholtz & Wertz (1975), Galvin (1976a) and Fjaervoll (1978). In all countries apart from the Soviet Union and Ireland, the major use of peat is in agricultural and horticultural fields (Moore & Bellamy, 1974). Hinrichsen (1981) includes Finland with the Soviet Union and Ireland as primarily fuel peat producers. Drainage research projects have been aimed at increasing the national area of cultivated land by bringing new areas into production or by improving the productivity of existing areas. The increased harvesting of peat for fuel has produced large cut-over sites and subsequent cultivation of such areas has proved successful (Healy, 1980).

Table 1. Amount and percentage of peatlands in some countries (after Segeren & Smits, 1974).

Country	Area (million hectares)	% of national total land area
Soviet Union	71.5	3.2
Canada	9.6 *	1.0
Finland	10.0	29.7
Sweden	5.0	11.1
Norway	3.0	9.3
U.S.A.	32.4	4.1
Great Britain	2.4	9.8
Poland	1.5	4.8
Ireland	1.2	16.9
Federal Republic of Germany	1.2	4.9
German Democratic Republic	0.5	4.7
Indonesia	16.3	8.7
Malaysia	2.0	15.2
Sarawak	2.5	20.5
Zaire	1.0	0.4

* Total extent of organic terrain is 112.665 million ha, or 11 % of the toal land area of Canada.

GENERAL AIMS OF PEAT DRAINAGE

The main aim of drainage is to render the land more suitable for agriculture or forest by removal of excess water and improvement of soil properties. The extent and intensity of drainage is based on the proposed use of the area, the local climatic conditions and the existing drainage status of the peat. The drainage of previously untreated, waterlogged peats has been reported - Segeren & Smits (1974), Burke (1975a) and Chudecki & Blaszczyk (1976). Previously drained or drier peats and bogs which have been cut over for fuel have also been the focus of drainage experiments - Scholtz & Wertz (1975), Galvin (1976a), Pohjonen (1980) and Garvrilov (1981).

PRELIMINARY STEPS IN DRAINAGE DESIGN

Trafford (1975) gives the following steps as preliminaries to optimum design of drainage systems: (1) decide desirable water regime for the particular crop, (2) determine soil properties with respect to water movement and (3) obtain climatical statistics.

Watertable levels and crop growth

Excess water may occur on the surface, combined with waterlogging of the topsoil, or deeper down in the soil profile where waterlogging of the rootzone is an effect of impeded percolation or high watertables. The adverse effects on farming are impaired crop growth and impaired farm operations (Smedema & Rycroft, 1983). Drainage to lower the watertable will reduce the moisture content of the upper soil layers and improve conditions for growth. The optimal depth to which the watertable should be lowered in peat soil has been related to the needs of various crops. Caldwell & Richardson (1975) recommend the following values for English fen soils: ryegrass 45 cm; potatoes and celery 50-60 cm; sugarbeet and kale 100 cm.

Using research results in the Soviet Union, Ivitsky (1975) recommends the values shown in Table 2 as optimal in that country. Valmari (1977) reports from research in Finland that watertables at 50-60 cm below the surface are suitable and that many crop plants can tolerate a watertable depth of 20-40 cm for a period. He notes, however, that the bearing capacity of the peat is insufficient for farming operations when the watertable is less than 30-40 cm from the surface.

Table 2. Recommended depth to watertable (cm below surface) for various crops on two types of peat (after Ivitsky, 1975).

Crop	Shallow peat	Deep peat
Pasture	60-70	80-85
Cereals	80-90	100-110
Potatoes, sugarbeet	90-110	110-130
Food roots, cabbage	85-100	110-120

Schothorst (1974) has reported from work in the Netherlands that bearing capacities of the peat sod are considered sufficient if penetration resistance is 6 kp/cm^2 or higher. To achieve this value in wet periods, watertables should not be less than 30 cm below the surface.

Recommended watertables for forestry have also been reported, by Ferda (1968), Konstantinov (1980) and Heikurainen (1980). Values reported range from 40 to 80 cm below the surface. Drainage projects should aim to regulate the groundwater level and to hold it at the optimal depth.

Peat properties with respect to water movement

Trafford (1975) requires values of hydraulic conductivity and drainable porosity for all layers, together with knowledge of the location of impermeable layers at depth. Smedema & Rycroft (1983) emphasize the importance of evaluating hydraulic conductivity in relation to drainage, especially groundwater drainage. The natural drainage of the soil, the scope for and costs of drainage depend greatly on this information.

Hydraulic conductivity of peat. Boelter (1965) investigated a range of American peats and reports values varying with degree of decomposition of the peat- 3292 mm/day in undecomposed moss peat declining to 0.9 mm/day in decomposed peat and 0.7 mm/day in herbaceous peat. He also reported decreasing values at increasing depth of sampling, from 3000 mm/day at 15-25 cm sample depth to 0.9 mm/day at 50-60 cm depth.

Baden & Eggelsmann (1963) related hydraulic conductivity measurements in peats to the degree of humification on the von Post scale. Their results are summarised in Table 3.

Table 3. Relationship between degree of humification (von Post scale) and hydraulic conductivity (mm/day) after Baden & Eggelsmann, 1963.

von Post degree	hydraulic conductivity (mm/day)
less than H3	more than 500
H3 - H5	500 - 100
H5 - H8	100 - 20
more than H8	less than 20

Galvin (1976b) reports similar values for field measurements on Irish peats -

	Blanket peat	Old sphagnum	Young sphagnum	Reed fen	Woody fen
hydraulic cond. (mm/day)	6	28	209	126	564

This also follows the trend of decreasing values with increasing decomposition. Dasberg & Neuman (1977) report a mean hydraulic conductivity of permanently saturated peat in the Hula Valley, Israel, to be 25 mm/day. A trend of decreasing values at lower sampling depth was also apparent -

sampling depth (m)	1-2	2-5	5-10	10-15
hydraulic cond. (mm/day)	64.8	28.8	6.2	2.6

Nilssen (1978) reaffirms this trend from work in Norway -

sampling depth (cm)	30	50	70
hydraulic cond. (mm/day)	250	93	14

Air-filled porosity of peat. Russell (1973) gives the minimum air-filled porosity of the soil at which plants can thrive as 10 %. Njøs (1973) notes that the critical air volume depends on plant species and climatic factors such as temperature and relative humidity. Some grass species can survive in almost waterlogged soils in autumn, when temperatures are low and growth rate slow, but need 10-12 % vol. air during the growing season. Air-filled porosity of undrained peats is often below these critical values. Njøs reports values as low as 3 % vol. in some Norwegian peats while Burke (1978) gives 6-7 % vol. as a mean value for some Irish peats.

Drainable porosity of peat. This is a measure of the maximum proportion of water likely to be removed from the peat as the watertable falls, or is lowered by drainage. Figures represent the difference between the peat at saturation and pF 2. Galvin (1976b) gives a range of 0.08-0.38 ml/ml for Irish peats and compares this with American results which give a range of 0.08-0.86 ml/ml. Finnish results quoted here show a range of 0.10-0.67 ml/ml. Sturges (1968) had previously noted that drainable porosity values were least for decomposed peat. Surface peats contain larger voids which empty at low suctions but greater suctions were required to drain the smaller pores of decomposed peat. Galvin (1976b) applied a regression analysis to all the data available to give a formula relating drainable porosity to hydraulic conductivity:

$$\underset{(\mathrm{ml/ml})}{\text{drainable porosity}} = -\,0.008 + 0.141 \log \left(\underset{(\mathrm{mm/day})}{\text{hydraulic conductivity}} \right)$$

Climatical statistics

High rainfall, low evaporation rates and constant waterlogging are climatic features given by Moore & Bellamy (1974) as characteristic of a peat forming region. Rainfall data from countries with peat drainage projects confirm this. Burke (1975a) reports the annual rainfall in Irish peat regions to be 1250-1500 mm, falling on 250-270 days and fairly evenly distributed throughout the year. Hudson & Roberts (1982) give a mean annual rainfall of 2500 mm for a peat research area in Wales while Hove (1973) reports a value of 3000 mm for a peat area in Norway.

Evaporation is important where the watertable lies near the surface and its effectiveness depends on relative humidity of the air, wind speed, temperature and season. Valmari (1978) gives a mean value of 70-100 mm/month as the amount of evaporation during the growing season after snowmelt. Precipitation in the same period can be 100 mm/month and snow melt itself corresponds to 60-70 mm. Lundin (1975) estimates snowmelt as 80-100 mm and points out that the free storage volume of undrained peatland for precipitation water is negligible.

Baden & Eggelsmann (1963) compared the course of snowmelt on undrained and tile-drained highbog and found that run-off from undrained land reached a peak value of 88.6 $l/s.km^2$ whereas the maximum from drained land was 46.2 $l/s.km^2$. The difference is attributed to the storage capacity of the upper layers of drained peat.

FURTHER STEPS IN DRAINAGE DESIGN

Smedema & Rycroft (1983) recommend, in addition to those factors already described, investigations into the hydrology of the site with respect to possible run-off and outlet capacity. German standards (DIN 1185, 1959) also require hydrological data, with emphasis on site geology. Other German sources - Eggelsmann (1978), Scholtz & Wertz (1975) note the importance of surveying peat areas and predicting subsidence after drainage from knowledge of the properties of undrained peat.

Hydrological studies

The climatical -hydrological investigation should describe annual rainfall amounts and monthly distribution, evapotranspiration throughout the year, watertable fluctuations at the site, water storage capacity of the peat and details of land use and vegetation. Many investigations have been carried out on the hydrology of peat. Ivitsky (1975) stresses the importance of considering the water resources of the entire catchment area and recommends the combination of reclamation, hydrotechnical, forestry and agricultural activities to improve water resource utilization in the area.

Lundin (1975) estimates that initial bog drainage removes 5-6000 m^3 of water per hectare. For a watershed of 1000 km^2, of which 50 % is bog, this represents a possible volume of $250\text{-}300.10^6$ m^3 of water. The increased run-off due to drainage is, on average, 3 m^3/s for the 1000 km^2 watershed during the first three years after draining. This indicates that planning of larger drainage schemes should include the hydrology of rivers. van der Molen (1975) reports that lowering peat by 10 cm liberates 100 mm of water which must be removed by drainage or evaporation. Dasberg & Neuman (1977), from determination of specific storage of saturated peat, show that a unit volume of saturated peat can release almost 10^5 times more water due to compression than a unit volume of sand when the hydraulic head drops by one unit.

Hall & Prus-Chacinski (1975) note the importance of accurate rainfall records and knowledge of soil moisture storage capacity, which is reduced by peat subsidence after drainage. These data are essential in forecasting run-off volumes for drained peatlands and in flood control. Ivitsky (1975) has developed formulae to calculate drainage-induced run-off based on measurements of peat permeability, annual rainfall, catchment area and groundwater levels at the drain and in mid-field. Lundin (1975) determined the equilibrium water storage capacity of different soils at varying watertable depths by analysis of the relationship between moisture potential and moisture content of the soil.

Baden & Eggelsmann (1963) compared the hydrology of undrained and tile-drained peats. They recorded equal amounts of run-off from both areas after winter precipitation maxima but only from the undrained area after summer maxima. This difference was attributed to the higher water storage capacity of the upper soil layers in the drained area. It is also noted that, after a short period of intense rainfall (15-20 mm/day), run-off from undrained areas has a peak value of 154 $l/s.km^2$ while the drained areas had a maximum value of 48 $l/s.km^2$ occurring for a longer period of time.

Starr & Päivänen (1981) report work in Finland to determine the effect of forest drainage on run-off. Results are quoted from earlier work indicating that run-off is affected by type of drainage. Highest run-off values are recorded from catchments drained by open ditches. Drain spacing also affects run-off, with maximum flows inversely related to drain spacing. These authors describe conflicting results and theories regarding this topic which exist in Finland:

a) drainage shortens the duration of peak flows but raises peak values,
b) drainage extends the duration of peak flows but lowers peak values,
c) a compromise between a) and b), that drainage increases peak flow values and also minimum flow values (therefore total volume of run-off is increased).

Dooge & Keane (1975) report the experimental use of mathematical models to predict the effect of drainage on run-off from peat areas. The models were based on precipitation and run-off data and had only limited success in this work. Similar research has been reported by de Smedt et al (1977) who sought to construct a model of the hydrological water balance of a peat area. It was found that a model based on groundwater levels, rain intensity, evaporation, storage capacity and horizontal flow in the peat upper layers was not correct and that vertical flow to underlying layers must be included in the equation.

SOIL STUDIES AND SUBSIDENCE PREDICTION

Some properties of peat which necessitate drainage have already been discussed - low hydraulic conductivity, low air-filled porosity, high watertables. There are further characteristics of peat which should be determined before drainage, the most important being those which concern subsidence.

Properties of peat to be determined before drainage are: depth of peat layers, bulk density of the different layers, degree of decomposition of peat as described by von Post (see Appendix), moisture content of the peat before drainage.

The use of these parameters is discussed later, in the prediction of subsidence. Mursahko (1969) considers prediction of subsidence essential in the construction of canal drains, tile drains, roads and other installations. Changes in peat depth due to subsidence can result in deformation of canals, warping of pipes and changes in topography. Eggelsmann (1978), while reiterating the need for accurate prediction of subsidence, notes that real subsidence measurements can deviate by +/- 25 % from predicted.

Causes of subsidence

a) Removal of water means removal of mechanical support and this is marked by the strong initial response. This effect is augmented by the pressure exerted by the upper, drying layers upon those layers below the watertable. The total pressure, P, acting below the watertable level is obtained from $P = \rho\ g\ h$, where ρ = density of peat (kg/m^3), g = acceleration due to gravity (m/s^2) and h = depth of watertable from the surface. This relationship is given by Murashko (1969).

Further compaction may be caused by farming operations involving heavy traffic.

b) Peat particles exposed by drainage break down and assume a tighter packing formation, a process marked by increase in bulk density of the layers. Puustjärvi (1982) has presented results on the decomposition products of peats which show that ligneous matter breaks down to form a quantity of glutinous products (primarily humic acids) sufficient to shrink the peat. This is apparent as a visible compaction of the peat and as increased bulk density of the organic matter.

c) Loss of soil due to microbial oxidation of the organic matter, with evolution of CO_2 and production of inorganic nitrogenous compounds which are generally lost through leaching. Such mineralization of peat is accompanied by an increase in the ash content.

Prediction of subsidence

It is possible to predict the amount of subsidence which will occur after drainage by applying empirical formulae to data on the initial depth of peat layers, bulk density and moisture measurements.

Subsidence in the upper layers. Segeberg (1960) compares existing formulae for calculation of subsidence derived by Hallakorpi (1937) and Panadiadi & Ostromecki (1956) and derives a third equation from these;

Hallakorpi	$S = a(0.07\ t_n \cdot T + 0.066)$
Panadiadi & Ostromecki	$S = A\sqrt[3]{T \cdot t_n}$
Segeberg	$S = K \cdot t_n \cdot T^{0.707}$

where S = subsidence (m), T = original depth of peat (m), t_n = drain depth from surface after subsidence (m) and K is a coefficient dependent on % vol. dry matter (L_d) according to $K = 0.05 + {}^1/L_d$.

Segeberg's equation is recommended in the Fieldbook for Land and Water Management (1972) for prediction of subsidence in upper peat layers.

Subsidence due to oxidation. Schothorst (1977) gives the formula $S = d \cdot w_{m2} / w_{m1} - d$, where S = total subsidence (cm), w_{m1} = initial bulk density of mineral elements (g/cm^3), w_{m2} = actual bulk density of mineral elements (g/cm^3) and d = actual thickness of the layer (cm).

Subsidence in the lower layers due to increased load. This is usually described by the Terzaghi equation (1948 cit ILRI Fieldbook, 1972): $dz/z = 1/c \cdot \ln(p2/p1)$ where dz = compaction (m), z = original thickness (m), p1 = stress due to initial load (N/m^2) and p2 = stress due to final load (N/m^2). Fokkens (1970 cit van der Molen, 1975) has derived expressions for 1/c, where c is the constant in the Terzaghi equation, for two situations; uncompressed peats and pre-compressed peats.

Murashko (1969) has produced general formulae to predict subsidence in any part of a drained bog over any period of time.

Segeberg (1960) refers to a standard drain depth after subsidence of 1.2 m (t_n = 1.2) and for this Hallakorpi's formula becomes S = a (0.08T + 0.066). Eggelsmann (1978) gives the relationship between the 'a' factor in this latter formula and relative peat density and solid matter content (Table 4).

Table 4. Relationship between peat density, volume of solids and the 'a' factor in Hallakorpi's formula (after Eggelsmann, 1978).

Relative density	Solids (vol. %)	Factor 'a'	Subsidence formula
almost floating	less than 3	4.00	S = 0.32T + 0.26
loose	3 - 4.9	2.85	S = 0.23T + 0.18
rather loose	5 - 7.4	2.00	S = 0.16T + 0.13
rather dense	7.5 - 12	1.40	S = 0.11T + 0.10
dense	more than 12	1.00	S = 0.08T + 0.07

Hovde (1979) reports that best predictions under Norwegian conditions are obtained using the formula $Y = Ax^3 - Bx^2 + Cx - D$ where Y = subsidence (m), x = depth to watertable (m) and A, B, C, D are constants relating to peat type and degree of compaction.

Nesterenko (1976), while reiterating the need for accurate subsidence prediction, advises the use of actual data on subsidence in a given area if these are available.

Amount of subsidence - actual data

The actual amounts of subsidence and the annual rates have been reported for a number of countries and climatic conditions. Ilnicki & Burghardt (1981) have recorded the values shown in Table 5 on a repeatedly drained German highmoor.

Table 5. Subsidence values in relation to peat density (after Ilnicki & Burghardt, 1981).

	peat density loose	moderately loose	dense
total surface subsidence over 11 years (cm)	38.3	24.0	22.0
total drain subsidence (cm)	26.8	12.3	5.0
reduction in drain depth (cm)	11.5	11.7	17.0
final drainage depth (cm)	96.0	93.0	87.0
rate of subsidence (cm/year)	3.2	2.3	1.9

Murashko (1975) reports that Maryino marshland in Byelorussia which had an initial thickness of 2.8 m subsided 91 cm over a 30 year period. Mean annual rate of subsidence was 2.9 cm beside the canal but 1.7 cm at a point midway between drains.

Schothorst (1977) gives a total subsidence value of 6-10 cm for the 6 year period after drainage of Netherlands peats. Of this early subsidence, he estimates that 65 % could be ascribed to shrinkage and oxidation of organic matter in the layer above the watertable. The remaining 35 % was due to compression of the lower layers by increased load. Long term effects were estimated by comparing the bulk densities of organic matter in the layers above and below the watertable. It was found that approximately 15 % of the subsidence which had occurred over 1000 years was due to compression and 85 % due to mineralization. Subsidence as a result of various factors is shown in Table 6.

Table 6. Relative contribution of compression, oxidation and irreversible shrinkage to observed subsidence in a peat soil (after Schorthorst, 1977).

Test site	Depth to water in drain (cm)	Subsidence of surface (cm)	Compression (cm)	Oxidation (cm)	Irreversible shrinkage (cm)
A	25	4.5	1.5	1.4	1.6
	75	9.2	2.7	2.9	3.6
B	35	1.0	0.0	1.2	-0.2
	70	5.2	1.6	1.9	1.7
	100	10.1	3.8	4.6	1.7

Results published by Pedersen (1978) give values of 1-2 cm/year for a Danish peat, of which 50 % was caused by mineralization. Stephens & Speir (1969) report rates of subsidence after initial settling of 3 cm/year in the Florida Everglades. They cite rates of 7.6 cm/year for peats of the San Joachim delta, California. From 55 to 75 % of this subsidence was attributed to microbial oxidation of the upper layers, a process accelerated by the warm temperatures, low watertables and high organic content of these peats. Armstrong & Watson (1974) recorded rates of 0.6-2.5 cm/year in Australian fens, mainly due to increase in bulk density of the upper layers. Oxidation is regarded as less important in this area, which supports perennial pasture. Burke (1978) observes that where forestry is established on newly drained shallow peat, subsidence is reduced by the reinforcing effect of the roots. Values of subsidence shown in Table 7 were recorded in Norwegian peats.

Table 7. Subsidence rates in relation to peat depth (from Sorteberg, 1978).

Depth of peat (m)	Years after draining	Subsidence (cm) total	Subsidence (cm) annual	Total subsidence (%)
3.61	19	137	7.2	38
2.40	16	44	2.8	18
1.63	16	29	1.8	18
0.89	19	18	0.9	20

This shows greater annual subsidence with increasing peat depth. On all sites, subsidence was reported strongest during the first 2 years.

FIELD DRAINAGE PLANNING

The field plan of a drainage project should include data on the following (Trafford, 1975): layout, drainage depth, drain spacing, drainage technique, drain dimensions and materials, filter installation and materials and secondary treatments.

Layout

This is determined by peat properties, site topography, slope and hydrology. Meteorological factors - run-off, rainfall, snowmelt - must be taken into account. Trafford recommends the simplest type of layout, since more complex patterns with a high number of junctions lead to installation difficulties. DIN 1185 (1959) recommends the use of interceptor drains across the slope to prevent surface water flowing into the area to be drained, a practice which is standard procedure in the Soviet Union (Maslov & Panov, 1980). Valmari (1977) recommends siting drains under low points in the area, where snow is deep and frost is thus less severe. This assists in removing the peak run-off caused by snowmelt. He also recommends open catchment drains to collect the initial melt water.

Eggelsmann (1978) plans layout according to the relief of the mineral subsoil, siting main drains over areas of deep peat. Segeren & Smits (1974) recommend flexible planning since predictions of subsidence, which are essential to design, may be approximate values. Correct drain spacing and better predictions of subsidence can be obtained using data from field trials in the area. Galvin (1976a) puts surface grading as the first priority in drainage. Levelling of the surface to prevent ponding and increase infiltration will improve the surface of the peat and allow better control of the watertable. It is recommended that the surface be graded down to open collector drains.

Lie (1972) notes the inconvenience of open drains to future farming operations and that careful siting of these canals is necessary to minimize obstruction.

Depth of drainage

Trafford (1975) lists the following factors which influence drainage depth determination: layering of soils, desired watertable level, outflow limitations, machine capabilities. The first effect of deepening drainage is lowering of the watertable and since subsidence is related to watertable depth, this must also be considered.

Depth to the watertable is also a reflection of the water storage capacity of the soil (Lundin, 1975) and lowering the watertable by drainage reduces the amount of surface run-off at times of high precipitation or snowmelt (Baden & Eggelsmann, 1963).

Studies in the Hula Basin, Israel, reported by Avnimelech et al. (1978) have shown that nitrate leaching in the drainage water is most serious when outflow from the drained area is high, for example during winter rainstorms. Lowering of the watertable to 150 cm just before winter was found to increase the water storage capacity of the soil sufficiently to prevent peak run-off. However, since high oxidation due to favourable climates is another feature of these soils (annual rate of subsidence is 10 cm) it is necessary to minimize the depth of the aerated layer by raising the watertable during the summer. Experiments showed that 60-80 cm was the optimum summer watertable depth, balancing the oxidation risk and crop requirements. The loss of nitrogen due to drainage was initially as high as 250 to 500 kg/ha but control of water levels is reported to reduce these losses by 50-80 %. Terry et al (1980) report that nitrogen losses in drainage water in the Florida Everglades increased greatly at lower drainage depths. Average annual losses increased from 60 to 120 kg/ha when the watertable was lowered from 60 to 90 cm below the surface. It is also noted that while raising the watertable to 30 cm below the surface may help to reduce soil subsidence and lower nitrate levels in the drainage water, the levels of other water pollutants such as NH_4^+-N and PO_4^{3-}-P are greatly raised by the higher water levels.

In determining tile drainage depth, consideration must be given to future subsidence, which can change surface and drain depth. Segeberg (1960) used empirical formulae to predict subsidence and to allow for this at time of installation to achieve the final desired drain depth. Eggelsmann (1975) cites these recommendations as percentage to be added at time of drainage to achieve a desired drain depth on a particular peat density (Table 8).

Table 8. Recommended increments (%) in drain depth to allow for subsidence in peats of various densities (from Eggelsmann, 1975).

Peat density	Desired final depth of drain (m) 0.8	1.0	1.2	1.4	1.6	1.8
	% to be added on draining					
dense	12	12	14	16	18	20
rather dense	15	17	20	23	25	28
rather loose	21	26	30	34	38	42
loose	31	38	45	51	58	65
almost floating	no drainage by pipe					

Eggelsmann (1978) gives a general recommendation of 1.2 m drainage depth in rather permeable peats and 0.9-1.0 m in poorly permeable peats. Burke (1975b) gives the Irish optimum as 0.9 m and Heikurainen (1980) recommends 0.7 m on peat drained for forest use in Finland.

Segeren & Smits (1974) recommend waiting for some years after initial drainage by open canal before installing subsurface drains, thus avoiding the initial heavy subsidence. Schothorst (1974) reports the effect of drainage depth on soil bearing ability, especially where farming operations involve heavy machinery or intense stocking rates. For adequate bearing strength, groundwater level must be at least 0.3 m below the field surface. This requires lowering the depth to open water in the collector canals to 1 m below the soil surface, compared to the traditional depth of 0.4 m at a drain spacing of 35 m. According to Ivitsky (1975) the final decision on depth of drainage must be based on a knowledge of limitations of the technique to be used and on eventual crop requirements.

Drain spacing

Spacing of pipe drainage is generally calculated from Hooghoudt's formula (1960 cit Eggelsmann, 1978):

$$L^2 = \frac{8\ k_2\ dh}{q} + \frac{4\ k_1\ h^2}{q}$$

where q = precipitation (m/day), h = height of watertable above drain level at a point mid-way between drains (m), d = equivalent depth for distance between drain level and the underlying impermeable layer (m), k_1 and k_2 are the respective hydraulic conductivity values of the soil above and below drain level (m/day) and L = drain spacing (m). However, since this formula is based on hydraulic conductivity values at the time of drainage, it is not very accurate in drainage of organic soils where hydraulic conductivity values can decrease sharply after drainage (Segeren & Smits, 1974). Drain spacings required some years after drainage may be half as great as those calculated from the formula. It is best to determine spacing from field trials on similar soils in the area. The drain spacing requirements of peats have been reported for many countries and there is a wide variation in the optimum values given. In an investigation into the drainage requirements of Irish peats, Burke (1961) cites the conflicting data shown in Table 9.

Table 9. Summary of drain spacing recommendations from various sources (cit. Burke, 1961).

Country	Source	Drain type	Peat type	Spacing(m)
USSR	Yangal (1940)	mole	sedge, moss	40
Germany	DIN 1185 (1959)	tile	cultivated lowmoor	20-30
"	"	"	pasture lowmoor	25-40
"	"	"	cultivated highbog	12-20
"	"	"	pasture highbog	15-25
"	Kraemar (1954)	"	lowmoor	20-25
"	"	"	raised moss	8-10
France	Ferroniere (1954)	"	uncultivated bog	50
New Zealand	ven Elst (1956)	mole	"	3
Ireland	Burke (1961)	mole	raised moss	3-3.6

More recent reports also give values which vary considerably.Casselman & Green (1971) experimented with different spacings of moles at 0.7 m depth and concluded that, even at spacings of 3 m, these drains were not effective in controlling watertables in that area. Valmari (1977) gives the optimum spacing of open drains in pasture as 15 m, with 0.75 m depth. Wider spacings required deeper drainage - for example, pipe drains at 20 m spacing were best at 1.1 m depth. Halvorsen (1974) recommends 8-10 m spacings of drains in pasture and reports improved trafficability of the peat at even shorter spacings (5 m). Soviet research, described by Maslov & Panov (1980), has produced the following recommendations: surface canals for preliminary drainage to be spaced at 100-150 m, depending on hydrogeology of the area. These are supplemented on peats which are moderately decomposed by mole or slit drains at 6-10 m for arable land and at 8-12 m for pasture. When the peat is underlain by sand, deeper drains (2-3 m) are dug into the sandy layer at 300-600 m spacing. Tile drains are installed after initial subsidence has occurred, at depths and spacings shown in Table 10.

Table 10. Recommended drainage parameters on thick peat soils of two feed types (after Maslov & Panov, 1980).

Crop	Drain depth (m) groundwater feed	dammed water feed	Drain spacing (m) groundwater feed	dammed water feed
meadow - foddercrop	1.2-1.4	1.4-1.6	30-35	20-25
field crops	1.4-1.6	1.6-1.8	25-30	15-20
vegetable - foddercrop	1.6-1.8	1.8-2.0	20-25	10-15

Konstantinov (1980) states that the aim of forest drainage in the Soviet Union is to maintain the post-drainage watertable at 20-25 cm. This is achieved in a cut-over bog by 0.4-0.5 m deep drains at 10-15 m spacing depending on condition of the undrained peat and in mature forests by 1.0-1.3 m drains at 100 m spacing.

Determination of drain spacing must also take into account the amount of precipitation in the area and the degree of decomposition of the peat before drainage (Table 11).

Table 11. Recommended tile drain spacing (m) with regard to precipitation and degree of decomposition of peat (Lie, 1977).

Degree of decomposition	annual precipitation (mm)		
of peat	under 600	600-1000	over 1000
well decomposed	8-10	6-8	4-6
moderately decomposed	10-12	8-10	6-8
poorly decomposed	12-14	10-12	8-10

Eggelsmann (1972) determines tile drain spacing according to degree of decomposition, type of peat and intensity of drainage required (Table 12):

Table 12. Recommended tile drain spacing (m) with regard to peat type and desired intensity of drainage (after Eggelsmann, 1972).

Peat type	von Post degree of decomposition	spacing (m) for light - intense drainage	
lowmoor	H1	30-18	these values are set for a mean annual precipitation of 700 mm; for every 100 m more or less than this, reduce or increase spacing by 1 m.
	H5	25-10	
	H10	15-5	
high moor	H1	20-12	
	H5	15-10	
	H10	5-3	

Research on Newfoundland (Rayment, 1970) showed that deepening drains from 60 cm to 120 cm was less effective in lowering watertables than reducing drain spacing from 45 m to 20. Rayment recommends a maximum drain spacing of 25 m, which minimizes surface ponding and gives adequate sod bearing ability. Where more intense drainage is required, wooden covered ditches are installed at 8-10 m.

From these results, it is difficult to make a general recommendation for drain spacing. When consideration has been given to factors such as peat decomposition, peat type and location, climatic factors and crop needs, approximate values can be obtained.

DRAINAGE TECHNIQUES

The chosen technique will ultimately determine the depth and spacing at which drains can be installed. Open ditches cannot be installed at closer spacings without considerable obstruction of farming operations. The dense pattern of tile drains necessary to lower watertables satisfactorily in some areas is too expensive to be economically justifiable, since at a spacing of 3-4 m, between 2000 and 3000 metres of drain are required per hectare (Burke & McCormack, 1969).

The techniques available at present can be summarised as follows:

OPEN DITCHES	DEEP: canals, deep ditches
	SHALLOW: plough furrows, shallow ditches
SUBSURFACE DRAINS	PIPE: clay tiles, plastic pipes
	COVERED: sod drains, wooden, stone or gravel drains
	PIPELESS: mole drains, tunnel drains

Open ditches

Open ditches can be used as a main drainage system or in combination with another method. Caldwell & Richardson (1975) describe the open drain system of the East Anglian fens, where deep ditches surrounding long, narrow fields (100 m wide) provide adequate drainage as long as the ditches and outlets are maintained in good condition. In these lowmoor peats, subsurface drainage only becomes necessary when subsidence has reduced peat depth to less than 90 cm.

Segeren & Smits (1974) recommend a preliminary drainage system of field ditches, to be replaced by pipes when initial subsidence has occurred. In subtropical soils, where subsidence due to oxidation continues at a rate of 3-5 cm/year, these authors regard tile drainage as uneconomical and give preference to a permanent system of open drains.

Maslov & Panov (1980) also recommend a system of open canals as a preliminary drainage technique for deep peats, combined with mole drainage where peats are heavily decomposed.

Lie (1972) noted the importance both of installing collector ditches and lowering outlets to allow for sufficient fall in these after subsidence.

A system of deep open drains gradually replaced by tunnel drains is the most efficient method of draining deep blanket bog (Galvin, 1976a).

Shallow open drains are installed by ploughing. O'Carroll et al. (1981) describe the drainage of blanket peat for forestry, where a channel is excavated by a single (SMB) or double (DMB) mouldboard plough. Trees are planted in the inverted sod which lies beside the drainage channel. SMB ploughs give a channel with dimensions 45-60 cm deep and 50-90 cm wide, while DMB channels are 20-30 cm deep and 70-80 cm wide.

For forestry on shallow peat, a system of surface furrows draining into 60 cm deep drains at 10 m intervals is described by Braekke (1978).

Cut-over bogs can be adequately served by widely spaced open ditches sited to drain low areas and to intercept surface run-off from outside the area (Galvin, 1976a).

Päivänen (1976) compared open and closed drains for forestry and recommends closed types wherever possible, since they require less excavation at installation and they continue to function in winter when water in open ditches has frozen and flow ceased.

Subsurface drains

Pipe drains. The first consideration with pipe drainage is its economic feasibility. Eggelsmann (1978) recommends use of pipes only where peats are sufficiently permeable, i.e. those with hydraulic conductivity of greater than 0.06 m/day. A very intense spacing of pipes is necessary where peats are less permeable or where precipitation is high. Hudson & Roberts (1982) used 75 mm clay tiles with backfill to drain 0.5-1.5 m thick peat in an area with high rainfall (2500 mm/year). They found that, to be effective in lowering the water-table, drains had to be installed at 2 m spacing. This was not considered economically feasible.

Previous pipe drainage involved the use of clay tiles and these are still commercially available in most countries. However, more emphasis is now being placed on the use of plastic pipes which are lighter, easier to transport and to install. These factors, as well as the fact that they are available in continuous lengths which reduce the need for supports against sagging, mean that plastic pipes are more suitable for peat drainage. The strength of clay pipes may be one advantage of their use in peats, since subsidence and compression after drainage lead to increased load on the pipe. Reduction in depth of drains can lead to pipes being subjected to pressure from traffic (Håkansson, 1971). Scholtz & Wertz (1975) describe the most common types of PVC pipe in use in GDR, including a recently developed model consisting of two longitudinal parts which clip together to form a pipe 145/170 mm in diameter. The advantage of this larger diameter pipe is that it requires no slope at installation, it is easier to store or transport and it can be installed rapidly by a trenchless drainage machine, at a rate of 240 m/hour.

Use of filters is recommended with pipe drains (Eggelsmann, 1978). Filter material is laid around the pipe either totally or partially and backfill is used to increase permeability above the pipe. The action of the filter is to remove larger particles from the drainage water and thus increase hydraulic performance. The filter may also reduce or prevent ochre clogging of the pipe. Materials used for filters include natural products such as gravel, coarse sand, straw, sawdust, coconut fibre, heather or turf and synthetic products such as fibres, felts or slag.

Method of pipe installation and choice of filter material depend on the local availability of materials and drainage machinery and on cost considerations. Former methods of pipelaying which involved separate digging and pipe transport machines have been streamlined, especially since the development of flexible plastic pipe. Eggelsmann (1978) describes present day machinery. A cutter-chain machine can combine the operations of trench digging, pipe laying, filter installation and trench backfilling. Trenchless drainage machines install the pipe without trench excavation and are capable of assembling clay or plastic pipes with or without filter. These machines have an installation rate 2 to 4 times that of a cutter-chain machine.

Covered ditches were the traditional drainage technique for peat before the development of tile drains. The original designs were installed manually and the ditches formed by excavating relatively narrow, deep drains, constructing a channel at the bottom with stone slabs, inverted sods or wooden supports and backfilling with peat. Though manual installation is no longer practical, some types of covered drain have been adapted for modern use. O'Carroll (1962 cit. O'Carroll et al., 1981) describes the experimental use of traditional Irish sod drains in drainage for forestry. Rayment (1970) reports the combined mechanical - manual installation of 'Norwegian' type wooden covered ditches in a Newfoundland peat.

Pipeless drains

Pipeless drains are a cheaper alternative to tile drains if the mole or tunnel has a reasonable lifetime in the peat. Durability of mole drains is influenced by peat density expressed in terms of vol.% of solid matter. Eggelsmann (1975) shows this relationship in Table 13.

Table 13. Expected service life of mole drains in relation to peat density (after Eggelsmann, 1975).

Relative density of peat	Solid matter content (vol.-%)	Service life of unlined mole drain (years)
dense	12.0	8
rather dense	12.0-7.5	8-5
rather loose	7.4-5.0	5-3
loose	4.9-3.0	3-1
almost floating	3.0	1

There are two ways in which pipeless drains can be installed: (a) by a mole plough which displaces peat with an expander drawn after the plough share, the expander having diameter 12-20 cm in peat soils (Eggelsmann, 1978), (b) by a tunnel plough where a ribbon of peat is extruded, leaving a channel 38 cm deep and 20 cm wide, which is similar in dimensions to the traditional sod drain.

Use of the latter method in forest drainage is described by O'Carroll et al (1981) and an adaptation of the technique for highbogs has been made in FRG where a milling machine removes peat to produce a channel 20 cm by 15 cm (Eggelsmann, 1978).

Mole drains can be supported by 20 mm washed gravel laid on a 15 cm wide polythene strip at time of installation (Burke & McCormack, 1969). This prolongs the mole life, especially in pasture where there is heavy traffic.

Casselman & Green (1972) describe a technique for plastic lining of moles during installation and compare it to standard moles in an area of the Florida Everglades. Neither the new nor the old moling technique proved successful on these soils.

Where peat is highly decomposed, dammed water and high water retention cause waterlogging and in such peats the mole outlet into the catchment drain must be supported by a socket of wood or plastic (Eggelsmann, 1978).

Grubb & Burke (1979) discuss the optimum size and shape of tunnel drains and their stability. They conclude that optimum dimensions were 38 cm deep x 28 cm wide, since a reduction in cross-section occurs immediately after installation. Tunnel size is reduced by 50-80 % depending on peat strength. Measurements of peat strength were made using a shear vane test and from observations in successfully drained peats the following rule was produced:

vane readings greater than 150	-	tunnel drains successful
readings between 100 and 150	-	success variable
readings less than 100	-	not suitable for tunnel drains

EFFECTIVENESS OF VARIOUS DRAINAGE TECHNIQUES

Many results from drainage experiments in peat soils have been published. Some research compares the effectiveness of existing techniques, others describe the development of a new method to solve a particular problem.

Päivänen (1976) investigated the relative effectiveness of draining open bog with the following techniques:

a) ordinary open ditches

b) plastic pipes - smooth PVC, 40 mm diameter

c) narrow, vertical-walled trenches

All drains were installed at 85 cm depth and 35 m spacing. Measurements of run-off from plots showed that open ditches were the most effective method and narrow trenches the least effective in removing precipitation water. Water-tables in plots drained by pipe were on average 10 cm higher than in those areas drained by open ditches. It was also noted that water transport ability of pipes decreased with time due to build-up of algae, ochre and silt.

Lie (1977) regards covered ditches as a very suitable method of drainage for some types of peat, especially where farming operations involve much surface traffic. Where tile drains are used, experiments in Norway have led to the following recommendations:

- pipes must be strong enough to withstand pressure from soil load and surface traffic
- pipes with narrow slits are prone to clogging by peat fibres
- coarse sawdust is an adequate filter material and is readily available. Gravel with 0.5-20 mm particles may have better filtering ability but is more expensive to purchase and to transport.

Menonen & Päivänen (1979) investigated the effectiveness of different types of subsurface drains:

a) covered ditches (wooden) 62 x 102 mm

b) PVC pipe with diameter 45 mm or 65 mm, with or without a synthetic fibre filter

c) mole drains

Groundwater levels were measured for each plot as a parameter of drainage efficiency. It was found that mole drains were ineffective in lowering the watertable while the covered ditches gave satisfactory results. Plastic pipe drains had an intermediate effect and use of a filter impeded rather than improved the drainage effect.

Inability of mole drains to lower watertables has also been reported by Casselman & Green (1972) who studied the effect of lined and unlined moles in shallow organic soil. Moles of 150 mm diameter were installed at 80 cm depth and at a range of spacings from 3 to 25 m. Recording of groundwater levels during the growing season showed that even at the closest spacing, neither lined nor unlined moles could bring levels down sufficiently for crop growth in these soils.

Fukunaka (1980) reports on the ease of installation and drainage efficiency of these subsurface drains:

a) clay tiles; 60 mm diameter, covered with rice straw
b) smooth PVC pipe; 45 mm diameter, 4 m lengths, synthetic fibre filter
c) drain hose; galvanized iron coil, covered with a nylon fibre mat
d) corrugated PVC pipe; 50 mm diameter, continuous, with or without filter
e) mole drains

Work and time requirement in installing these five treatments was in the ratio 1:0.5:0.7:0.6:0.01, showing a greatly increased work efficiency for moling. Use of continuous and lightweight pipe speeded up installation rate to a much lesser extent. It was found that continuous plastic pipe was the most effective type of subsurface drain in controlling the watertable, since they were not deformed by differential subsidence of the peat.

Rayment & Campbell (1980) report the effectiveness of these drains in peat:

a) covered ditches with wooden supports
b) corrugated PVC pipe with sawdust filter
c) corrugated PVC pipe with fibreglass filter

(all treatments with or without supplementary slit drains)

Measurements of water flow in drains and watertable levels indicated that use of supplementary slit drains increased run-off rates in the 24 hour period after heavy rainfall. In dry periods, however, run-off was higher from areas without supplementary drains, indicating slower drainage from these areas. Differences between drainage techniques were also observed, in that flow in the covered ditches fluctuated considerably as a result of silting up followed by a clearing flush after heavy rainfall. However, these ditches have a long life (estimated 20 years) and can be installed at the required 8 m spacing without impeding farming operations and at a reasonable cost. The more expensive system of PVC pipes is only recommended for more lucrative enterprises such as commercial vegetable production. Sawdust proved to be a cheaper and more durable filter than fibreglass, though it was more difficult to install.

As has been stated, the high precipitation in some peat areas necessitates dense drain spacing and the cost of drainage can be prohibitive because of this. The search for a cheaper alternative has led to the development of mole and tunnel drainage techniques. Burke (1978) reports an experiment comparing the newly developed tunnel drain with conventional methods. Plots with the following types of drainage were compared:

a) forest drained by open ploughed ditches 0.3 m deep and at 2 m spacing
b) the same forest where tunnel drains 0.7 m deep were installed at 2.2 m intervals
c) pasture intensively drained with pipes at 0.6 m depth, supplemented by gravel drains.

It was observed that shallow draining increased the air-filled porosity of the peat from the original 7 % vol. to 13 % vol. This effect was restricted to the upper 30 cm; below drain depth, no improvement occurred and tree roots did not penetrate this layer. In the tunnelled area, air-filled porosity ranged from 56 % vol. in the upper 15 cm to 17 % vol. at 60 cm depth. The effect of tunnels in increasing the volume of air in the soil was augmented by localised shrinkage in the rootzone, which led to the formation of cracks in the soil. A porous, friable layer with ideal rooting properties developed to a depth of 60 cm. In intensively drained pasture, drainage was accompanied by considerable compaction and an increase in bulk density of the peat. This resulted in diminished drainable porosity and a suitable rooting zone developed only in the upper 15 cm.

O'Carroll et al (1981) report similar results for the effect of tunnel drains in forest. They compared tunnel drains to the conventional method of plough furrows presently used in forest drainage and found that the shallower plough drains restrict both horizontal and vertical root development, whereas tunnel drains were very suitable for blanket peat deeper than 1.5 m.

Burke & McCormack (1969) compared the effect of 14 types of drain in blanket peat and found no improvement in watertable levels or surface conditions from any of the methods used. Gravel-filled drains were developed for easy installation and longer lifetime and these drains were found to be best suited to semi-intensive agriculture where they support the channel under traffic (Burke, 1978).

SECONDARY TREATMENTS

This concerns treatments used in conjunction with, or following drainage, to improve flow toward the drain, to improve soil structure and to provide a suitable surface for farming operations.

Caldwell & Richardson (1975) describe the following techniques used in Great Britain: 'claying' is a traditional practice in East Anglia and involves digging up underlying fen clay, spreading it on the peat surface and mixing it in by cultivation after it has been weathered during the winter. This reduces erosion and improves light peat soils. Mixing peat with a mineral subsoil is a technique designed to create a more homogenous soil, to distribute lime deeper and to reduce oxidation of organic matter by covering the peat and bringing it nearer the watertable.

Halvorsen (1974) compares treatments to improve peat surfaces after drainage, namely shallow ploughing, rotavation and ridging, where an arched surface is created between drains. It was thought that the latter would increase flow toward the drain and so improve surface conditions but research showed that this was not the case. As a cultivation method, rotavation gave 24 % better yields from subsequent crops and it also maintained watertable levels an average 5.6 cm deeper than in a shallow ploughed area.

Galvin (1976a) describes surface grading of peats. This involves several operations, including rotavation, levelling and rolling the surface. This improves surface trafficability, prevented surface ponding and provided a plane area for farm machinery. In less permable peats, slit drains made with a chainsaw were found to improve passage of water to the main catchment drains.

Lie (1977) recommends use of secondary treatments to bring peat into cultivation after drainage. In comparing shallow ploughing with rotavation, he found that the latter is more beneficial since it does not disrupt capillary transport to the rootzone and rotavated soils are more resistant to drying-out than ploughed soils.

PEAT AS A LIMITED RESOURCE - CONSERVATION VERSUS UTILIZATION

Peat can be regarded as a limited resource, with conflicting interests regarding its utilization. Some such interests are:

- preservation of peatlands in their natural state, conservation of indigenous flora and fauna, protection of the micro- and macro- ecosystems
- utilization of peat for energy, noting the economic and political importance of selfsufficiency in energy production

- drainage and development of peat for forestry, timber or biomass production
- drainage and cultivation of peat for agriculture, noting the importance of self-sufficiency in food production and the effect on rural sociology.

Moore & Bellamy (1974) summarize the global balance of peat resources and utilization: there are an estimated 230 million hectares of peat which represent 330 x 10^9 tonnes of potential energy and which, if oxidised, are capable of producing 500 x 10^9 tonnes of carbon dioxide. Global rate of peat formation is, at most, 3 t/ha/year. If all peat areas had this re-growth rate, 450 million tonnes would be produced per year. However many peats in northerly, cooler regions have only a fraction of this and cut-over sites may have no re-growth whatsoever. The rate of peat utilization, an estimated 90 million tonnes per annum, exceeds the rate of actual re-growth.

Pyavchenko (1980) regards agricultural development of bogs as a more efficient use of natural reserves than harvesting peat for fuel. He recommends restriction of utilization as follows:

a) all lowmoor peats, which are rich in nitrogen and ash, should be reserved exclusively for agriculture
b) peats of transitional type, which have fewer nutrients but are still agriculturally productive, should be used for forestry, possibly energy forests or high biomass plantations.

Such restrictions would conserve peat deposits and utilize them more efficiently. Any losses of peat will be due to natural wastage such as mineralization and will be dependent on its rate.

Bramryd (1980) notes that drainage of peatlands for forestry does not result in as high losses of the organic peat layer due to oxidation as drainage for agricultural purposes.

Hallgren & Berglund (1962) regard undeveloped peat as a reservoir of potentially productive agricultural land, which will be consumed by cultivation. In a time of over-production of food, it may be advisable to delay reclamation of peatlands. When population growth raises the demand for food, better economic returns will be available and more profitable use of peat can be achieved.

Countries which are not self-sufficient in food production, for example Norway, aim to expand reclamation programmes. Fjaervoll (1978) reports that Norway has an official target of increasing cultivated areas by 100,000 hectares within 15 years.

Where intense drainage has been maintained over a great number of years, peat subsidence and wastage can lead to a situation where water has to be pumped up to the main outlet drains which are embanked high above the level of the fields. In coastal areas, fields may subside below sea level, necessitating construction and maintenance of sea defences (Prus-Chacinski 1962 cit. Moore & Bellamy, 1974).

A combination of utilization of peat for energy and food production has been practised in those countries with a large fuel peat industry. Healy (1980) describes the utilization of ridge raised bogs in Ireland. In their original state, the upper layers of these peats are unsuitable for agriculture. These layers are harvested for fuel, exposing highly productive agricultural peat soil. Research has been carried out on the use of these cut-over areas for vegetable production, forestry, beef, sheep, dairy or cereal enterprises. However these are recent experiments and nothing is known of the wastage in these peats which will occur with time and continued use.

In most countries, economic considerations will limit the extent and intensity of drainage investment made by the individual farmer. However, the system of grant aid which is available to farmers in many areas distorts the economic balance. In E.E.C. countries, up to 70 % of investment costs can be met by grant aid and farmers are encouraged by this to drain and reclaim areas of marginal land for agriculture. The economic benefit depends on the life of the improvement but annual returns are generally low, since these areas are suitable for the more intensive and profitable farm enterprises (McAfee, 1980).

In view of the current E.E.C. food surpluses, further support of food production is of less importance than socio-economic support in remote rural areas.

SUMMARY

Estimates of the total world area of peat vary from 150 to 450 million hectares and countries with a high national percentage of peat include Finland (30 %) and Ireland (17 %). Utilization of peat for agriculture involves lowering of groundwater levels, thus improving soil trafficability and aeration. The depth to which watertables are lowered is based on consideration of crop needs, balanced against prevention of losses due to peat mineralization which are increased at lower groundwater levels.

Peats have often low permeability and poor aeration. The air-filled porosity of the upper layer can be as low as 3 % vol., while the minimum for plant roots is usually said to be 10 % vol. Properties of peat are related to their degree of humification and variations due to this characteristic must be taken into account in drainage planning.

The need for drainage is increased by climatic factors such as high rainfall and low evapotranspiration. Before implementing a drainage programme, it is necessary to consider the effects on the hydrology of the catchment area. Possible effects include change in run-off pattern, changes in water storage capacity of the peat and the ability of discharge pathways to accomodate any increase in run-off.

Subsidence of drained peats is caused by mechanical settling, increase in bulk density of layers, microbial oxidation of organic matter and in some areas erosion. The relative effect of these factors depends on the climate of the area and the original depth and density of the peat layers. Prediction of subsidence from empirical formulae is a necessary part of planning and design of subsurface drainage systems. Recorded amounts of subsidence vary from 0.2 cm/year to 10 cm/year after initial severe subsidence has occurred. Many sources recommend a preliminary system of open drains to produce this initial subsidence before installing the chosen subsurface drainage system.

Layout, depth and spacing of drainage systems are determined by local conditions and the technique used. Factors involved in depth of drainage include: choice of crop and crop needs, minimization of peat losses due to oxidation, reduction of nitrate leaching in drainage water and improvement of peat trafficability. Spacing recommendations vary widely depending on drainage technique, peat type and climatic factors.

Techniques available for peat drainage are: deep open ditches, shallow furrows, tile drains, covered ditches and mole/tunnel drains. The advantages and disadvantages of each must be considered in relation to the proposed use of the area. Factors include traffic movement and load involved in the farming enterprise, the cost of the technique at the necessary spacing, the local availability of materials and machinery, the life of the technique and its maintenance requirements. Some techniques are best suited to a certain type or depth of peat, or to forestry rather than agriculture.

Results from research into effectiveness of different drainage methods are conflicting on, for example, the effect of mole drains or of filter materials. It is evident that local results are of most value in planning and installing a drainage system.

Pipeless forms of subsurface drains, such as moles or tunnels, represent a cheaper way of achieving the dense drain spacings required for peat.

Secondary treatments of the upper layers are necessary after drain installation to provide a suitable surface for farming operations and to produce a more homogenous soil. Present research gives preference to light cultivation such as rotavation rather than the traditional ploughing.

A conflict of interests or demands for peat may lead to closer investigation of most efficient utilization, where national and global energy needs are weighed against the need for food or forest production. Energy forest production is being investigated as a possible peat-conserving system. Food production on harvested peat sites is a means of compromise between interests.

SAMMANFATTNING

I denna litteraturöversikt redovisas forskning och försök vad gäller dikning av torvjordar. Här sammanfattas uppsatsen och dess viktigaste slutsatser. Myrmark och torvbildande växtsamhällen förekommer över hela världen. Frekvensen är högre inom den norra tempererade zonen. Den beräknade totalarealen är mellan 150 och 450 miljoner hektar och bland de myrrikaste länderna är Sovjet, Finland och Irland. Den vanligaste brukningsformen i de här länderna är torvtäkt men i andra länder används de för jordbruks- eller skogsbruksändamål.

Användningen av torvmarker för odling kräver olika slag av förberedelser som t.ex. grundvattenreglering genom dikning. Dränering är viktig för att förbättra markbärigheten och öka luftinnehållet. Torvjordar har ofta låg genomsläpplighet och luftinnehållet kan vara så lågt som 3 vol. %. Med dränering töms de övre skikten på 15-20 vol. % vatten som ersätts med luft.

Dikesdjupet bestäms med hänsyn till grödans vattenbehov och till kravet på markbärighet. Ju djupare man dikar, desto bättre blir markbärigheten. Däremot är ytsänkning ett problem som blir större, ju djupare grundvattennivån ligger.

Det är osäkert hur dikningen påverkar ett områdes hydrologi. En åsikt är att grundvattensänkningen ökar torvjordens vattenförrådslapacitet och att avrinningsmängden blir jämnare. En annan åsikt är att nederbörden når avloppsdikena snabbare efter dikningen och att avrinningsmängden koncentreras till en kortare period.

Ytsänkningen av dränerade myrjordar är en viktig faktor vid dikningens planering och utförande. Ytsänkningen orsakas dels av mekanisk sättning när grundvattnet sänks, dels av ökad kompaktdensitet och dels av mineralisering och erosion. Faktorer som temperatur, torvdjup och brukningsintensitet påverkar sättningens storlek. Med hjälp av empiriska formler kan man uppskatta förväntad sättning efter dikning. Dessa tar hänsyn till torvens kompaktdensitet,

myrtypen och dräneringsintensiteten. Uppmätta värden kan variera med +/- 25 % från de beräknade värdena och det kan vara lämpligt att använda uppmätta värden från lokala undersökningar. Sättningens storlek i olika länder är mellan 0.2 cm/år och 10 cm/år, efter den kraftiga sättning som sker direkt efter dikningen.

Dikesdjup och dikesavstånd bestäms med hänsyn till det lokala behovet och den dräneringsteknik som används. Faktorer som påverkar valet av dikesdjup är bl.a. grödans vattenbehov, förväntad mineraliseringsgrad, kväveförluster i avloppsvattnet och förbättring av markbärigheten. Rekommendationer för dikesavstånd varierar mycket beroende på dräneringstekniken, myrtypen och klimatiska faktorer.

De dräneringstekniker som används är: öppna diken, dikning med rör, täckta diken och tubulering. Den dräneringsteknik som används i ett område beror på kostnaden vid ett bestämt dikesavstånd, jordbrukets behov, tillgång till material och maskiner och metodens livslängd. Några tekniker är lämpligare för ett visst torvdjup, andra passar skogsbrukets behov bättre än jordbrukets behov. Resultaten från försök med olika metoder och material är osäkra t.ex. när det gäller tubuleringens effektivitet och livslängd eller val av filtermaterial. Rörlösa diken, som tub eller tunneldiken, är ett billigare dräneringssystem där intensiv dikning behövs.

För att få en homogen profil och en jämn yta efter dikning behövs en bearbetning av jorden. Lätt bearbetning med hjälp av harv eller jordfräs anses lämpligare än plöjning av myrjordar. Det framtida utnyttjandet av myrjordar måste vara en kompromiss mellan energibehovet och matbehovet. Både torvtäkt och jordbruk innebär en förändring av miljön, alltså kan en konflikt uppkomma mellan de som vill utnyttja torven och naturvårdsintressena.

Materialförlusterna vid skogsodling anses försumbara. Energiskogsodling kan vara en bra kompromiss mellan olika brukningsformer.

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APPENDIX. Degree of humification determination according to the von Post scale (von Post 1921 cit. von Post & Granlund, 1925).

Grade	Humification Status	Reaction to Manual Pressure
H1	totally unhumified	gives colourless, clear water
H2	almost totally unhumified	almost clear, yellowish water
H3	very weakly humified	discoloured water but no solids, residue not sticky
H4	poorly humified	strongly discoloured water, residue somewhat sticky
H5	somewhat humified, plant structure still obvious	strongly discoloured water, some solids pass between fingers, sticky
H6	more humified, plant structure not obvious	max. 1/3 solids pass out, sticky, plant remains visible in residue
H7	quite well humified, plant structure only slightly discernible	1/2 solids pass between fingers, any water extruded is thick, dark
H8	well humified, plant remains very indistinct	2/3 solids pass out leaving residue of resistant root remains
H9	almost totally humified	almost all sample passes out as a homogenous slurry
H10	totally humified	all sample passes out, no water freed

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