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WATER RETENTION ABILITY AND MOISTURE TENSION (*pF*) OCCURRING AT FIELD WATER CAPACITY IN ARTIFICIAL HOMOGENEOUS PROFILES OF SEVERAL POLISH SOILS

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INTRODUCTION AND REVIEW OF LITERATURE

When determining field water capacity of some soils in field conditions in 1961 and 1962, and comparing the results obtained with those calculated from moisture tension determinations in samples of the same soils in the laboratory, a wide divergence was found in the results [1, 2]. In the literature available at the time field water capacity was reported to occur at a moisture tension of about 1/3 Atm., which strictly corresponds to a water head of 345 cm. i. e. to a *pF* value of 2.54 [8, 9]. With a view to elucidating these controversial results, investigations in greater detail were undertaken which, to achieve high precision and reproducibility of results, were carried out on artificial homogeneous soil profiles. It only became known later that also other authors dealing with this problem experimentally found that the field capacity of soils occurs at a much lower moisture tension of about pF 2 [7].

Trials to elaborate the water characteristics of the soil — a complex and variable factor — have been also undertaken by way of theoretical considerations and verifying experiments [3].

As regards water retention in the soil profile, theoretical calculations and their experimental corroboration were given by Childs in 1962 [3]. In order to confirm the correctness of the theoretical premisses, porous substances of accurately known capillary size were used [11]. In the same year Panfiłok [6] publishing his data of the optimum moisture conditions for wheat production claimed that, 10 days after saturation of the soil with water (at what he called moisture of capillary chain rupture) the moisture stabilizes in the soil profile, changing no more in the next 10—20 days. In the present investigations, the results of which are reported below, the longest period after which the water retained in the profile was determined was 10 days.

AUTHORS OWN INVESTIGATIONS

The studies were performed in the period 1962—1963 in the Department of General Soil and Plant Cultivation, Warsaw Agricultural University, on soil from the Experimental Agricultural Station in Chylice. The following four soils were inwestigated:

1. arable layer of black soil,
2. light loam underlying the black soil,
3. light sandy-loam from the arable layer of podsol,
4. loose sand on sandy-loamy subsoil.

After sieving the soil through a 2 mm. mesh and thorough mixing, a homogeneous material was obtained from which 140 cm. high artificial profiles were prepared in plexiglass tubes. Care was taken to maintain, as far as possible, a uniform texture of the entire profile. For each soil 3—4 replicas of the profile were made. The soil in the profiles was saturated with water for 2—3 days by means of a dosing device, so that water would not stand on the profile surface. This procedure allowed to saturate the whole profile accurately, and at the same time prevented air bubbles from remaining in the pores. The water permeating, partly or all, through the profile, was drained off at the bottom. After saturating the profiles, the surface was protected from evaporation, and they were left to stand for a definite period to let the free water drain off.

In one group of experiments, a water table was maintained at a depth of 140 cm in the profiles, and 2, 3 and 4 days were assumed as a time sufficient for draining of the excess water.

In the second group of experiments, instead of the water table, a metal mesh constituted the bottom of the profile. For draining of the excess water, the profiles were left to stand for 3—10 days, then they were divided into 10-cm. layers and in each of these the water content and the specific volume weight of the soil were determined.

Parallelly the moisture tension of the soil (*pF*) was determined in soil with a texture as that in the respective profiles at a pressure of 0.01, 0.03, 0.1, 0.3, 1, 2, 10 and 16 Atm. Some physical and chemical properties of the soils used for the artificial profiles, which might influence the moisture conditions, were also determined: specific weight (pycnometrically) index of water permeability (according to Polish Standard. PN-55/B-04492), percentual content of humus (Tiurin's method), and mechanical composition (Bouyoucos method in Casagrande's and Prószyński's modification).

The results of these determinations are compiled in Tabs. 1 and 2.

It is seen from the data in these tables that the soils used for the artificial profiles differ widely from one another. These differing types of soil were selected purposely in order to study on them the problem of water retention and the moisture tension in the profile at the water field capacity (after 3 days) and somewhat later (10 days).

Table 1

Some physical and chemical properties of the soils under investigation

Soil	Specific weight	Index of permeability to water in cu.cm. in the conditions of the profile	Indes of permeability to water in cu.cm./min. with load of 0.4 kg./sq.cm.	Humus %
Black soil	2.61	0.160	0.015	1.70
Light loam	2.63	0.046	0.006	0.26
Light sandy-loam	2.65	0.240	0.048	0.80
Loose sand	2.68	0.660	0.255	0.07

Table 2

Mechanical composition of soils under investigation

Soil		Soil fractions %	Percentual content of soil fractions (diameter in mm.)								Total percentage of soil fractions (diameter in mm.)		
			1-0.5	0.5-0.25	0.25-0.1	0.1-0.05	0.05-0.02	0.02-0.006	0.006-0.002	<0.002	1-0.1	0.1-0.02	0.02
Black soil	2.70	97.30	13.7	21.6	24.2	7.5	8.5	8.0	4.5	12.0	59.5	16.0	24.5
Light loam	3.95	96.05	10.0	21.4	25.1	10.5	7.5	7.0	4.5	14.0	56.5	18.0	25.5
Light sandy-loam	1.13	98.87	17.7	26.3	34.0	10.0	3.5	2.5	3.5	2.5	78.0	13.5	8.5
Loose sand	1.48	98.52	19.3	32.6	37.1	5.5	1.0	1.0	2.0	1.5	89.0	6.5	4.5

The retention forces in the particular soils (artificial profiles) were determined in laboratory conditions on ceramic plates and membranes. The results of the determinations are represented by the pF curves in Fig. 1.

As seen from the graph, there are rather wide differences in the water-retention ability between the particular soils. Loose sand retained the smallest amount of water (both available and nonavailable), light sandy-loam had o somewhat higher retention ability, whereas black soil and light loam exhibited a much higher content of water retained. As regards the last named two types of soil, black soil retained more water up to *pF* 2, and above this value the reverse occured.

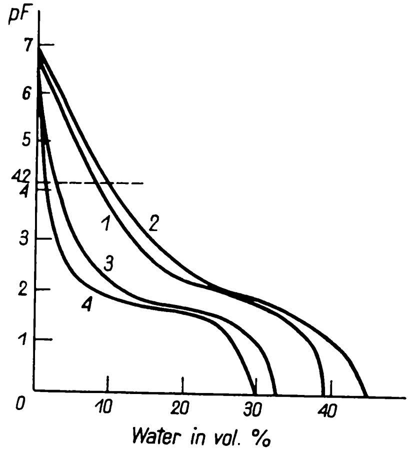

Fig. 1. *pF* curves and porosity of the four soils studied:

1 — black soil, 2 — light loam, 3 — light sandy loam, 4 — loose sand

Soil	Capillary porosity			Non capillary porosity	Total porosity
	large pores >10 μ	medium pores 10-0.2 μ	small pores <0.2 μ		
Black soil	27.2	8.8	8.5	6.5	51
Light loam	18.7	10.6	9.7	12.0	51
Light sandy loam	21.7	8.0	3.3	7.0	40
Loose sand	22.3	6.2	1.5	7.0	37

The moisture relations in the artificial profiles of the soils under study formed in various time periods after saturation with water and in dependence on the presence or absence of a water table are illustrated by Fig. 2. This Graph shows the percent by volume of water nonavailable to plants in the 20-cm. layers of the profile, the total amount of water retained at various times after saturation (including field capacity), the capillary and total capacity, the contribution of the solid phase and the moisture tension expressed as a pF value at various times after saturation of the profile.

It results from the graphically presented data (Fig. 2) that the soil material had, at various depths, a uniform texture. The contribution of the solid phase in black soil was 49, in light loam 49, in light sandy-loam

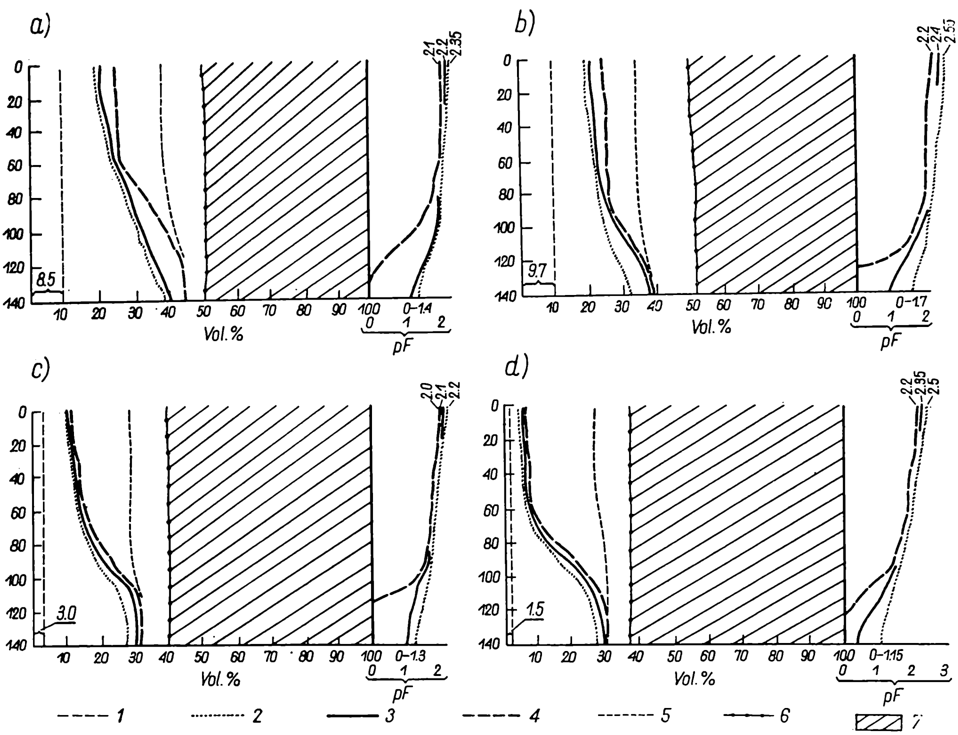

Fig. 2. Moisture relations in the four soils studied: *a* — black soil, *b* — light loam, *c* — light sondy-loam, *d* — loose sand

1 — nonavailable water, *2* — water retained after 10 days in profile without water table expressed in vol. % and as *pF* value, *3* — water retained after 3 days in profile without water table expressed in vol. % and as *pF* value, *4* — water retained after 3 days in profile with water table at depth of 140 cm. expressed in vol. % and as *pF* value, *5* — capillary porosity, *6* — total porosity, *7* — constant soil phase

60 and in loose sand 63 per cent. However, the ratio of capillary to noncapillary porosity was somewhat changed. In the lower layer of the profile, as seems to result from the graph, capillary porosity increased at the cost of noncapillary porosity. This was most probably caused by a partial shift of soil particles during filtration after saturation of the profile with water, and by a reorientation of soil particles which did not give any corresponding change in the specific volume weight of the soil.

The soils differed widely in the quantity of water retained (available and nonavailable). If the particular soils are considered, the conclusion may be advanced that, in dependence on the time elapsed after saturation and the presence or absence of the water table, wider differences occurred in heavier soils than in light ones.

The moisture pattern at various depths of the profile was also characteristic. Depending on the type of soil it slightly increased to a depth of 60—90 cm., wheres in the deeper layers it rose steeply reaching at the water table the full capillary capacity. The fact that the absence of the water table and a longer time period elapsing after complete saturation did not radically change these conditions, may be ascribed to the water-holding forces in the profile. These forces seem to be stronger in the deeper soil layers (below 70—90 cm.), since the quantity of water retained here is greater. It is possible that this is caused by a lack of direct connection between the larger capillaries (over 8 μ in diameter), and consequently, to the occurrence of additional tension (moisture tension) due to the water bound by stronger forces in the medium capillaries (8—0.2 μ) which interconnect the large ones.

This phenomenon also allows the supposition that the presence of a water table in the soil should be ascribed not only to the impermeability of the substrate but also to the retention forces in the deeper soil layers in which, as the present studies seem to indicate, even as late as after 10 days the content of water retained in the layers below 120—130 cm. was close to capillary capacity (even in profiles without water table and in soil with a relatively loose texture). The confirmation of this hypothesis requires, however further investigations.

The second object of the investigations performed on the artificial profiles was to establish to what pF values does "field water capacity" correspond, and what are the relations governing this problem not only in the surface but in the deeper situated layers. The pF value most frequently reported in the literature is 2.54 [11], though some authors characterise also the soil water properties at pF 2 [4, 5].

The measurements of field capacity effected by us in field conditions differed widely from this value. The soil moisture at field capacity was higher than that at *pF* 2.54 indicating that either the subsoil must be impermeable or else the calculated value is too high.

This was confirmed by the determinations carried out in the artificial profiles (Fig. 2), from which it results that at "field capacity" the pF value is lower, and that it is not a constant value. Namely, depending on the type of soil and the presence or absence of the water table, the following values were obtained for the pF value in the upper layers of the profile:

— after 3 days in profiles with water table at a 140 cm. depth 2.0—2.2,
— after 3 days in profiles without water table 2.1—2.4,
— after 10 days in profiles without water table 2.2—2.55.

The *pF* value characterising the water retained decreased with depth, at first slightly to 70—90 cm and further with increasing depth, of course, much more rapidly reaching, after 3 days in profiles with a water table, a zero value, whereas in those where the water table was absent *pF* = = 0.5—1.2. Even after 10 days its value was still 1.15 to 1.7.

It should be stressed that, in the artificial profiles, the soil texture was rather loose and easily permeable to water. It is therefore probable that, when the texture is more compact and the permeability reduced, as is most frequently the case in a natural field profile, the water content at field capacity may be higher, thus the pF value lower both in the upper and lower layers of the profile. This of course does not refer to the arable layer in which the texture as well as the water condictions are more changeable.

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WASSERHALTEVERMÖGEN UND BODENSAUGKRAFT (*pF*-WERTE) BEI DER FELDKAPAZITÄT IN KÜNSTLICHEN PROFILEN EINIGER POLNISCHEN BÖDEN

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Zusammenfassung

Zu den in 1961—1963 durchgeführten Untersuchungen wurden 4 verschiedene Böden herangezogen, aus welchen man künstliche, 140 cm hohe, und aus einheitlichem Material gebildete Bodenprofile hergestellt hatte. Die Profilen wurden mit

Wasser gesättigt, vor oberflüchlicher Verdunstung geschützt und zur Absickerung des übermässigen Wassers für verschiedene Zeitdauer (2—10 Tage) abgestellt. In einem Teil der Bodenprofile wurde der Wasserspiegel erhalten; im anderen dagegen nicht. Nach einer gewissen Zeit wurde die Menge des in verschiedenen Tiefen der Bodenprofile erhaltenen Wassers, bestimmt. Es wurden grosse Unterschiede in der Menge der aufgehaltenen Wassers (des für Pflanzen aufnehmbaren und nicht aufnehmbaren) in Abhängigkeit von der mechanischen Bodenzusammensetzung (leichter Lehm, lehrniger und loser Sand), festgestellt. Der Zeitverlauf nach der Sättigung, wie auch die Anwesenheit oder das Fehlen des Wasserspiegels, übten dagegen einen kleineren Einfluss auf die Veränderungen der Bodenfeuchtigkeit der einzelnen Profilschichten, aus. In den unteren Schichten des Profiles, abgesehen von der Absickerungszeit, war der Wassergehalt gleich oder nahe der vollen kapillaren Wasserkapazität, was zur Annahme führt, dass des Wasserhaltevermögen mit der Tiefe ansteigt. Wahrscheindlich sollte man das Erhalten des Wasserspiegels in natürlichen Bodenprofilen auch auf das Zeitweiligen Wasserhaltevermögen, und nicht nur auf die Verminderung der Permeabilität zurückführen. Es wurde auch festgestellt, dass die Saugkräfte der oberen Bodenschichten bei der Feldkapazität kleiner sind, als der im allgemeinen in der Literatur angegebene *pF*-Wert = 2,54. Aus unseren Untersuchungen ergibt sich, dass in durchschlässigen Boden mit Wasserspiegel in 140 cm Tiefe die *pF*-Werte der Feldkapazität bei 2,0—2,2 und ohne Wasserspiegel bei 2,1—2,4 liegen. In Bodenprofilen ohne Wasserspiegel lagen die *pF*-Werte, erst nach 10 Tagen, zwischen 2,2—2,55. In natürlichen Verhältnissen, bei grösserer Verdichtung des Untergrundes und Verminderung der Durchlössigkeit, kann man annehmen, dass die aufgehaltenen Wassermengen grösser und die Saugkräfte (*pF*-Werte) kleiner sind, als in künstlichen Profilen derselben Böden. Genauere Erklärung dieser Probleme erfordert weiterer Untersuchungen.

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CAPACITÉ DE RETENTION D'EAU ET LE POTENTIEL CAPILLAIRE pF ("FORCE ASPIRANTE") CORRESPONDANT À LA CAPACITÉ DU CHAMP DANS LES PROFILS ARTIFICIELS DE QUELQUES TYPES DE SOL EN POLOGNE

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Résumé

Les essais réalisés en 1961—63, concernent 4 profils artificiels homogènes de 140 cm de profondeur, composés de matériaux provenents de différents sols. Les profils saturés d'eau, protégés contre l'évaporation superficielle, reposaient 2 à 10 jours, afin de permettre l'écoulement du surplus d'eau. Dans certains profils l'on maintenait un niveau d'eau élevé. Après un certains temps on dosa la quantité d'eau rérenue dans les différents horizons du profil. On a constaté que la capacité de rétention d'eau (accesible et non accesible pour les plantes) varie selon la composition granulométrique du sol (argile sableuse, sable faiblement argileux, sable). La durée de saturation ainsi que la présence ou l'absence du niveau d'eau dans le profil avaient une influence moins prononcée sur l'humideté de certaines couches du profil.

Dans les couches plus profondes des profils la teneur en eau était égale ou presque égale à la capacité capillaire. On peut supposer que la capacité des couches profondes augmente avec la profondeur du profil; On a constaté de même les forces de rétention d'eau dans les couches superficielles du sol n'atteignent pas la valeur pF = 2.54, citée en général dans les publications. Nos essais démontrent que la valeur du pF varie de 2,0 à 2,2 pour les sols perméa ables avec le niveau d'eau à la profondeur de 140 cm, tandis que pour les mêmes sols, sans niveau d'eau, cette valeur varie de 2,1 à 2,4. On a constatés dans ces derniers sols, après 10 jours de saturation, la valeur du pF constaté était de 2,2—2,5.

Dans les conditions naturelles et en cas de grande compacité du sous-sol ainsi que d'une perméabilité plus faible que dans les profils artificiels du même sol. Afin d'élucider le problème d'une façon plus poussée, il est indispensable de poursuivre les études entamées.

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ZDOLNOŚĆ MAGAZYNOWANIA WODY ORAZ SIŁY SSĄCE PRZY POJEMNOŚCI POLOWEJ W SZTUCZNYCH PROFILACH KILKU TYPÓW GLEB POLSKICH

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Streszczenie

Do badań prowadzonych w latach 1961—1963 wzięto 4 różne gleby, z których wykonano sztuczne profile glebowe wysokości 140 cm, składające się z jednorodnego materiału. Profile te nasycono wodą i zabezpieczono przed powierzchniowym wyparowywaniem i pozostawiono na różny okres (od 2 do 10 dni) dla odcieknięcia wody. W części profilów utrzymywano lustro wody, w innych nie. Po określonym czasie oznaczono ilości zmagazynowanej wody na różnych głębokościach profilu. Stwierdzono dużą różnicę w ilości zatrzymywanej wody (dostępnej i niedostępnej dla roślin) w zależności od typu gleby. Natomiast różny czas po nasyceniu, jak również obecność lub brak lustra wody wpływały w mniejszym stopniu na zmiany w uwilgoceniu poszczególnych warstw profilu. W dolnych warstwach profilu, bez względu na czas odsiąkania, zawartość wody była równa lub bliska pełnej pojemności kapilarnej, co nasuwa przypuszczenie o zwiększającej się sile utrzymywania wody wraz z głębokością. Jej też prawdopodobnie, a nie tylko zmniejszającej się przepuszczalności, należałoby przypisać utrzymywanie się przejściowego lustra wody w glebach. Stwierdzono również, że siły zatrzymywania wody w górnych warstwach gleby przy wodnej pojemności polowej są mniejsze niż podawana na ogół w literaturze jako wartość pF = 2,54. Z naszych danych wynika, że na glebach przepuszczalnych z lustrem wody na głębokości 140 cm wynoszą one 2,0—2,2, a bez lustra wody 2,1—2,4 pF. Dopiero po 10 dniach w profilach bez lustra wody wilgotność wyrażona współczynnikiem pF wahała się od 2,2 do 2,55. W warunkach naturalnych przy większym stopniu zbitności podłoża i zmniejszonej przepuszczalności ilość magazynowanej wody będzie prawdopodobnie wyższa, a siły jej wiązania wyrażone współczynnikiem pF niższe niż w profilach sztucznych tych gleb. Dokładniejsze jednak wyjaśnienie tego zagadnienia wymaga prowadzenia dalszych badań.

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ВЛАГОУДЕРЖИВАЮЩАЯ СПОСОБНОСТЬ И СОСУЩАЯ СИЛА (*pF*) ПРИ ПОЛЕВОЙ ВЛАГОЕМКОСТИ В ИСКУССТВЕННЫХ ПРОФИЛЯХ НЕСКОЛЬКИХ ПОЛЬСКИХ ПОЧВ

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Резюме

Исследования проведены в 1961—1963 гг. на четырех насыпных колоннах их разных типов почв. Высота профиля, состоящего из однородного материала 140 см. Профили эти пропитывали водой, затем защищали от поверхностного испарения и оставляли на различный срок (от 2 до 10 дней) для стекания избытка воды. В одних профилях поддерживали зеркало грунтовой воды на глубине 140 см, другие находились в условиях свободного оттока. После определенного времени обозначели содержание воды в различных горизонтах профиля. Установлены большие разницы в количестве удерживаемой воды (доступной и недоступной для растений) в зависимости от механического состава почвы. Период стекания, а также наличие или отсутствие уровня грунтовой воды в меньшей степени влияли на изменение увлажненности в отделных горизонтах профиля. В нижних слоях профиля, независимо от периода стекания, содержание воды было равно или близко полной капилярной влагоемкости. Это позволяет предполагать, что влагоудерживающая сила увеличивается с глубиной. Предполагается, что сила эта, а не только уменьшающаяся проницаемость, обуславливает удерживание зеркала грунтовой воды в почвах.

Установлено также, что влагоудерживающая сила верхних слоев почвы при полевой влагоемкости меньше, чем это обычно указывается в литературных источниках (величина $pF =$ 2,54).

Из наших данных следует, что на водопроницаемых почвах с зеркалом грунтовой воды на глубине 140 см величина pF составляет 2,0 до 2,2, а без уровня грунтовой воды — 2,1 до 2,4. Только после 10 дневного периода в профилях со свободным оттоком воды, коэффициент pF колебался в пределах 2,2 до 2,55.

В естественных условиях, при более плотной подстилающей породе и меньшей водопроницаемости, количество — задерживаемой воды повидимому будет выше, а влагоудерживающия сила почвы, выраженная коэффициентом pF будет ниже, чем в профиле насыпных колонн тех же почв.

Более точное выяснение этого вопроса требует дальнейших исследований.