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SILVA FENNICA. Sisältää etupäässä Suomen metsätaloutta käsitteleviä kirjoitelmia ja pienehköjä tutkimuksia. Ilmestyy epäsäännöllisin väliajoin.

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GROUND WATER TABLE AND WATER CONTENT IN PEAT SOIL

LEO HEIKURAINEN, JUHANI PÄIVÄNEN AND JUHANI SARASTO

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Prefage

This paper is part of a more comprehensive study on the water content in peat soil being carried on at the Institute of Swamp Forestry, University of Helsinki. The group of problems is examined mainly from the point of view of forest production, but it is natural that also the general aspects of the water economy of peat should be studied. So far, two preliminary works bearing on the permeability of peat have been published on the basis of these investigations (Sarasto 1961 and 1963), and another preliminary work dealing of the transpiration of growing stock (Heikurainen 1963). Also the present paper is of tentative nature.

The research methods used in this work and the results obtained have been drawn up and worked out by the team mentioned in the list of authors. The undersigned has planned the main part of the project, Dr. Sarasto has supervised the laboratory experiments, and forest officer Päivänen has been in charge of the field work.

January 1964.

Leo Heikurainen

Contents

1. Introduction

The ground water table has long been used as an indicator of the water economy of peat lands. Thus, the drying influence of ditches has been widely studied by measuring the level of the ground water table, defined here as the distance of the ground water table from the ground surface. The ground water table, in other words, is the water surface which appears in a hole made in the peat when enough time has elapsed after the hole has been dug, e.g. 44 hrs (cf. MULTAMÄKI 1936).

Attempts have been made in many studies, particularly in recent times, to determine more closely the correlation between the level of the ground water table and the water content in peat. It has been generally found that the water content in the surface peat is higher the closer the ground water table is to the ground surface (e.g. JUUSELA 1945, HAUDE 1953, EGGELSMANN 1957 and PAAVILAINEN 1963). In all the studies mentioned above the water content of peat has been determined either by taking one-time samples or by calculating the water stock on the basis of precipitation, runoff, and evaporation values. Correlation on the basis of one-time samples has generally proved to be clear but relatively loose. In the results by PAAVILAINEN (op.cit.), for instance, the correlation coefficient in one case studied was —0.646 and in another —0.740. It is thought that the high dispersion is caused by the heterogeneity of soil, on the one hand, and by the fact that the volume of soil samples is not always the same as intended, on the other (cf. e.g. WÄRE 1947). With the method based on calculating the water stock the correlation has been closer; e.g. EGGELSMANN's (1957) correlation coefficient was —0.962.

Also the correlation between the tension of the water in the soil and the level of the ground water table has been studied and a correlation has been established (e.g. RICHARDS 1941, HEINONEN 1954 and PAAVILAINEN 1963). BURKE (1961) has observed that the tension of water at the level of the ground water table is zero.

The present study deals with the correlation between the level of the ground water table and the water content of peat in swamps drained for forestry. The results have been obtained partly from field studies and partly from experiments in the laboratory. As the method used is at least partly new and seems to give good results, it is believed that this work, although a preliminary study for a larger project, merits publication.

2. Methods and materials

The basic idea behind the method is this: The same soil samples are weighed repeatedly and at the same time the level of the ground water table is measured. Thus, the differences in weight at different measurements are differences of water content in the samples; concequently changes in water content are measured with the same accuracy as used in weighing. Soil samples to be weighed repetedly can be relatively large, and therefore the heterogeneity of peat does not cause so much dispersion as when small one-time samples are used. Also, when relatively large samples are used, the volume of a sample can be determined with a relatively greater accuracy. In field experiments the level of the ground water table varies according to weather conditions; in laboratory experiments the ground water table can be adjusted to a level desired.

In field experiments the samples were peat cylinders 25 cm in diameter cut from the surface parts of a swamp. A part of the samples consisted of a single layer, and the height of a sample was 20 cm. Apart from these samples 40 cm in height were also studied, and these were divided into three parts: the topmost part-sample was 0—15 cm, the middle part 15—25 cm, and the bottom part 25—40 cm. Each sample was placed in a pot made of perforated aluminium; the top of the pot was open and the bottom consisted of a copper wire mesh with 2-mm holes. The samples were kept in pots in the ground placed in the same holes from which the samples had been originally taken. Weighing took place by lifting a sample from the ground and determining its weight with an accuracy of one gram. The level of the ground water table was measured from a ground water hole nearly.

Samples used in the laboratory experiments consisted of three layers each 8 × 8 × 10 cm. The samples were placed in pots with closed sides. These pots, one on top of another, were placed planted tightly together in a larger water container whose water level could be regulated. Weighing took place sample by sample with an accuracy of 0.01 g.

As regards the one-layer field samples, three were examined; these were situated in the same swamp at a distance of 5—10 m from one other. The samples were weighed at one-week intervals in the summers of 1962 and 1963. Thus, there were 30 weighings for each sample. The level of the ground water table varied from 8 cm to 47 cm. The peat was MCS-t, H_4.[1]

The three-layer soil samples were situated in the same swamp around a water hole at a distance of about 6 m from it. One sample only was subjected to a closer examination and, as to the three others, some main results are given. The samples were weighed in the summer of 1963 only and there were 15 weighings. The level of the ground water table varied from 11.7 cm to 43.0 cm. Peat in different part-samples was:

Top layer,	0—15 cm	MCS-t, H_3
Middle layer,	15—25 »	MSC-t, H_{4-5}
Bottom layer,	25—40 »	SMC-t, H_6

Since all the samples under examination are still in the ground and they are to be remeasured in summers to come, it has not been possible to determine their dry weights yet, nor have their volumes been measured accurately. In this publication only changes in weight are examined, that is, changes in the amount of water as such, either as weight units or relative figures.

In the laboratory, using the samples described above, the correlation between the ground water table and the water content of the peat above it has been studied; also the influence of rain and a long dry period on the water content of the surface peat has been examined. To study the influence of rain the series of samples have been watered with quantities corresponding to different amounts of rain, and after watering changes in the weight of the topmost sample have been followed at short intervals. In this connection results received from four samples after watering with an amount corresponding to a rainfall of 10 mm were examined. The influence of a long dry period has been studied with one series of samples by letting the sample series evaporate 114 days without watering it. As the water container in which the sample series was is relatively large, the level of the ground water table has stayed at almost the same level all the time. The peat type used in the laboratory experiments was ErS-t, H_{3-5}.

3. Correlation between the level of the ground water table and the water content in peat soil

31. Correlation in the surface peat

The correlation between the water content in the surface peat and the level of the ground water table is examined in the light of the results from the three one-layer samples of surface peat.

Fig. 1 shows the results from sample No 2. It reveals that a clear correlation has been obtained in both summers between the level of the ground water table and the weight of the sample. In 1962 the correlation coefficient has been —0.842 and in 1963 —0.943. It can be seen in addition that the regression lines run almost parallel, the regression coefficient for 1962 is —0.051 and for 1963 —0.053. The lines, however, are on different planes; in 1962 the sample has been about

[1] MCS-t = woody sedge *sphagnum* peat
MSC-t = woody *sphagnum* sedge peat
ErS-t = *Eriophorum sphagnum* peat
H = humification according to von Post

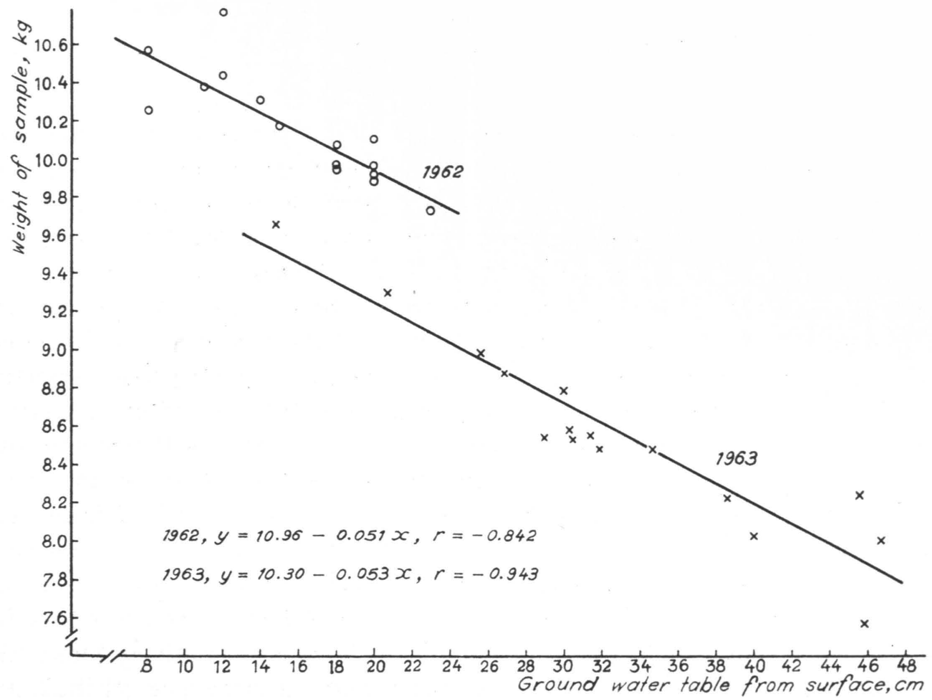

Fig. 1. Correlation between the level of the ground water table and the water content of the surface peat (0—20 cm), separately in the summer of 1962 and of 1963.

0.7 kg heavier than in 1963 with the same level of the ground water table. The same result has been received from two other samples; the regression lines in two successive years run exactly parallel, but the line for 1963 is on a lower plane.

The question as to what has caused the decrease in weight of the sample during the winter has not been answered with certainty. Unfortunately, the level of the ground water table in 1962 and 1963 was measured at different points, and for this reason it is not possible to determine the true difference. It remains to be clarified in later studies how much results in different summers differ from each other. To base the following discussion on a larger material and on a wider range of variation as regards the level of the ground water table, the materials of the summers of 1962 and 1963 have been combined; before doing this, however, the differences between weights in 1962 and 1963 have been subtracted from the weights of samples in 1962; in other words, the line of the summer of 1962 has been converted to the level of the line of the summer of 1963.

The results of the material thus combined have been shown in Fig. 2. We can see from the diagram that the correlation between the level of the ground

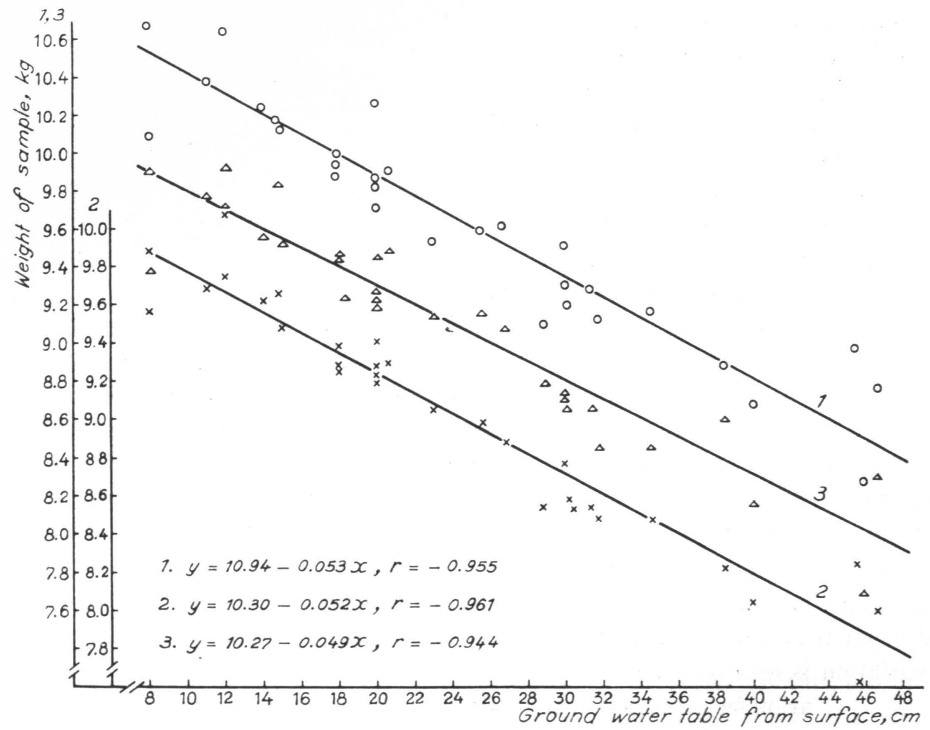

Fig. 2. Some examples from one and the same sample plot of the correlation between the level of the ground water table and the water content in surface peat (0—20 cm).

water table in all the samples have been very close and significant. The correlation coefficients are:

Sample 1	r = —0.955
» 2	r = —0.961
» 3	r = —0.944

The correlation coefficients were tested by converting them into Z-values obtained from tables, by computing their standard errors, and by using the t-test in testing the 0-hypotheses of the Z-values. It appeared that all correlation coefficients were significant at the level of 0.1 % at least. Also in the material not published the correlation coefficients were very high throughout. Only in rare instances has the coefficient been under —0.850 and coefficients exceeding —0.950 are quite common.

Another fact revealed by Fig. 2 is that the regression lines of parallel samples run almost parallel. The regression coefficients are quite close to each other, as is seen from the diagram. Also, the differences between the planes of the lines are small, and they may have been caused, as are the differences between the regression coefficients, by the fact that the parallel samples are not exactly the same size. It appears then that the correlation between the level of the ground water table and the water content in the surface peat in the same kind of peat is very similar. If we examine the magnitude of the change in the water content of the surface peat when the ground water table is at different levels, we can observe that in the cases studied a change of 10 cm in the level of the ground water table corresponds to a change of about $^1/_2$ kg in the amount of water. In a 10-liter sample it is, in weight percentages, about 5 %.

Samples of other types of peat have given different regression coefficients. It is worth mentioning that also in sample areas where the changes in the level of the ground water table were from 50 cm to 80 cm, a close straight correlation was observed. It remains to be clarified in future studies what kind of correlation obtains in different peat types and different degrees of humification.

Studies by Richards (1941) are worth mentioning in this connection; according to them the correlation between the tension of water and the water content is not rectilinear. In his studies, however, the range of variation in tension corresponded to a change of almost 5 m in the level of the ground water table, and when the curve is gently sloping, the correlation is rectilinear if the range of variation is relatively narrow.

The correlation between the water surface and the water content of the peat above it was studied with laboratory experiments. Fig. 3 shows the results obtained with the samples described above. The diagram reveals only the chan-

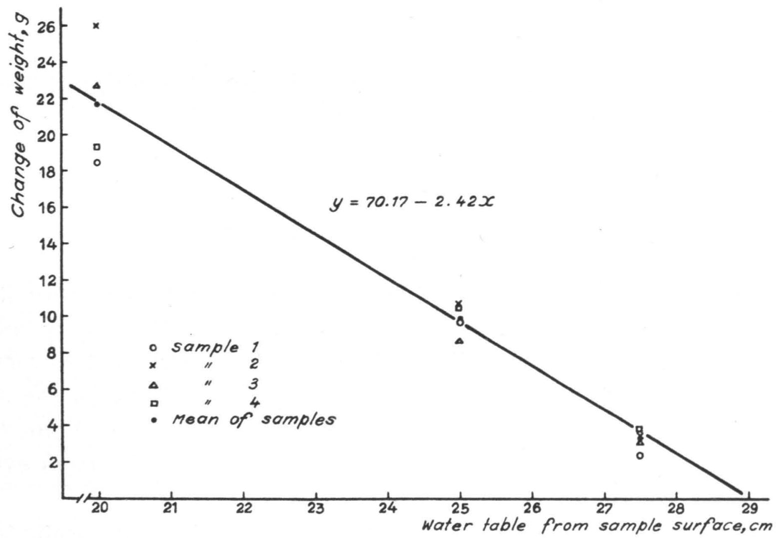

Fig. 3. The correlation between the water level and the water content in peat above it according to laboratory experiments. See text for further explanation.

ges in weight of the top parts of the sample as a function of the level of the water surface. It can be seen from the diagram that in different samples which are almost similar as regards the peat type and the degree of humification the correlation is almost the same, and the means of four samples give an almost exactly rectilinear correlation. A change of 10 cm in the level of the ground water table corresponds to a change of about 24.3 g in the amount of water. As the volume of the samples is about 640 cm³, it signifies a change of about 4 % in weight percent. This result is of the same magnitude as the one obtained in the field experiments. As was observed before, the regression coefficient for different types of peat is different; in this connection we can only conclude that the result of field trials and laboratory experiments in this case is of the same magnitude and that in both cases also the peat has been of the same type. It is quite possible that the correlation between the level of the ground water table and the water content of peat can be best clarified with laboratory experiments.

32. Change of correlation in vertical direction

Although the root system in drained swamps generally does not go deeper than 20—30 cm (Heikurainen 1955 and 1958) knowledge of the water economy of deeper layers is of some importance. Dependence of the water content of deeper layers on the level of the ground water table is examined on the basis of the three-layer samples described above. By comparing results from different peat layers with each other it is possible to form an idea as to how the correlation of the level of the ground water table and the water content in peat varies in the vertical direction.

Fig. 4 shows, as an example, results from a series of samples of the summer 1963. The weights of the samples are given as relative figures so that the weight of a sample is 100 when the level of the ground water table is 0. In this way the part-samples have become more easily comparable. We can see in the diagram that in all the three layers a clear rectilinear correlation has been obtained between the level of the ground water table and the weight of a sample. Although there are only 15 measurements, the correlation coefficients are large, as can be seen from the following table.

Topmost sample (A)	r = —0.957
Middle sample (B)	r = —0.977
Bottom sample (C)	r = —0.940

The correlation coefficients were tested in the way described above and they were all significant at 0.1 % level.

It is notable that a rectilinear correlation has been obtained also in the bottom layer, at the depth of 25—40 cm, although the sample has been part

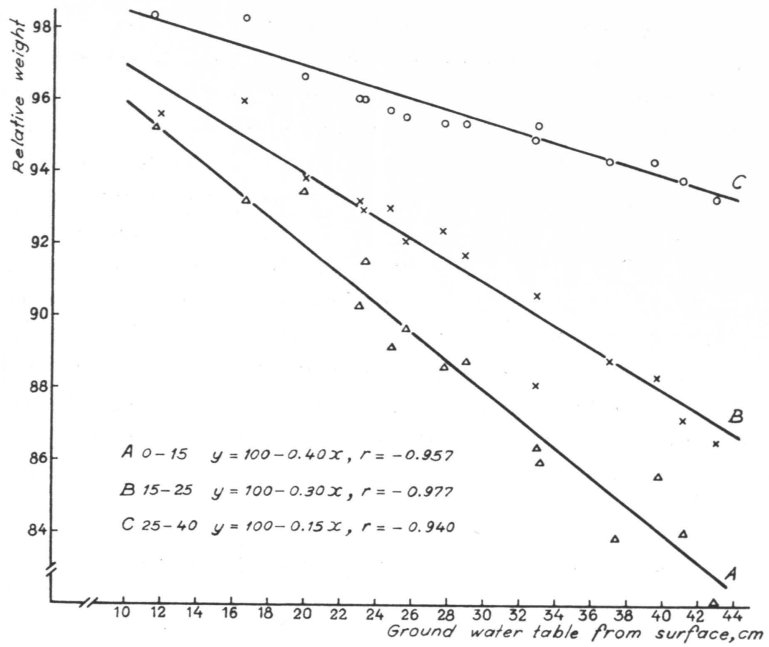

Fig. 4. Variation in the correlation between the level of the ground water table and the water content of peat at different depths in the peat.

of the observation period (6 measuring instances) completely below the surface of the ground water table, and for the main part of the observation period (13 measuring instances) at least the bottom of the sample has been below the surface of the ground water table. This result is probably best interpreted to mean that the surface of the ground water table is not a limit below which the water content is constant. It may be a limit where the tension of water is 0, but the water content apparently rises also below this limit. This result can, according to Richards (1941), be explained by the facts that below the surface of the ground water table there exists water pressure and above it water tension.

It is not clear, on the basis of this material, how deep the correlation between the water content of peat and the level of the ground water table continues. In our examples, however, the regression coefficient is smaller the deeper the sample in question is. If we go deep enough the regression coefficient is apparently 0; in other words, the water content of peat is constant and independent on the level of the ground water table. Other cases studied have given similar results. The regression coefficient of the regression line has been smaller the deeper the peat sample examined has been, as can be seen from the following table.

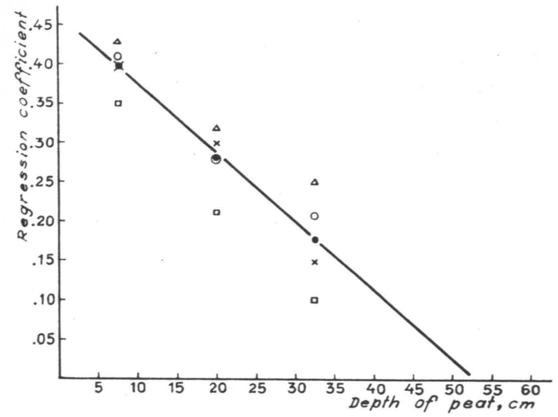

Fig. 5. Variation in the regression coefficient of the regression line indicating the correlation between the level of the ground water table and the water content of peat, as a function of the depth of peat.

No. of sample series	1	2	3	4	Mean
Topmost sample (A)	—0.40	—.041	—0.43	—0.35	—0.40
Middle sample (B)	—0.30	—0.28	—0.32	—0.21	—0.28
Bottom sample (C)	—0.15	—0.21	—0.25	—0.10	—0.18

Samples in the same sample plot have given results of the same magnitude. Dispersion is considerable, but on the other hand, the layers in different sample series are perhaps not exactly the same and this may increase dispersion. Fig. 5 shows how the regression coefficient changes as the depth of peat increases. The change seems rectilinear, and, as the mean of the four samples examined, the result would signify that the regression coefficient would be zero at the depth of about 53 cm; that is, the correlation between the level of the ground water table and the water content of peat would cease at the depth of about 53 cm. It remains to be clarified in future studies what factors regulate the correlation between the water content of peat and the level of the ground water table in the vertical direction.

33. Factors causing dispersion

There is, of course, some dispersion in the correlations between the level of the ground water table and the water content of peat presented above. It has been observed by analyzing the results of the field experiments that the points above the regression line are mostly results of weighing on a day succeeding a couple of rainy days, whereas the points below the line are from weighings after a long dry period. It was not considered advisable to attempt any further clarification of dispersion on the basis of the field experiments. It will suffice to observe in this connection, by referring to Fig. 2, for instance, that even the greatest deviations correspond to a change of only about 7—10 cm in the level of the ground water table.

In the laboratory experiments have been made to clarify tentatively the influence of a long dry period and of a rainy period on the water content of the surface peat. To clarify the influence of a long dry period a series of three part-samples (alltogether 8 × 8 × 30 cm) was put into a water container so that the water surface was at the upper limit of the bottom part-sample or at the depth of 20 cm, and water could evaporate through the peat layers only. The experiment was kept in progress in the laboratory for 114 days. Temperature was kept at 19—20° C and relative moisture at 12—30 %. When the experiment was terminated, the change of weight in the topmost layer was 87.8 g or about 0.77 g per day. In the middle layer the change of weight was only 1.4 g or only about 0.01 g per day. Expressed as volume presents the decreases in weight during the experiment in the topmost layer (0—10 cm) 13.7 % and in the middle layer (10—20 cm) 0.2 %. In addition, the level of the ground water table had fallen 2.2 cm during the experiment, which, according to Fig. 3, signifies a decrease of about 1 volume per cent in the water content of the topmost layer and in the middle layer the same decrease of weight, perhaps, as was observed in weighing.

The change of weight in the topmost layer is very high as against that in the middle layer, and it is possible that the contact between the first and the second layers has been poor. Taking into consideration that the experiment lasted almost four months and that it was carried out in a dry and warm place, the result has to be interpreted to mean that water rising because of the capillary force or diffusion can keep the water content of the surface peat relatively constant even during long dry periods. A dry period of two weeks, for instance, would have meant, even in the topmost layer, a decrease of only about 10 g in the amount of water or a change of about 1.6 volume per cent, supposing that the decrease of weight has been rectilinear. The relative smallness of the change in weight and the intensity of the capillary flow even in the topmost layer become evident if we compare it with the amount of water which had evaporated through the sample during the experiment. The amount of water evaporated was 1.430 kg, or 16 times larger than the amount of water lost by the topmost sample during the experiment.

The influence of rain was studied with samples described before by watering the sample series from above with certain amounts of water. When a sample series was in a large water container in such a position that the surface of water in the sample rose to a depth of 20 cm, watering did not cause any notable rise of the water surface. Fig. 6 shows the changes of weight in the topmost sample as a function of time, when watering corresponded to a rainfall of 10 mm. The results are averages of four samples. The diagram shows that the increase in the total amount of water, a total of 64 g, has fallen to 28 g one hour after watering, after two hours and a half to about 19 g, after twelve hours to about 8 g, and after twenty-four hours about 1 g remains of the weight increase due to

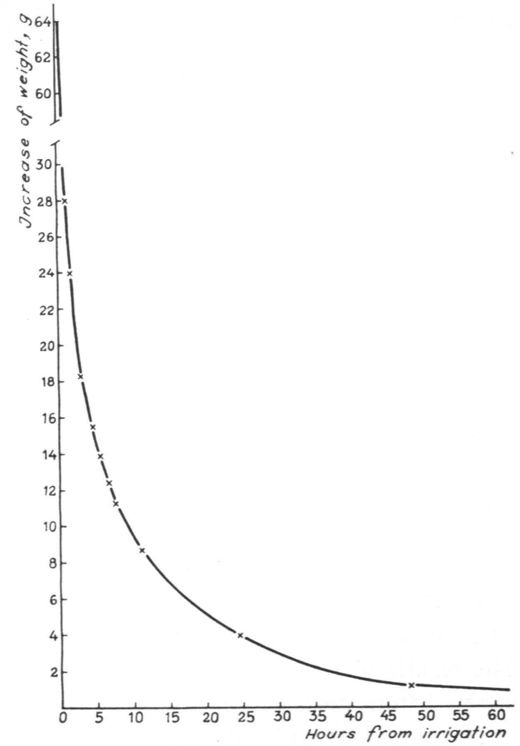

Fig. 6. Variation in the weight increase caused by watering as a function of time. See text.

watering. In other words, only about 1.5 per cent of the water increase caused by watering is left after 24 hours. We can observe, therefore, that a weight increase due to watering is of short duration, and, more generally, the influence of a rainfall on the water content of surface peat is ephemeral.

It is probable that the influence of a rainfall varies according to the type of peat and its degree of humification. The clarification of these questions has been left to future studies.

4. Summary of results

Experiments both in the field and in the laboratory have proved that a close rectilinear correlation obtains between the level of the ground water table and the water content of surface peat. As was mentioned before, the correlation, if the variation range is wide enough, is apparently not rectilinear but a gentle hyperbola; but in the cases studied the variation range is so narrow that the function remains rectilinear. In the vertical direction the correlation generally changes so that the absolute value of the regression coefficient of the regression line decreases from the surface downward. In other words, a given change in the level of the ground water table corresponds to a smaller change in the water content the deeper the peat layer examined is situated. If we go deep enough the correlation apparently ceases; the water content remains constant or at least it does not correlate with the level of the ground water table. In the cases studied this limit seemed to be somewhat lower than the lowest level of the ground water table.

The change in the water content in the surface layer (0—20 cm) in the cases studied was of such a magnitude that a change of 10 cm in the level of the ground water table corresponded to a change of about 5 volume per cent. In deeper layers the change was smaller. The correlation is probably different in different types of peat.

Dispersion around the regression line was relatively small. The main causes of dispersion were rain and long dry periods. The influence of rain in the cases studied did not last long and the influence of dry weather was relatively small. Thus the state of equilibrium regulating the water content of peat, which is well expressed by the level of the ground water table, is relatively stable.

The results are partly known before, partly new. The correlation between the level of the ground water table and the surface peat is, generally speaking, well known, as was mentioned in the preface, but the continuation of the correlation in deeper layers and its stability have not been observed in earlier studies. The results of this study also proved that the correlation is closer than can be inferred from most earlier studies.

The method used in the present studies, the repeated weighing of peat samples in their original place, has proved to be very useful and decisevely better than the method based on one-time samples. The experiments also indicate that the correlation can be determined with laboratory experiments.

5. Optimum drainage in the light of results

In the case of our example (Fig. 2) a change of 10 cm in the level of the ground water table corresponded to a 5-% change in the water content as volume percent. Thus, a difference of 50 cm, for instance, in the level of the ground water table corresponds to a change of 25 % in the amount of water. This change is so large that the range of variation probably covers a considerable part of the optimum curve of the water economy of trees, e.g. areas of excess water and readily available water, or areas of readily available water and less available water (cf. HEINONEN 1954).

It is possible that the so-called optimum drainage for each tree species can be theoretically determined on the basis of the correlation between the water content of peat and the level of the ground water table. Fig. 7 shows the idea of this theoretical solution in the light of a constructed example. Diagram A shows the optimum curve of the water content in the site of the tree species in question constructed on the basis of the correlation between the vegetative

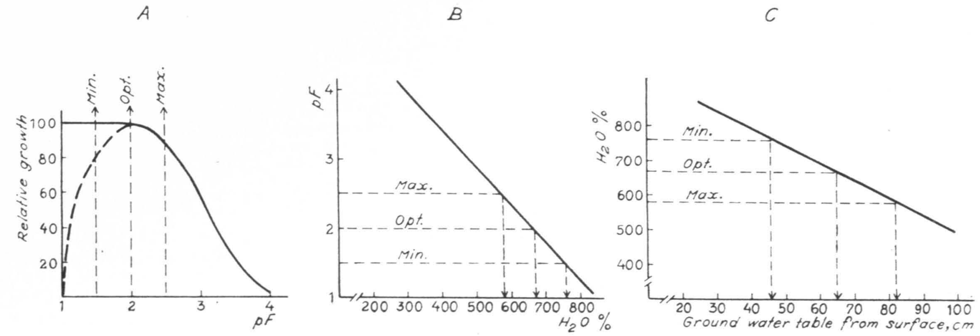

Fig. 7. Theoretical determination of optimum drainage. See text.

growth of certain cereal species and energy conditions of water in the site (HEINONEN 1954). The presupposed optimum drainage has been pF 2, minimum drainage pF 1,5, and maximum drainage pF 2,5. The decrease of increment from pF 2 to pF 1 is caused by secondary factors, above all a increasing lack of oxygen. Diagram B shows the pF function of a peat type according to the results of tentative studies with a »*pressure plate extractor*» and a »*pressure membrane extractor*» at the Institute of Swamp Forestry. Optimum drainage would correspond to a water content of 670 %, maximum drainage to a water content of 580 %, and minimum drainage to a water content of 760 %. Diagram C shows the regression line of sample 2; it has been altered from the one presented in Fig. 2 so that the vertical axis shows the amount of H_2O as of dry weight. The optimum drainage in the case of our example would correspond to a 65 cm depth of the level of the ground water table, the depth for the minimum drainage would be 46 cm and maximum 82 cm. In other wors, drainage should be such that the level of the ground water table would not rise above 46 cm and would not fall under 82 cm and that its average depth would be 65 cm. It should be determined separately, of course, how such drainage can be attained, in the manner MESHECHOK (1960) has proposed, for instance.

The solution of the optimum drainage in the way described would be universal; it would be applicable to all kinds of peats and conditions, if the concepts of water economy which form the basis for the solution are known well enough. As was mentioned before, the numerical values of our example are mainly hypothetical. The optimum curves of the water economy of site for trees have not been presented; pF functions of different peat types and degrees of humification have been clarified tentatively only (PUUSTJÄRVI 1963) and studies on the correlation between the water content of surface peat and the level of the ground water table have only begun. Only when enough information has been gathered about the circumstances mentioned will we be in a position to evaluate the significance of the theoretical solution of the optimum drainage presented.

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