Effect of drying and freezing on certain physical properties of peat

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Summary

The growing demand for peat for horticultural use in the Netherlands has stimulated research to improve the more decomposed peats to serve this purpose better. To this end, detailed investigations were made into some of the physical properties of raised bog peats (mainly *Sphagnum* peat with an average H of 6 to 7) and into the effect freezing had on these properties. The results may be summarized in the following conclusions:

1. Freezing of fresh peat causes a considerable decrease of the tension with which moisture over and about 100 g per 100 g of dry peat is retained. This is due to enlargement of the average pore diameter on freezing.
2. After freezing of fresh peat, shrinkage on drying is also much smaller and removal of water is much less irreversible. The quantity of water taken up again by air-dried peat is linearly related to the rate of shrinkage on drying results in an increasingly higher rate of re-uptake of water by air-dried peat.
4. The correlation between the percentage of total shrinkage and the degree of decomposition of peat is rather unfavourable.
5. The volume of fresh peat decreases approximately linearly with loss of moisture, the latter being expressed in g per 100 g of dry peat. Freezing beforehand, causes a strong deviation from this course of shrinkage on drying.
6. The percentage by volume of reswelling of the investigated peat appeared to be constant irrespective of the stage of drying (and shrinkage).
7. The main effect of freezing on (rather small volumes of) peat was achieved in a single freezing period at a temperature of —5° C during at least three days, but a lower temperature proved to be preferable.
8. The effect of frost on peat is smaller when the moisture content at the moment of freezing is lower.

Zusammenfassung

Die zunehmende Nachfrage nach Torf für gartenbauliche Zwecke in den Niederlanden veranlasste zu Untersuchungen wie durch entsprechende Behandlungen die Verwendbarkeit der stärker zersetzten Torfe erhöht werden könnte. Dazu wurden einige physikalischen Eigenschaften des sog. Schwarztorfes und der Einfluss des Durchfrierens auf diese Eigenschaften eingehend untersucht. Die Ergebnisse werden in den nachstehenden Schlussfolgerungen zusammengefasst:

1. Das Durchfrieren vom grubenfrischen Torf verursacht eine erhebliche Abnahme der Spannung womit das Wasser dass über etwa 100 g pro 100 g trockenen Torfes anwesend ist, festgehalten wird. Diese Abnahme muss einer Vergrösserung des durchschnittlichen Porendurchmessers beim Durchfrieren zugeschrieben werden.
2. Weiter hat dieses Durchfrieren eine viel geringere Schrumpfung beim Eintrocknen zur Folge und daher ist der Wasserentzug auch viel weniger irreversibel. Die Menge des vom lufttrockenen Torfe wieder aufgenommenen Wassers hängt gradlinig und sehr gut gesichert zusammen mit dem Ausmass der beim Trocknen stattgefundenen Schrumpfung.

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3. Je geringer die Schrumpfung beim Trocknen an der Luft, um so grösser ist die Geschwindigkeit der Wiederaufnahme des Wassers beim lufttrockenen Torf.
4. Der Zusammenhang zwischen dem Ausmass der Schrumpfung und dem Zersetzungsgrade des Torfes ist ziemlich stark gestreut.
5. Das Volumen des grubenfrischen Torfes nimmt annähernd linear ab mit dem Wasserverlust in Grammen pro 100 g trockenen Torfes. Durchgefrorener Torf zeigt aber ein stark abweichendes Verhalten.
6. Der Volumenprozentsatz der erneuten Quellung des untersuchten Torfes zeigte sich als unabhängig vom Eintrocknungs- (und Schrumpfungs-) Grade.
7. Der Einfluss des Durchfrierens (nachgeprüft bei ziemlich kleinen Torfscheiben) war in Hauptsache schon erreicht wenn der Torf, einmal während zumindestens drei Tagen, auf —5° C gehalten wurde. Eine tiefere Temperature war jedoch günstiger.
8. Die Grösse der Frosteinwirkung nimmt ziemlich stark ab je nachdem der Torf schon stärker eingetrocknet ist vor dem Durchfrieren.

1. Introduction

The physical properties required in peat for use as a fuel are quite opposite to those for agricultural use. For use as a fuel a strong and irreversible shrinkage by volume of the peat upon drying is very desirable; this gives hard, compact sods which do not take up water again. Peat for agricultural purposes, on the other hand, must have a loose and porous structure and take up water quickly and reversibly. According to PENNINGSFELD (1957) the structure and especially the water and air capacity determine whether a peat can be used as a substrate for plants or not. Now it is known that, generally speaking, shrinkage and irreversibility of loss of water are related to the degree of decomposition. That is the reason why the less decomposed peats are preferred for horticultural use, whereas for fuel the more decomposed peats are favoured.

In the Netherlands most peats have a von Post-degree higher than 5 (mainly moss-, sedge- and wood peats). However, the demand for peat for horticultural use is growing and there is now only a small demand for peat as a fuel. Therefore, the question if and how these more decomposed peats can be improved for horticultural use is of increasing importance.

The beneficial effect (from the view-point of the fuel-peat industry, however, a detrimental effect) freezing has on the physical properties of peat material is well known (STADNIKOW, 1930). Exposing fresh peat for horticultural use to the effect of frost is an old practice in certain parts of the Netherlands. As far as we know, a close investigation into this effect and the optimal conditions for its realisation is lacking. We have tried to meet this demand.

2. Materials and methods

2.1. Description of peat

The investigations were centred on raised-bog peats in the North-East of the Netherlands, mainly consisting of old, dark brown *Sphagnum* peat mixed with *Eriophorum* (so called "black peat"), over-laying a gently undulating diluvial sand soil. Other plant debris, as such from *Calluna, Carex, Scheuchzeria* and others are generally also present (partially in thin layers), but in relatively minor quantities. (The original upper layer of slightly-decomposed *Sphagnum* peat is or has been used for production of peat-moss bales). The depth of the "black peat" profile mostly varies from 2 to 3 metres.

The degree of decomposition (von Post-scale) sometimes varies from 3 to 9 in one profile; the mean value is about 6 to 7. The pH-H_2O is about 4.5, the content of plant nutrients is very low, the loss on ignition is about 98 to 99 % and the total-nitrogen content generally varies from 0.9 to 1.2 % of the dry matter.

2.2. Sampling and measurements

First, some typical profiles were extensively sampled for chemical and physical analysis (the chemical data will be published *in extenso* elsewhere). The physical analysis concerned determination of moisture characteristics (pF-curves) in the first place. Therefore, sharp-edged cylinders (height 5 cm, volume 100 ml) were pressed carefully and horizontally into a fresh profile wall (4 cylinders per layer of 10 to 20 cm thick). The cylinders were freed by carefully cutting away the surrounding peat with a sharp knife, and then sealed air tight to ensure a minimum loss of moisture prior to determination.

Two of each four cylinder-shaped samples were used directly for determination of the moisture characteristics (pF-values 0.4, 1.0, 1.5, 2.0, 2.7, 4.2, and 6.1 respectively). The method is described by PEERLKAMP and BOEKEL (1960). From the other two cylinder-shaped samples the pF-curves were determined after the peat had been frozen during a week at a temperature of about — 7° C. The volume of all four peat samples was determined when air dry, by measuring the "displacement" of glass beads (850—1000 μ diameter) of a known weight by volume; from these percentages by volume of shrinkage were calculated (decrease in volume as a percentage of the original volume).

Then all the peat samples were placed on a wet sand surface with a pF 0.4 and the rate of water uptake was determined by weighing the samples after 1, 3, 8, 24, 48 and 200 hours. Thereupon, the samples were completely saturated with water and then the pF-curves were determined again.

Other investigations concerned the course of shrinkage during air drying of fresh peat and of peat which had been frozen previously, and the optimal conditions for the effect of freezing. These investigations were carried out with two bulk samples of this "black peat", from which disks were made by carefully filling cylinders of 4.5 cm diameter and 2 cm height with the fresh peat. The experiments with these peat disks (after removing the cylinders) were performed in duplicate at least, often in quadruplicate. Here, volume measurements were made with the simple aid of a sliding gauge, which proved to be as accurate as the above-mentioned method, the shrinkage being more regular here.

3. Results and discussion

3.1. Investigation of the effect of drying and freezing on undisturbed peat samples

In TABLE 1 the average moisture characteristics, weight by volume and percentages by volume of shrinkage, are recorded of 4 profiles (46 samples), determined directly for fresh peat, after freezing and thawing, after air drying and resaturation with water and after freezing, air drying and resaturation.

There appeared to be distinct differences depending, amongst others, on the degree of decomposition and botanical composition of the peat samples, but the samples were too few to separately determine the influence of these factors on the moisture characteristics with sufficient accuracy.

Because the volume of the samples does not remain constant during removal of water, the moisture contents at different pF-values are given in g per 100 g of dry peat in TABLE 1. The same applies to FIG. 1 where the corresponding pF-curves are averages for all the samples.

TABLE 1 and FIG. 1 show that fresh peat releases only a relatively small quantity of water at pF 2 (100 cm tension), which confirms, as is well known in practice, the fact that the air capacity of fresh peat is very low. Contrary to this, the quantity of moisture released between pF 2.0 and 4.2 (available moisture) is extremely high.[1]

Freezing of fresh peat causes a substantial decrease of the quantity of water released between pF 2.0 and 4.2 and a corresponding increase of that released between pF 0.4 and 2.0. This is in accordance with results published earlier (HOOGHOUDT *et al.*, 1960)

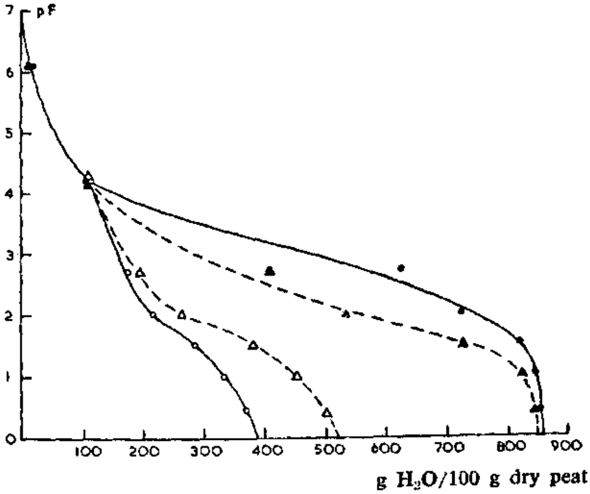


FIG. 1
Average pF-curves of "black peat" in different conditions

concerning the decrease of the centrifuge-moisture equivalent (at which determination the pF is about 3.0) after freezing other peat types. This is undoubtedly due to a considerable enlargement of the average pore diameter. So, freezing results in a distinct increase of the air capacity (it may be pointed out here, that freezing also causes an apparent decrease of the degree of decomposition when estimated according to von Post, as water is compressed more easily).

As can be seen from the pF-curve for peat which has been air dried and resaturated with water, drying involves a loss of water-retaining capacity (when calculated in g/100 g of dry peat), which increases with decreasing pF. This is due to the strong and largely irreversible shrinkage on drying.

[1] DALTON (1954) reviews different schemes of classification for water in peat. All these schemes have this in common that they based on the manner in which water is assumed to be bound. Terms as "capillary" or "free" water, "colloidally", "osmotically" and "chemically"-bound water are used. Now it has been found that in organic colloids there is no sharp transition between the different manners in which water is held. The terms mentioned often overlap each other partially, e.g. "capillary" water and "colloidally-bound" water. Therefore we prefer a classification for water in peats, as is used in mineral soils (see PEERLKAMP and BOEKEL, 1960), that is based on the energy with which it is retained (pF = logarithm of the specific free energy when the latter is expressed in cm H_2O).

TABLE 1. Average moisture characteristics, weights by volume and shrinkage of four profiles

Profile No.	Treatment	Initial H_2O %	g H_2O per 100 g dry peat at pF 0,4	1,0	1,5	2,0	2,7	4,2	6,1	0,4-2,0	2,0-4,2	Weight by vol.	Shrinkage (% by vol.)
IV	fresh	89,2	883	876	847	731	624	103	14	152	628	10,6	70
	after freezing		899	866	730	526	390	104	14	373	422	10,4	58
	after drying and resaturation		355	314	276	208	167	104	—	147	104	37,6	—
	after freezing, drying and resaturation		504	434	350	250	177	95	—	254	155	26,1	—
I	fresh	89,1	876	873	840	744	651	108	15	132	636	10,5	71
	after freezing		871	846	729	538	438	105	15	333	433	10,3	58
	after drying and resaturation		380	328	258	191	175	108	—	189	83	37,8	—
	after freezing, drying and resaturation		532	465	369	256	208	114	—	276	142	25,2	—
III	fresh	88,9	881	868	841	747	634	105	15	134	642	10,7	69
	after freezing		842	820	734	551	390	111	15	291	440	11,2	57
	after drying and resaturation		418	389	347	272	209	107	—	146	165	35,7	—
	after freezing, drying and resaturation		518	486	440	305	205	103	—	213	202	26,5	—
II	fresh	88,0	775	772	753	674	586	109	14	101	565	11,7	67
	after freezing		774	763	702	515	412	104	16	259	411	11,6	56
	after drying and resaturation		329	298	256	188	154	102	—	141	86	37,2	—
	after freezing, drying and resaturation		452	426	379	235	186	104	—	217	131	26,8	—

This shrinkage appeared to be much smaller (see TABLE 1) after the peat had been frozen. Then the peat remains more porous after drying (which may also be concluded from the weights by volume) and consequently takes up more water again per 100 g of dry peat than without freezing, especially at lower pF-values. Thus after freezing, the capacity to reabsorb water after drying is far less impaired.
It is worth noticing that at about 100 g moisture per 100 g dry peat, the wilting point (pF 4.2) is reached, no matter how the peat has been treated.
In TABLE 2 the water uptake is recorded after placing the dry peat samples on a wet surface at pF 0.4 for an increasing number of hours. From these values may be concluded that not only the amount, but also the rate of water uptake is greater in peat which has been frozen. In FIG. 2 the relation between the quantity of water taken up in 200 hours by air-dried peat samples and their percentage of shrinkage on drying is shown. The relation appears to be: $y = -1.06\ x + 105.2$, irrespective of the peat being frozen or not. The correlation coefficient is -0.82, so the relation is very significant in this case.

TABLE 2. Rate of moisture uptake of air-dry peat at pF 0.4; average values of four profiles

Profile No.	Treatment before air drying	g H_2O per 100 g dry peat at pF 0,4 after 0	1	3	8	24	48	200 hrs
IV	none	10,7	22	54	—	167	182	277
	frozen	11,6	103	216	—	272	293	404
I	none	13,3	26	54	160	233	268	303
	frozen	12,6	103	229	327	372	405	457
III	none	11,4	52	110	139	169	202	377
	frozen	11,3	133	194	226	251	269	472
II	none	10,2	27	86	193	238	263	291
	frozen	10,3	112	274	337	370	393	422

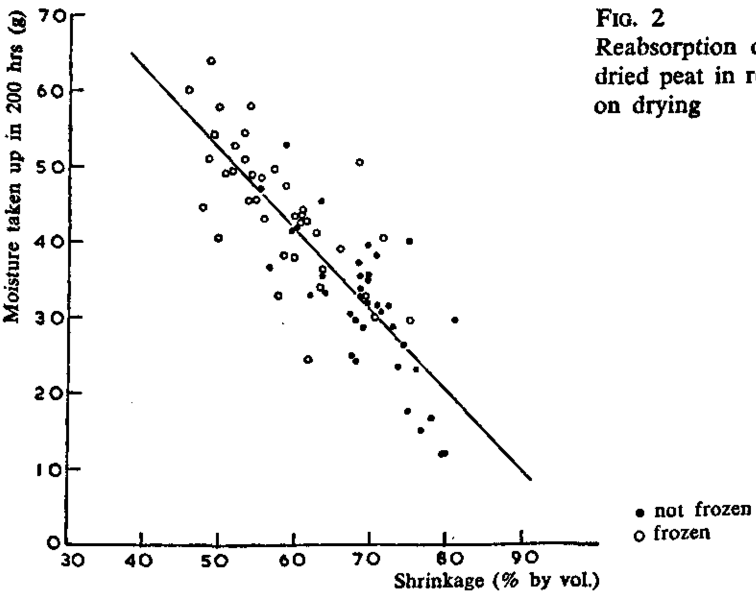


FIG. 2
Reabsorption of moisture by air-dried peat in relation to shrinkage on drying

FIG. 3 shows the rate of water uptake by air-dried peat, in dependence of the percentage of shrinkage on drying. The effect of freezing is once more evident from the distribution of the samples over the classes of shrinkage, as indicated in FIG. 3.
The obtained data offered the opportunity to examine the relation between the percentage of shrinkage and the degree of decomposition. As can be seen in FIG. 4, the divergence appeared to be rather large (the calculation of the product-moment-correlation coefficient gave a value of only 50), indicating that there are other factors affecting the shrinkage, of which the botanical composition is presumably the most important one (it may be mentioned here that the correlation is no better when the degree of decomposition is determined according to other methods).
It may be interesting to compare our results with those to be presented in a further publication by SEGEBERG (1962).

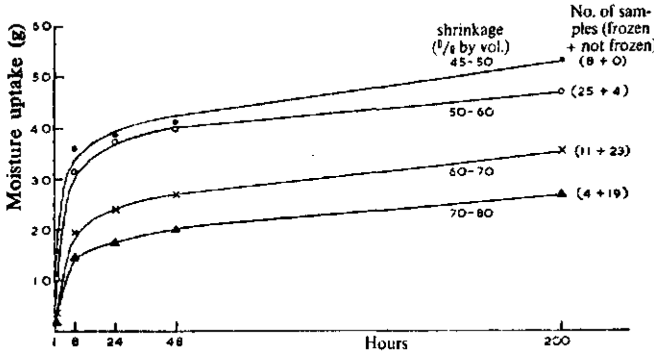


FIG. 3
Rate of moisture uptake of air-dried peat in relation to shrinkage on drying

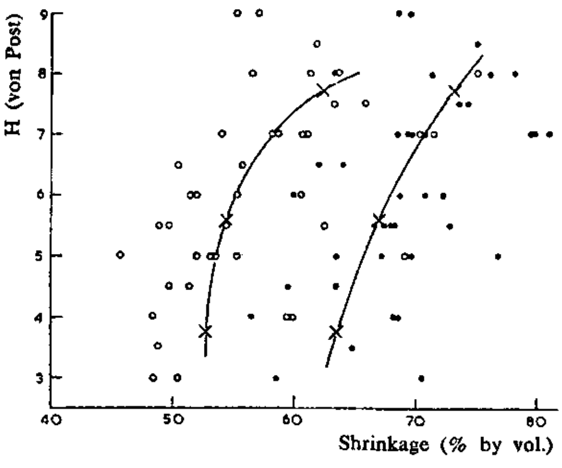


FIG. 4
Relation between the degree of decomposition and shrinkage upon drying

• not frozen
o frozen
× average values for H = 3—4½, 5—6½, 7—9

3.2. The course of shrinkage during drying as affected by freezing

The course of shrinkage during air drying of fresh peat and peat which had been frozen (3 days at — 5° C) when it was still fresh, was studied in different stages of drying by measuring the volume of peat disks prepared as described before. All measurements were made in quadruplicate. The results are shown in FIG. 5.

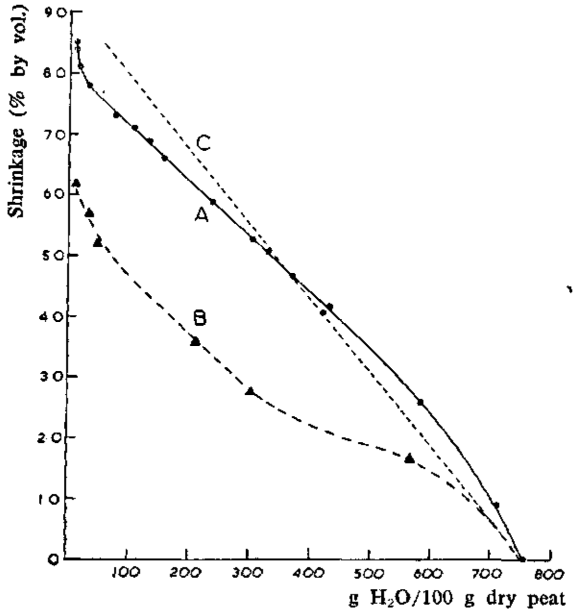


FIG. 5
The course of shrinkage during air drying of fresh peat and peat frozen when fresh

A not frozen
B frozen
C if every g of moisture evaporated had caused a decrease in volume of 1 ml

Curve A shows, as was also stated by LUIKOV (1935), that the volume of fresh peat decreases approximately linearly with loss of moisture when the latter is expressed in grams per 100 g of dry peat. It appears that curve A does not deviate much from the theoretical curve C which would have been obtained if the decrease in volume of peat during the whole course of drying was exactly equal to the volume of water that is evaporated. Curve A even suggests that at the beginning of drying shrinkage should exceed the volume of water lost. This can only be the case when some air is present in large "pores" in fresh peat which contract on drying (perhaps some small air bubbles were still entrapped) although the cylinders were carefully filled with peat.

In the first stage of drying (to a moisture content of about 70 % is reached, *i.e.* to about 235 g H_2O per 100 g dry peat), evaporation is considered to take place from a saturated surface (LUIKOV, 1935), or from constantly filled pores (NASSEDKIN, ref. DALTON, 1954), the rate of evaporation being independent of the moisture content. It is evident that the decrease in volume of the peat then will indeed be equal to the volume of water removed. The force of contraction exerted on the peat here is governed by the tension with which the removed water was retained.

LUIKOV and others suppose that in the next stages of drying (from about 70 % moisture, that is about 235 g H_2O per 100 g dry peat) evaporation takes place from an unsaturated surface (the rate of evaporation is then strongly dependent on the moisture content). Thus the water evaporated is assumed to be partly replaced by air. This implies a turn of curve A towards the abscissa. The degree of this turn, *i.e.* the deviation from the calculated curve (here only small), is a measure for the replacement of water by air, which is an important datum for the suitability of fresh peat for use as a substrate.

We have no plausible explanation for the upward turn of curve A (and B) at the end of the drying process, which suggests a very heavy contraction, whereby not only water is removed but also part of the penetrated air. A very considerable shrinkage of "black peat" when the moisture content decreases below 27 % is also mentioned by NAUCKE and BECK (1956).

The course of shrinkage on drying of peat, which has been frozen when still fresh, is given by curve B in FIG. 5. This curve greatly deviates from A and C. The volume decrease at the beginning of drying is considerably smaller than the volume of water that evaporates. So, already at the beginning of drying part of the evaporating water is replaced by air. As is shown by the pF-curves in FIG. 1, the moisture tension in this region decreased by freezing, so the contractive force exerted on the peat is also smaller. Besides that, freezing may have resulted in a greater rigidity of the peat (giving a greater counterforce for shrinking) which would explain (part of) the smaller shrinkage.

From a moisture content of about 300 g per 100 g of dry peat, curve A and B run parallel. So removal of water in this region appears to cause the same shrinkage, irrespective of whether the peat has been frozen or not.

It is worth noting that the shrinkage of the disks made of well-mixed peat is larger than that of the undisturbed samples. This is a well-known fact in practice.

Knowledge of the course of shrinkage during drying is important, because it provides the possibility of calculating the relation between pF and the percentage by volume of water or the "solid-fluid-air ratios" at different pF-values as then the volume of peat is known at every pF-value.

Unfortunately, no measurements were made of the course of shrinkage of the 46 profile samples, but as a first approximation a linear course may be assumed, *viz.* from 0 to 69 % (the average value of total shrinkage of the fresh samples) and from 0 to 57 % (the average value of total shrinkage of the samples which have been frozen) respectively. From these curves the average volume of these disk-shaped samples at the different pF-values were derived and the corresponding percentages by volume of water were calculated for fresh peat and for peat which had been frozen.

To calculate the percentages by volume of water at the different pF-values after drying and resaturating another way had to be followed, because no direct data about reswelling on resaturation and consequent shrinkage on redrying were available. Here we assumed that on resaturation of the dry peat all pores were filled with water and that the course of shrinkage on redrying is linear and ended again at the same values of 69 en 57 % respectively.

In this way we converted FIG. 1 into FIG. 6 where the pF is related to the estimated average percentage by volume of water. The latter figure demonstrates clearly that freezing causes an increase of the air capacity without significantly lowering the amount of available water per given volume of peat (between pF 2.0 and 4.2 the curves for fresh peat and for peat which has been frozen are about equidistant). Drying the peat simultaneously increases the air capacity and greatly decreases the amount of available water per volume unit of peat. The decrease is less in peat which has been frozen before drying, in which case the air capacity has then increased even more.

It may be mentioned here that the pF-curves of JAMISON (1942) were determined for peat which was previously dried and that he did not give a correction for shrinkage of peat when drying the resaturated (and reswollen) peat. The form of the curve (double S-shaped), however, is the same.

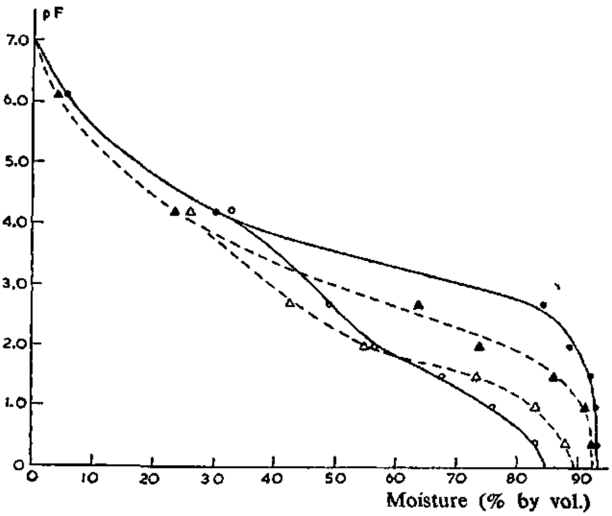


FIG. 6
Estimated pF-curves of "black peat" in different conditions; moisture content in "percentages by volume"

After the unfrozen peat disks in the foregoing experiment had reached their respective, previously-fixed moisture contents and their volume had been measured, two of these disks were placed on a pF 0.4 box without further drying during 7 days in which reswelling took place. The original volume, however, was never reached again. There appeared to be a linear relation $y = 0.96\ x - 9$ between "irreversible" shrinkage (= remaining shrinkage after reswelling) and total shrinkage, which means a gradient of 44°. If we assume a gradient of 45°, this relation (shown in FIG. 7) becomes $y = x - 11$. Then, in every stage of drying reswelling is the same, *viz.* 11 % of the original volume. If extrapolation to $x = 11$ is permitted, then the com-

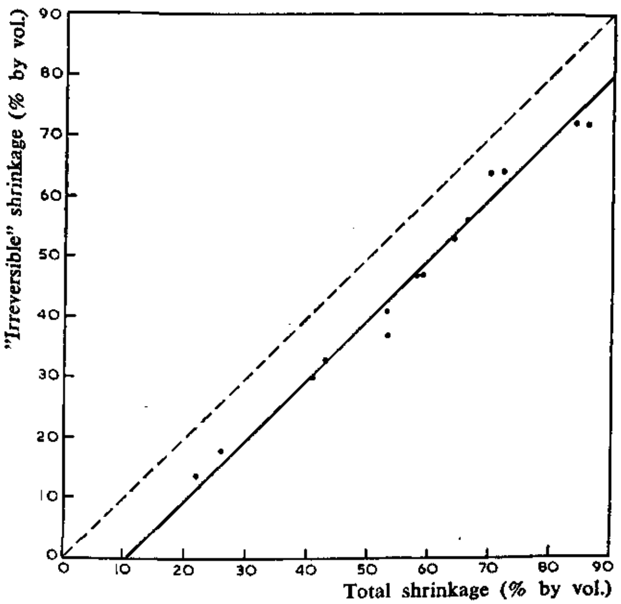


FIG. 7
Relation between total and "irreversible" shrinkage

mon opinion that shrinkage in the first stage of drying is completely reversible, is confirmed here (at x = 11, y = 0). (The percentage of reswelling is not a constant value for all samples. With another sample of the same type of peat a reswelling of 13 % of the original volume was found for dry peat which had not been frozen and one of 22 % for dry, previously frozen peat.

3.3. Optimal conditions for the effect of freezing

Information about the effect of different duration of freezing, different times of freezing and thawing and different temperatures is given in TABLE 3. As reported, these and further determinations were carried out with peat disks made from two bulk samples of "black peat" (moisture content 88.2 %).

TABLE 3. The effect of duration of freezing, repeated freezing/thawing and temperature on shrinkage and reabsorption of moisture by air-dried peat

No. of freezings x duration (days)	Temperature (°C)	Total shrinkage (% by vol.)	Moisture uptake [1]	"Irreversible" shrinkage (% by vol.)
0	—	79	146	66
1 x 1	—5	62	319	45
1 x 2	—5	60	323	42
1 x 3	—5	58	371	35
1 x 5	—5	54	370	34
1 x 7	—5	54	374	33
1 x 10	—5	58	372	40
1 x 5	—5	54	370	34
2 x 5	—5	53	374	37
3 x 5	—5	50	379	35
4 x 5	—5	50	405	31
1 x 5	—5	54	370	34
1 x 5	—7	48	418	30
1 x 5	—9	52	443	33
1 x 5	—11	49	462	29

[1] in g/100 g of dry peat in 200 hrs at pF 0,4

Judging from the values given in TABLE 3 the main effect of freezing at a temperature of — 5° C is reached in about one freezing period of three to five days. Maintaining a temperature of — 5° C for a longer period or repeatedly freezing and thawing has little or no additional effect. So the statement of KRAEMER (1951) that the oftener peat is frozen, the greater the effect is on the structure, was not confirmed here. With peat sods as fabricated in practice, however, a period of 3 days at a temperature of — 5° C may be considered as a minimum. It seems that as the temperature drops lower, the effect of freezing increases, especially where the important property of the re-uptake of water is concerned. In the experiments described below, however, the peat was always kept at — 5° C for 3 days during the freezing period.

Next, experiments were carried out to determine the effect of freezing on shrinkage of peat which is already partly dried up. For these experiments two disks were made of fresh peat and dried to a different extent (and of known volume) and then frozen, thawed and air-dried further, whereafter their volume was measured again. The results are shown in FIG. 8. The dots through which the straight line A is drawn, shows the total shrinkage of the air-dry disks, frozen at the corresponding moisture content, to be read from the ordinate. The course of this line A proves, as could be expected,

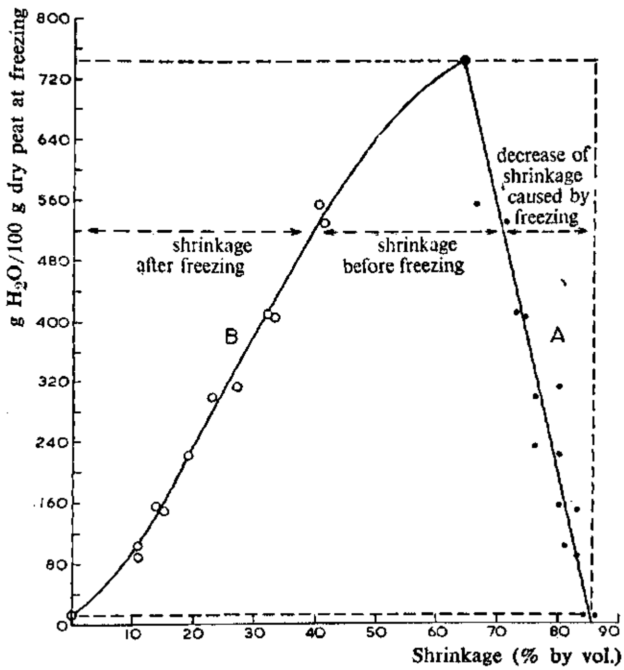
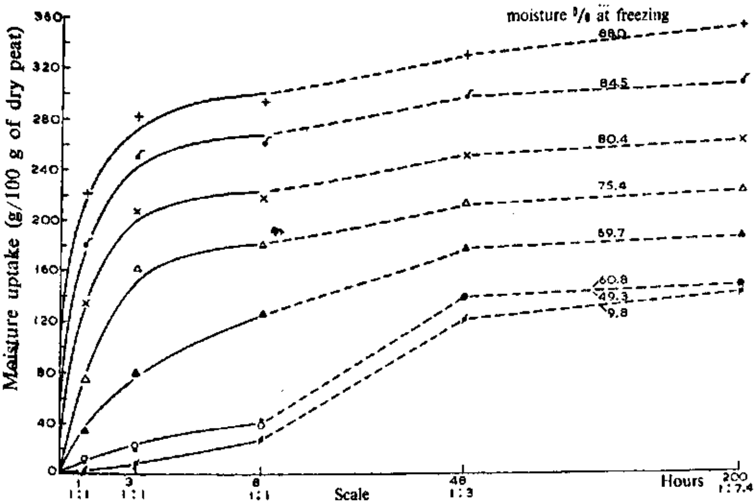


FIG. 8
Shrinkage of peat frozen at various stages of drying

FIG. 9. Rate of moisture uptake of air-dried peat at pF 0.4 in relation to the stage of drying when frozen



that the effect of freezing on shrinkage is greater when the peat is least dried up before freezing. The open dots through which curve B is drawn, give the shrinkage of the various peat disks after freezing at the corresponding moisture contents. So A and B divide the rectangular space enclosed by ordinate and dotted lines in three parts as is described in the figure.

Finally the air-dry peat disks of the last experiment were placed on the pF 0.4 box to determine the rate and the quantity of the re-uptake of water. FIG. 9 clearly shows that both, quantity and rate, depend on the moisture content of peat at the moment of freezing insofar as this moisture content is higher than 60 % (150 g water per 100 g of dry peat). When the peat is dried, however, until the moisture content is 60 % or lower, freezing no longer has any significant effect on rate or quantity of water uptake, but there is still an effect on shrinkage.

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