

DETERMINATION OF WATER RETENTION CHARACTERISTICS OF ORGANIC SOILS, USING THE INDIRECT FILTER–PAPER METHOD

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ABSTRACT

The paper describes the filter-paper method as an indirect method for the estimation of the pF characteristics. In this method, no direct measurements of soil water potential (pF) are performed, but the latter is determined on the basis of the gravimetric moisture content of the filter paper, which is in contact with the analysed soil samples. Therefore, there is a need to establish a calibration equation that would express the relationship between the value of the soil water potential (pF) and the gravimetric moisture content of the filter paper. The calibration procedure was performed using standard measurement methods of determining pF curves (sand box, pressure plates) and filter paper (Whatman no 42). Based on the research conducted, calibration curves were developed for the filter-paper method, for the analysed sapric (drainic) histosoles, developed from moss and alder peats of medium (hemic) and strong (sapric) degree of decomposition, originating from the mid-basin of the Biebrza river. The proposed calibration curves were presented as 3-degree polynomial equations. The aforementioned equations can be used for the estimation of retention characteristic for sapric (drainic) histosoles, showing similar properties and comparable degree of secondary decomposition of the peat mass.

Key words: retention characteristics, pF curve, indirect methods for the determination of pF curve, filter-paper method.

INTRODUCTION

Retention capacity of soils for water storage is described by means of pF curves (water retention curves) that express the relationship between soil suction (pF) and the corresponding moisture content (θ) [Klute 1986, Jury et al. 1991]. This is one of the basic characteristic features describing the ability to retain water in soil. The knowledge of the pF curve is necessary, among other things: for the assessment of current soil moisture and water availability for

plants; for the determination of field water capacity; for the potential (PRU) and effective (ERU) useful retention; for the determination of upper permissible groundwater level; for the determination of irrigation doses; and for the modelling of water flow in the aeration zone. In addition, in the case of organic soils, knowledge of the above characteristics makes it possible to control the changes in soil structure and water availability to plants caused by moorshification and mineralization processes, and to conduct rational water management in the aspect of protecting the

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soils against degradation [Brandyk 1990, Olszta and Zawadzki 1991, Ilnicki 2002, Brandyk et al. 2003, Szatyłowicz et al. 2007, Gnatowski et al. 2008, 2010, Gąsowska et al. 2015, Pokładek et al. 2016, Lipka et al. 2017]. The available methods for determining the water retention curve can be subdivided into laboratory methods, field methods, and intermediate methods. The standard methods for determining the characteristics of water retention curves are laboratory methods in which, in the process of water desorption using a pulverized or dust-kaolin block, a fragment of the pF curve is determined in the range of low values of soil water potential (pF 0–2.7). In the range of high values of soil water potential (pF 3.0–7.0), low-pressure and high-pressure chambers are used instead [Zawadzki 1973, Klute 1986, Mocek et al. 2010].

It is also possible to develop characteristics of water retention curves in natural (field) conditions. In that case, it is required that simultaneous measurements of the soil water potential (tensiometric method) and soil moisture (e.g. TDR method) are conducted in the soil profile at individual depths. In the case of this method of determining the pF curve, there may be some discrepancies in the results compared to the laboratory method, due to the fact that under laboratory conditions these characteristics are developed during desorption of water from soil samples (from full saturation to their gradual drying), while in the natural setting, due to changing meteorological conditions, these curves can be determined in conditions of sorption and desorption of water [Oleszczuk et al. 2000, 2013]. The above methodologies require access to specialized measuring equipment; furthermore, they are also labour-intensive and time-consuming. For these reasons, indirect methods for determining water retention curves have become very popular, consisting in developing statistical equations (usually multiple regression equations) between easily measurable physical parameters and characteristic points of the pF curve determined in laboratory conditions (point models), or description of the pF in its entire range (continuous models). Among examples of point models are the correlations developed, among others by Varaally and Mironienko [1979], and Ślusarczyk [1979], which make it possible to calculate the value of humidity at char-

acteristic values of soil suction, on the basis of grain size distribution and content of organic matter. In the case of continuous models describing the pF curve in the entire range of moisture changes, the multiple regression equations (the so-called pedotransfer function) are often applied, developed by Wösten et al. [1999] for individual pF (θ_s , θ_r , α , n) parameters, which are required in the analytical formula proposed by Van Genuchten [1980].

In recent years, indirect methods have become very popular, and there have been numerous publications that present the characteristics of pF curves as dependent on the basic physical and chemical properties [Wösten et al. 1999, Gnatowski et al. 2006, Hewelke et al. 2015, 2017, 2018].

One of the indirect methods for determining the pF curves is the filter-paper method [Bulut and Leong 2008]. In this method, no direct measurements of soil water potential (pF) are made, but the latter is determined on the basis of the weight humidity of the filter paper discs adjacent to the soil samples being tested. Therefore, in this method there is a need to develop, or adapt from the available literature, a calibration equation that would express the relationship between the value of the soil water potential (pF) and the moisture content of the filter paper. The soil sample, together with the filter paper placed on its lower and upper surface, is locked in an airtight container. It remains therein until the moisture balance between the soil sample and the filter paper is reached, which usually takes between a few to about a dozen days. The method is relatively simple; nevertheless, it still requires certain strictly defined conditions, which are presented in the next section. For mineral soils, calibration equations for this method were proposed by McQueen and Miller [1968], Al-Khafaf and Hanks [1974], Hamblin [1981], Chandler and Gutierrez [1986], Deka et al. [1995], Ophori and Maharjan [2000], Bulut and Leong [2008], Chaves et al. [2013], Leong et al. [2016] and Kim et al. [2016], whereas for peat soils, the proposal for the calibration equation was presented by Griffith et al. [1991]. These are usually equations describing two straight lines, developed for a range of low and high suction pressures.

The aim of the present work was to present and explain the filter-paper method, and to develop calibration

equations that would facilitate the determination of the soil water potential (pF) value based on the weight humidity (W) of the filter paper for organic objects.

RESEARCH MATERIAL AND METHODS

Calibration curves for the filter-paper method were developed on soil samples taken from two profiles of organic moorsh soils [Systematyka... 2011] from two sites: “Kwaterna 17” and “Wykowo”, located on the Kuwasy peat bog in the mid-basin of the Biebrza River (in Podlasie region of Poland) [Hewelke et al. 2014].

The basic properties of soil samples taken at various depths (see: Table 1) were determined using standard methods [Maciak and Liwski 1996, Sapek and Sapek 1997]. The studied soils are characterized by medium (Lodging 17 – MtlIbb) and strong (Wykowo – Mtl-IIcb) degree of advancement of the moorshification process. The type of peat material (fibric, hemic, or sapric) was determined according to the Systematics of Soils of Poland [Systematyka... 2011], while the types of moorsh (peat Z1, humic Z2, granular Z3) were determined according to the classification proposed by Okruszko [1976].

Table 1. Selected properties for the analysed organic soil materials in “Kwaterna 17” and “Wykowo” sites

Tabela 1. Wybrane właściwości fizyczne utworów organicznych na obiektach „Kwaterna 17” i „Wykowo” i ich klasyfikacja.

Layer Warstwa cm	Ash content, % a.d.m. Popielność, % a.s.m.	Bulk density Gęstość objętościowa gleby, $g \cdot cm^{-3}$	Total porosity, % vol. Porowatość ogólna, % obj.	Type of peat [Systematyka... 2011] or moorsh formation [Okruszko 1976] Rodzaj materiału torfowego [Systematyka... 2011] lub murszu [Okruszko 1976]
“Kwaterna 17” site (MtlIbb)				
0–10	13.41	0.238	85.30	humic moorsh mursz próchniczny Z2
20–30	13.22	0.198	87.73	moss peat, hemic torf mechowiskowy, hemic
40–50	14.23	0.135	91.69	alder peat, hemic torf olesowy, hemic
“Wykowo” site (MtlIIcb)				
0–10	16.00	0.338	79.5	grainy moorsh mursz ziarnisty Z3
10–20	15.30	0.270	83.7	humic moorsh mursz próchniczny Z2
40–50	11.80	0.156	90.2	alder peat, sapric torf olesowy, sapric

Source: own study – Źródło: wyniki własne.

The temperature of the room, in which the water retention measurements are carried out using the filter-paper method should remain in the range of $+20 \pm 3^\circ C$. The temperature fluctuations during the test should not exceed $\pm 0.01^\circ C$ in order to avoid condensation when the soil contacts the filter paper. For this purpose, the sealed samples were additional-

ly placed in a well-insulated container. The temperature and relative humidity of the surroundings have an impact on the loss of water contained in the paper during its transfer from the container with the soil in order to be weighed. This operation must therefore be carried out within 3–5 seconds (a 5–10 second exposure of the paper in a room with 30–50% rela-

tive humidity causes 5% or more of the weight loss by evaporation). The most important problem of this method is to determine the time it takes to balance the suction of the filter paper and the soil being tested, which on average should be 7 days. However, in many cases the balance is reached much earlier than that. When the water from the soil reaches equilibrium with the water absorbed by the filter paper, the weight of the filter paper mass and its weight humidity (W) are measured, and then, having the calibration equation ($pF = f(W)$), the value of soil water potential (h) is determined for the given value of the volume moisture of the soil sample.

For laboratory tests, soil samples were collected from characteristic intact layers, and placed in 68 cm³ cylinders (three replicates). The samples were brought to full saturation, and then placed on a dust block [Zawadzki 1973, Klute 1986], in order to determine the equilibrium at suction pressure of $pF = 1.0$, that is, 10 cm of H₂O. Having reached that specific state, and determining their mass, the three samples from the same depth were placed vertically one on top of another, while three Whatman no. 42 filter-paper discs were inserted in-between them. Two outer discs protect the middle disc from soil deposition, which might distort the weight moisture readings of the centre disc. Thus prepared, the sets of soil samples were wrapped in foil, and placed in a container in an air-conditioned room with a constant temperature of 20°C for a period of 7 days. After this time, each of the middle filter-paper discs was weighed (within 3–5 s) on the scale on which a lidded glass container was placed. Subsequently, the paper discs were dried at 105°C to a constant weight in order to determine their weight moisture. Whenever the paper was removed, the soil moisture content of the soil sample was also determined (according to the same procedure), which was then converted into volume moisture. Identical process was performed when setting the next values of soil water potential, that is the pF of: 1.5, 1.8, 2.0, 2.7, 3.0, and 4.2, using new filter paper discs for each measurement. Moisture content of soil objects for respective values of soil water potential between $pF = 1.0$ and $pF = 2.0$ was determined on the dust block, whereas for potentials between $pF = 2.7$ and $pF = 4.2$, low-pressure and high-pressure chambers were used [Zawadzki 1973, Klute 1986]. The calibration equations for the

filter-paper method were expressed as the relationship between soil water potential (pF) values and moisture content values of the filter paper (W), and presented in the form of polynomials of the third degree.

The research we have conducted further allowed us to determine the water retention curves for the analysed organic samples, by using standard laboratory methods (dust block, pressure chambers) [Zawadzki 1973], which has been described using the following analytical formula according to Van Genuchten [1980]:

$$\theta(h) = \theta_r + \frac{\theta_s - \theta_r}{(1 + |\alpha h|^n)^m} \quad (1)$$

where:

θ_s – humidity of the fully saturated state, cm³ · cm⁻³,

θ_r – residual moisture, cm³ · cm⁻³,

h – soil water potential, cm,

α , n – shape parameters of the pF curve, cm⁻¹, and (–) respectively,

m – shape parameter of the pF curve calculated from the formula $m = 1 - 1/n$

The fitting of the water retention curves was carried out using the RTEC software [Van Genuchten et al. 1991] for the variant in which the θ_r , α and n values were sought, whereas the value of θ_s was measured in the laboratory conditions.

RESEARCH RESULTS

The determined courses of water retention curves indicate that the retention capacity of organic deposits at all analysed depths from the “Wykowo” site (see: Fig. 1 d, e, and f) are much smaller than in the case of “Kwatera 17” site (see: Fig. 1 a, b, and c). This is additionally confirmed by the values of the parameters describing the pF curves (see: Table 2). The decrease in the retention capacity of peat soils indicates the greater advancement of moorshification and mineralization processes [Okruzsko 1993], which is also reflected in the differences concerning the studied properties of soils between the two sites (see: Table 1).

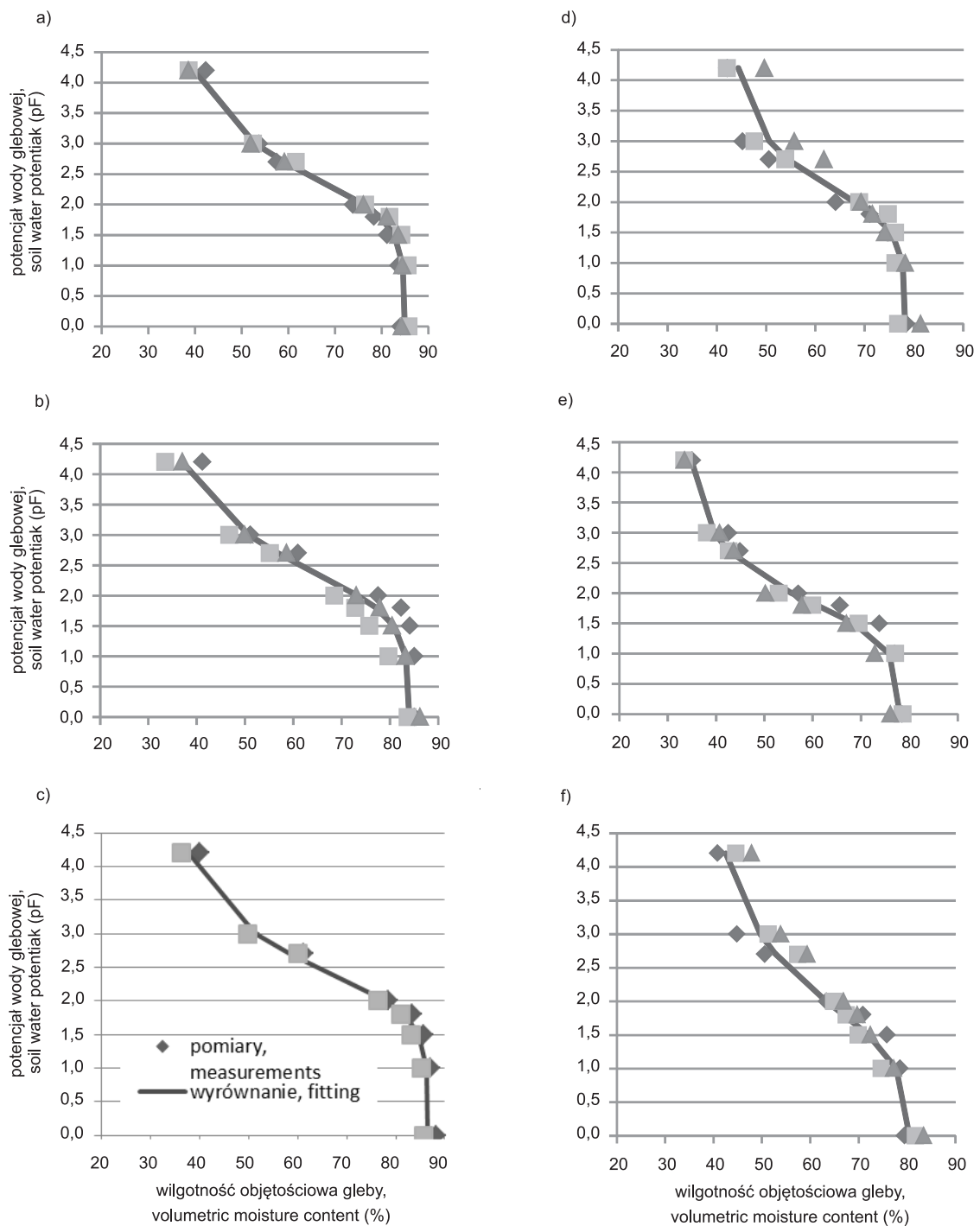


Fig. 1. Measured and fitted pF curves for “Kwaterna 17” site in the layers of: 0–10 cm (a), 20–30 cm (b) and 40–50 cm (c) and for “Wykowo” site in the layers of: 0–10 cm (d), 10–20 cm (e) and 40–50 cm (f). Source: own study

Ryc. 1. Pomierzone i wyrównane krzywe pF dla obiektu Kwaterna 17 w warstwach 0–10 cm (a), 20–30 cm (b) i 40–50 cm (c) oraz dla obiektu Wykowo w warstwach 0–10 cm (d), 10–20 cm (e) oraz 40–50 cm (f), źródło: opracowanie własne

Table 2. The required parameters in van Genuchten [1980] formula, describing pF curves of the analysed organic soil material

Tabela 2. Wymagane w równaniu van Genuchtena [1980] parametry opisujące krzywe pF w badanych utworach organicznych

Parametry – Parameters						
Layer Warstwa cm	θ_s $\text{cm}^3 \cdot \text{cm}^{-3}$	θ_r $\text{cm}^3 \cdot \text{cm}^{-3}$	α cm^{-1}	n	m	R^2
“Kwatera 17” site						
0–10	0.8497	0.3490	0.0088	1.4674	0.3185	0.999
20–30	0.8400	0.2975	0.0112	1.3887	0.2799	0.997
40–50	0.8660	0.3351	0.0075	1.5335	0.3479	0.997
“Wykowo” site						
0–10	0.7822	0.4280	0.0130	1.5861	0.3695	0.997
10–20	0.7803	0.3368	0.0297	1.5908	0.3714	0.995
40–50	0.8058	0.3844	0.0376	1.3192	0.2749	0.994

Source: own study – Źródło: wyniki własne

In the case of the “Kwatera 17” site (see: Fig. 2), the measurement points for sapric (0–10 cm) take slightly higher moisture values of filter paper with the same values of soil water potential (pF) compared to heminic peat, both alder (20–30 cm) and moss (40–50 cm).

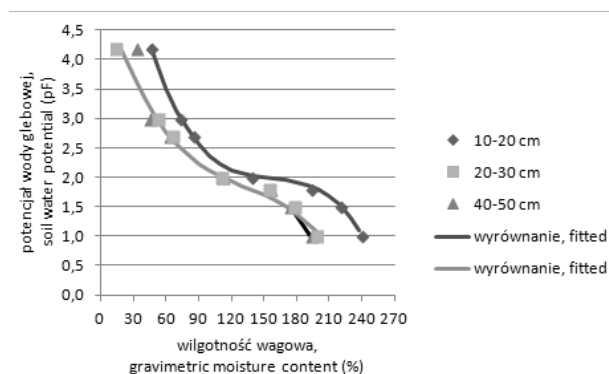


Fig. 2. The calibration curves for the filter paper method for organic soil objects from the “Kwatera 17” site. Source: own study

Ryc. 2. Krzywe kalibracji do metody bibuły filtracyjnej dla utworów organicznych z obiektu Kwatera 17. Źródło: opracowanie własne

This resulted in the need to develop two separate calibration equations, i.e. for sapric (2) and for hepe peat (moss peat and alder peat) (3) in the form of polynomials of the third degree (determination coefficients of $R^2 = 0.999$ and $R^2 = 0.962$, respectively):

$$pF = -1.453 \cdot 10^{-6} \cdot W^3 + 0.000689 \cdot W^2 - 0.1107 \cdot W + 7.99 \quad (2)$$

$$pF = -1 \cdot 10^{-6} \cdot W^3 + 0.0004 \cdot W^2 - 0.0609 \cdot W + 5.2062 \quad (3)$$

where:

pF – value of soil water potential, –,
 W – gravimetric humidity of the filter paper, % of weight.

From the measurement data (see: Fig. 3) it follows that in the case of the “Wykowo” site, it is possible to develop a common calibration equation in the form of a third degree polynomial (4) for all organic species present here, i.e. moorsh and sapric (alder) peat (coefficient of determination $R^2 = 0.966$):

$$pF = -8.336 \cdot 10^{-7} \cdot W^3 + 0.000417 \cdot W^2 - 0.0734 \cdot W + 6.2845 \quad (4)$$

where:

pF – value of soil water potential, –,
 W – gravimetric humidity of the filter paper, % of weight.

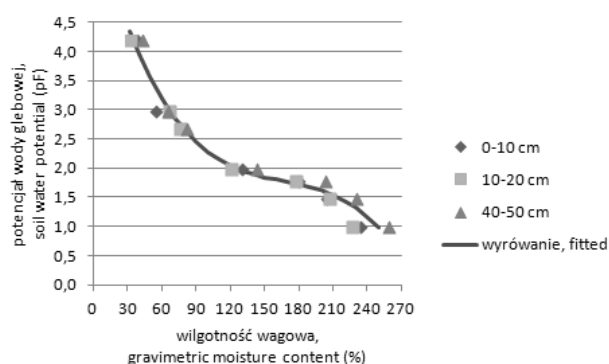


Fig. 3. The calibration curve for the filter-paper method, for organic soil materials from the “Wykowo” site. Source: own study

Ryc. 3. Krzywa kalibracji do metody bibuły filtracyjnej dla utworów organicznych z obiektu Wykowo, źródło: opracowanie własne

CONCLUSIONS

1. The filter-paper method can be used as an indirect method for determining water retention curves of organic moorsh and peat soils.
2. The paper proposes three equations of calibration curves for filter paper: for moorsh and for peat (moss and alder peat), and for saprovar (alder peat).
3. The developed calibration equations for filter paper, presented in the form of polynomial equations of the third degree, describe very well the relationship between suction pressure values in the measuring range of pF between 1.0–4.2, and moisture content of the filter paper, as evidenced by very high values of R^2 determination coefficients.
4. The comparison of parameters required in the Van Genuchten [1980] formula, and the course of water retention curves for moorsh, heme and saprovar peat, confirm the lower retention capacity of moorsh, which was particularly evident in the case of heavily degraded soils at the “Wykowo” site.

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WYZNACZANIE KRZYWYCH RETENCYJNOŚCI WODNEJ GLEB ORGANICZNYCH METODĄ POŚREDNIĄ – BIBUŁY FILTRACYJNEJ

STRESZCZENIE

W pracy przedstawiono jedną z metod pośrednich wyznaczania krzywych retencyjności wodnej jaką jest metoda bibuły filtracyjnej. W metodzie tej nie wykonuje się bezpośrednich pomiarów potencjału wody glebowej (pF), lecz wyznacza się go na podstawie wilgotności wagowej krążków bibuły filtracyjnej przylegającej

do badanych próbek glebowych. Opracowane równania kalibracji wyrażają zależność pomiędzy wartością potencjału wody glebowej (pF) a wilgotnością wagową bibuły filtracyjnej. Kalibrację przeprowadzono przy wykorzystaniu standardowych metod pomiarowych krzywych pF (blok pyłowy, komory ciśnieniowe) oraz bibuły filtracyjnej Whatman no 42. Na podstawie przeprowadzonych badań opracowano równania kalibracji dla metody bibuły filtracyjnej dla gleb organicznych murszowych, wytworzonych z torfów mechowiskowych i olesowych o średnim (hemic) i silnym (sapric) stopniu rozkładu, pochodzących ze środkowego basenu rzeki Biebrzy. Uzyskano równania kalibracji w formie równań wielomianu trzeciego stopnia. Powyższe równania mogą być stosowane dla określania zdolności retencyjnych utworów organicznych, charakteryzujących się podobnymi właściwościami i zbliżonym stopniem rozkładu materii organicznej.

Słowa kluczowe: krzywa retencyjności wodnej, krzywa pF , metody pośrednie do wyznaczania krzywych pF , metoda bibuły filtracyjnej