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WATER BALANCES IN UPPER LAYERS OF POSTMINING SOILS

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ABSTRACT. The paper presents results of field research and observations carried out in the hydrological years 1992/93 to 1997/98 in the inner waste heap of the "Pątnów" open pit, situated in the Kujawskie Lake District (52°20' N, 18°14' E). Field research and observations were conducted in five experimental plots undergoing agricultural land reclamation, with differing agricultural uses and uniform mineral fertilisation. The research results indicate that upper layers of agriculturally reclaimed soils in postmining areas are characterised by differences in grain composition and physical and hydrological properties, which significantly affects water balances in the soils of the area. However, the dominant factor influencing water balances in postmining soils is the type of weather conditions in terms of levels of precipitation and evapotranspiration. They have a decisive effect on water balance in the soils of the area.

Key words: water balance, water retention in soil, agricultural land reclamation, grain composition

Introduction

Intensive mining affects natural environment, especially such a basic element of biotope, as soil (**Boroń** and **Klatka** 1997). Brown coal opencast mining excludes large areas from agricultural and forest use (**Skawina** and **Trafas** 1972). Soils, usually of low quality class, are replaced by outer and inner waste heaps, and discarded opencast workings. Postmining soils are a result of human activity and as such are characterised by significant mixing, even within a small area, of all rocks dominant in the overlayer of the exploited open pit. It results in considerable

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variability in the composition of the upper layer of these soils, both in spatial arrangement, and in their profile, which in turn affects their permeability. Soils in postmining areas are in the initial stage of soil development, when structure and humus formation processes have just been initiated. They are characterised by typically precipitation-retention water economy. In this type of water balance, the main source of water for plants is precipitation, as the ground water table in these areas is located very deep and does not affect the moistening of upper layers of investigated soils (**Szafrański** and **Stachowski** 1998 a, b). Thus, meteorological conditions are a primary factor determining their moisture and available water (**Szafrański** and **Stachowski** 1997 b). The aim of this paper is to establish and analyse water balances in the upper layers of agriculturally land reclaimed soils in the postmining areas.

Methods

Results of field research and observations conducted in the hydrological years 1993/94 to 1997/98 are presented in the study. They were carried out in the Experimental Research Station of the Department of Land Reclamation of the Agricultural University of Poznań, which is located 10 km north of Konin, by the Konin-Bydgoszcz road. Agricultural land reclamation has been conducted there since 1978. Field research and observations are carried out in five experimental plots, 0.14 ha each, with differing agricultural uses: natural plant succession, lucerne, winter rye, green fallow (rye with annual legumes aftercrops) and black fallow. Three experimental plots were established in each area, i.e. one without fertilisation (0 NPK), and two with differing mineral fertiliser doses (1 NPK, 2 NPK). In this study, water balances in upper layers of postmining soils were analysed in detail in five plots with differing agricultural uses and uniform mineral fertilisation, calculated as 160 kg N, 270 kg P_2O_5 and 140 kg K_2O (1 NPK) per 1 ha.

Constant observations and measurements in the experimental site included:

– daily measurements of precipitation with the Hellmann's pluviometer, and during the vegetation season also with the pluviograph, while in the winter season the thickness of snow-cover and ground freezing depth were also measured,

– systematic measurements of soil moisture in five selected soil profiles typical for the experimental plots, which were taken every two weeks during the vegetation season with a neutron probe at the level of 15, 40, 70, and 100 cm in three replications at each level, as well as standardisation measurements before and after the measurements.

Field research and observations in experimental areas involved also some pedology investigations, such as drilling to the depth of 3 m, and soil pits up to 1.5 m deep, in the most typical (representative) site of the examined plots. On the basis of drillings and soil pits, areal coverage of soils with similar profiles was determined for each plot. These profiles, characteristic for the analysed experimental plots, were obtained with the use of the representative method based on intentional selection. Soil profiles established in this way are representative of the investigated plots in 70-80%. Meteorological conditions during the testing period were analysed on the basis of daily precipitation measurements in the university hydrometric station in Konin-Pątnów, and daily measurements of air temperature from the weather station of the Brown Coal Mine "Konin", based in Kleczewo, 20 km from the experimental site. While calculating water balances, measured precipitation was corrected with the application of Jaworski's formula, recommended by **Kędziora** (1995) for the conditions prevailing in the Wielkopolska region.

The calculations of actual evapotranspiration with the use of Penman's formula were done with the "Bilans" software, developed in the Department of Land Improvement and Environmental Development (**Przybyła** and **Fiedler** 1992).

Characteristics of the investigated area

The area under investigation is situated in the southern part of the inner waste heap of the "Pątnów" open pit in the Brown Coal Mine "Konin" (latitude 52°20' N, longitude 18°14' E). The analysed area of the inner waste heap of the "Pątnów" open pit is located in the Wielkopolska region, in the subprovince 315, within the mesoregion of the Kujawskie Lake District 315.57. The waste heap where the experiments took place is planated with the datums of the surrounding area and belongs to the waste heaps with their plateau adjusted to the level of adjacent areas. Upper layers of the inner waste heap of the "Pątnów" open pit are composed of all the rocks present in the overlayer mixed together. Individual rocks are mixed and distributed in the soil mass of the investigated part of the waste heap in a completely random way. In terms of individual lithological deposits in the total soil mass, the examined area of the inner waste heap is similar to other waste heaps in the Konińskie Coal Basin.

Detailed pedological investigations showed that analysed areas exhibit a wide differentiation in the grain composition and basic physical and chemical properties (**Szafrański** and **Stachowski** 1997 a). Surfaces with good, worse and even poor quality soil substrates are created in a random way. It results from a completely accidental and random mixing of these soils in terms of their spatial arrangement and profile. Grain composition is diversified, especially in the upper 1 m deep layer of analysed experimental surfaces (Fig. 1). In the experimental areas no. 1 (natural plant succession), and no. 2 (lucerne), deposits with sandy grain composition with the insertion of compact deposits are dominant. Firm loamy sands, coming from the Tertiary and Quaternary sands present in the overlayer, prevail in the upper layer up to 1 m deep. However, in the deposits lying below the upper layer it is

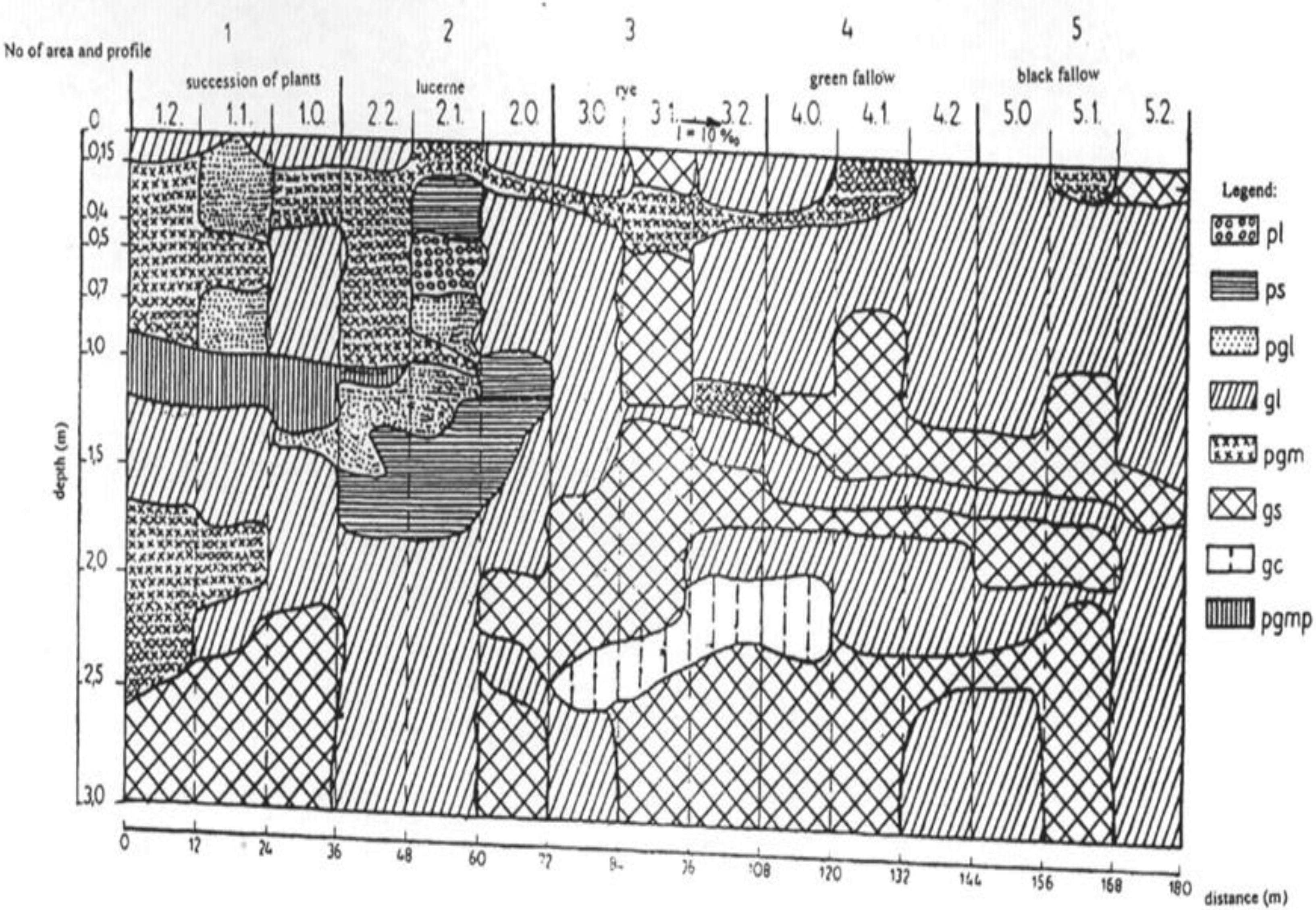

Fig. 1. Pedogenetical section of investigated experimental areas: pl – loose sand, ps – coarse sand, pgl – light medium sand, pgm – heavy medium sand, pgmp – heavy medium silty sand, gl – light loam, gs – medium loam, gc – heavy loam

Ryc. 1. Podłużny przekrój pedogenetyczny badanych powierzchni doświadczalnych: pl – piasek luźny, ps – piasek słabogliniasty, pgl – piasek gliniasty lekki, pgm – piasek gliniasty mocny, pgmp – piasek gliniasty mocny pylasty, gl – glina lekka, gs – glina średnia, gc – glina ciężka light and medium clays that are most common, with alternating deposits of sandy grain composition. Completely different deposits are found in the upper layer of the waste heap in the experimental plots with winter rye (no. 3), green fallow (no. 4), and black fallow (no. 5). As pedological tests indicate, in those areas the dominant deposits are light, medium and heavy clays with small inclusions of firm loamy sands. Upper layers of investigated soil profiles are most often composed of firm loamy sands and light clays. However, even within one surface, 36 m × 40 m in dimension, a wide differentiation in grain composition of individual soil profiles was found (Fig. 1). Such a diversification of grain composition, as well as physical and chemical properties of examined plots, resulted in differences in hydrological properties of the studied profiles of postmining soils.

The level of retention corresponding to soil field capacity (RPPW) is the lowest in the investigated profiles of postmining soils with the lighter grain composition (profiles with the natural plant succession and lucerne). In the other profiles, those with winter rye (3.1), green fallow (4.1) and black fallow (5.1), the level of retention at PPW is higher. At the same time, the content of available water (WOD) in the analysed soil profiles of postmining areas varied considerably. Profiles consisting of poor loamy sands and firm loamy sands were capable of holding the smallest amount of available water WOD in the layer of 1 m depth. Such profiles are typical for areas with the natural plant succession and those with lucerne growing (1.1 and 2.1). Average generally available water WOD content in these profiles in the 1 m layer is 150 mm, which according to Ridder (**Kędziora** 1995), enables us to rate them as moderately retentive. However, the other analysed profiles, composed of soils with a heavier grain composition, exhibit a bigger capacity of storing water available for plants. Such profiles may be considered advantageous from the point of view of water retention. The conducted experiments also showed differences in the content of water easily available for plants (WŁD). Field tests indicated as well some significant differences in the permeability of upper layers of investigated profiles of postmining soils, which were undergoing the process of agricultural land reclamation. Considerably smaller infiltration capacities were found in profiles typical for reclaimed plots with winter rye, as well as green and black fallows (3.1, 4.1, and 5.1). In these plots, composed primarily of light and heavy clays, infiltration coefficient in the 0-30 cm layer was on average 1.6 $cm \cdot h^{-1}$, whereas for plots 1.1 and 2.1 it ranged from 8.3 to 10.8 $cm \cdot h^{-1}$. Values a few times lower were obtained in the 30-60 cm layer of the examined postmining soils. The rate of percolation of water into the ground is higher also in profiles with a lighter grain composition (profiles with natural plant succession and lucerne), and averages approximately 1.45 $cm \cdot h^{-1}$. However, the measured percolation coefficients in the remaining analysed profiles were approx. 0.34 $cm \cdot h^{-1}$.

Results and discussion

In order to perform proper balancing of water resources for soils in postmining areas, in which a typical precipitation-retention water economy is found, it is necessary to determine individual elements of water balance. Similarly to mineral soils, also in this case soil cover forming the upper layer of the investigated waste heap affects significantly water cycles. It may have a considerable impact on infiltration and precipitation water runoff, on the percolation of water into the profile, on water retention in the aeration zone and on the flow of water in various directions.

Table 1 presents the results of calculations for individual elements of water balance for a layer of soil 100 cm deep in the experimental plots for four selected vegetation seasons. Based on these seasons, each with different precipitation totals, air temperatures and soil moisture values, it is possible to see how the elements of water balance for postmining soils tend to fluctuate. It results from the analysis of data presented in Table 1 that in water balances for these areas precipitation and actual evapotranspiration play a crucial role. These factors determine changes in soil retention in examined periods of time.

In the vegetation season 1994, which may be described as dry due to the prevailing weather conditions, the role of capillary conduction was also marked in the water balance for the 100 cm layer of soil. In individual plots its value ranged from 24 mm (plot 1.1) to 54 mm (plot 5.1). The mean value of capillary conduction in analysed soil profiles was 36 mm, which constituted 12% of precipitation total in that period. Upper layers of postmining soils were supplied by capillary conduction of perched ground water accumulating at various depths from the surface of the waste heap. It was found in impermeable layers composed primarily of medium and heavy clays with insertions of the Poznań type silt, which was confirmed by field research. Perched ground water table appeared periodically when high precipitation totals were observed, and disappeared in precipitation-free periods. In the dry vegetation season of 1994, a reduction in the reserves of moisture in the upper layers of postmining soil was recorded. The smallest water storage was observed in the soil profiles with a lighter grain composition, characteristic for experimental areas with lucerne (no. 2) and natural plant succession (no. 1). It ranged from 46 mm (profile 2.1) to 59 mm (profile 1.1) (Tab. 2). Moistening in these profiles fell below the level of moisture corresponding to water easily available for plants. In that case plants were forced to use the storage of water available with difficulty. However, in the profiles composed of light and medium clay, with winter rye (profile 3.1), green fallow (profile 4.1) and black fallow (profile 5.1), the minimum water storage was bigger and ranged from 97 mm (profile 3.1) to 106 mm (profile 5.1). Definitely the most significant moisture depletion in the 1994 vegetation season and the longest periods of water shortage (from 60 to 101 days) were observed in profiles with limited retention capacities (profiles 1.1 and 2.1) (Tab. 2).

Table 1

Water balance in 100 cm soil layer of experimental plots in dry, average, medium-wet and wet vegetation periods
Bilans wodny 100-centymetrowej warstwy poletek doświadczalnych w suchym, średnim, średnio mokrym i mokrym okresie wegetacyjnym

Balance period Okres bilansowy	No. plot (profile) Numer poletka (profilu)	Use Użytkowanie	Ps (mm)	ETr (mm)	ΔR (mm)	H (mm)	Pk (mm)
1.04-30.09	1.1	succession of plants – sukcesja naturalna	301	345	−20		24
1994	2.1	alfalfa – lucerna	301	351	−16		34
dry	3.1	winter rye – żyto ozime	301	360	−28		31
suchy	4.1	green fallow – ugór zielony	301	354	−15		38
	5.1	black fallow – czarny ugór	301	333	−10		54
1.04-28.09	1.1	succession of plants – sukcesja naturalna	393	339	8	46	
1995	2.1	alfalfa – lucerna	393	348	5	40	
medium	3.1	winter rye – żyto ozime	393	353	36	4	
średni	4.1	green fallow – ugór zielony	393	341	44	8	
	5.1	black fallow – czarny ugór	393	330	22	11	
1.04-23.09	1.1	succession of plants – sukcesja naturalna	460	382	−78	156	
1997	2.1	alfalfa – lucerna	460	384	−66	142	
wet	3.1	winter rye – żyto ozime	460	405	−76	131	
mokry	4.1	green fallow – ugór zielony	460	420	−57	97	
	5.1	black fallow – czarny ugór	460	378	−26	68	
7.04-30.09	1.1	succession of plants – sukcesja naturalna	378	326	−54	106	
1998	2.1	alfalfa – lucerna	378	326	−49	101	
medium-wet	3.1	winter rye – żyto ozime	378	367	−65	76	
średnio mokry	4.1	green fallow – ugór zielony	378	366	−49	61	
	5.1	black fallow – czarny ugór	378	334	−28	72	

Ps – precipitation, ETr – real evapotranspiration, ΔR – increase of soil water retention, H – outflow, Pk – capillary risc.

Ps – opad skorygowany, ETr – ewapotranspiracja rzeczywista, ΔR – przyrost retencji gruntowej, H – odpływ, Pk – podsiąk kapilarny.

Table 2

Maximum and minimum water contents in layer 0-100 cm and number of days with water deficiencies in vegetation periods of chosen hydrological years

Maksymalne i minimalne zapasy wody w warstwie 0-100 cm oraz liczba dni z niedoborami wody w okresach wegetacyjnych analizowanych lat hydrologicznych

Balance period Okres bilansowy	No. plot (profile) Numer poletka (profilu)	Use Użytkowanie	Water contents – Zapasy wody				Number of days with water deficiency Liczba dni z niedoborami wody
			max. maks. (mm)	%PPW	min. (mm)	%PPW	
1.04-30.09	1.1	succession of plants – sukcesja naturalna	129	65	59	30	60
1994	2.1	alfalfa – lucerna	123	67	46	25	101
dry	3.1	winter rye – żyto ozime	162	65	97	39	56
suchy	4.1	green fallow – ugór zielony	174	69	103	41	—
	5.1	black fallow – czarny ugór	175	70	106	42	—
1.04-28.09	1.1	succession of plants – sukcesja naturalna	159	80	124	62	9
1995	2.1	alfalfa – lucerna	170	92	127	69	—
medium	3.1	winter rye – żyto ozime	200	80	133	53	—
średni	4.1	green fallow – ugór zielony	251	99	171	68	—
	5.1	black fallow – czarny ugór	238	95	177	71	—
1.04-23.09	1.1	succession of plants – sukcesja naturalna	194	97	82	41	58
1997	2.1	alfalfa – lucerna	169	92	99	54	38
wet	3.1	winter rye – żyto ozime	244	98	113	45	15
mokry	4.1	green fallow – ugór zielony	245	97	172	68	—
	5.1	black fallow – czarny ugór	263	105	193	77	—
7.04-30.09	1.1	succession of plants – sukcesja naturalna	150	75	75	38	79
1998	2.1	alfalfa – lucerna	175	95	130	71	—
medium-wet	3.1	winter rye – żyto ozime	215	86	96	38	—
średnio	4.1	green fallow – ugór zielony	225	89	165	65	—
mokry	5.1	black fallow – czarny ugór	258	103	222	89	—

During a typical vegetation season of 1995, precipitation total equalled 393 mm. Actual evapotranspiration reached the values of 330 mm in the plot with black fallow (plot 5.1) to 353 mm in the plot 3.1 with winter rye (Tab. 1). Average value of actual evapotranspiration in the investigated plots was 342 mm, which constituted 87% of precipitation total corrected in that period. It should be noted that the vegetation season of 1995 was characterised by quite uniform distribution of precipitation, as well as air temperature higher than long-period average by 1.4°C. In 1995, a short period of water shortage was also observed in the soil profile characteristic for the natural succession plant cover (profile 1.1). Higher daily precipitation totals in the second half of August and in September resulted in the final water reserves higher by 5 mm (plot 2.1) to 44 mm (plot 4.1) than the reserves in the beginning of the vegetation season. The highest runoff was found in profiles with a lighter grain composition (profiles 1.1 and 2.1), and equalled 46 and 40 mm, respectively. However, in the profiles composed of light and medium clays (profiles 3.1, 4.1, and 5.1), exhibiting bigger retention capacities, the runoff of water to deeper layers was slight and ranged from 4 to 11 mm (Tab. 1).

In the vegetation season of 1997, which due to the precipitation total (460 mm) may be termed wet, the rate of runoff in the water balance for the investigated postmining soils was the biggest. During that period, a highly unfavourable distribution of precipitation was observed, which resulted in both shortages, and surpluses of water in the layer of soil 100 cm deep. The longest lasting water shortages were found in the profile 1.1, corresponding to natural plant succession. The biggest runoffs during the periods of high moistening of that layer were observed in profiles with smaller retention capacities (profiles 1.1, and 2.1). They ranged from 142 mm to 156 mm, which corresponds to 31 and 34%, respectively, of precipitation totals in the vegetation season. In the other investigated profiles, underground runoff was lower and averaged 24% of precipitation in the 1997 vegetation season. Due to lower precipitation totals in August and September of that year, final water reserves in the 100 cm layer of soil were from 26 mm (profile 5.1) to 78 mm (profile 1.1) lower than water reserves in those profiles in the beginning of the vegetation season. The calculated actual evapotranspiration in 1997 ranged from 378 mm for the black fallow plot to 420 mm for the green fallow plot. The mean value of actual evapotranspiration for the analysed experimental plots was 394 mm and constituted 86% of the precipitation total for that period. The highest reserves of water in profiles typical for plots 3.1, 4.1, and 5.1 ranged from 244 mm (profile 3.1) to 263 mm (profile 5.1), which corresponded to 98% and 105% of reserves corresponding to PPW, respectively (Tab. 2). At the same time, in the two remaining profiles, those with a lighter composition and more limited retention capacities, maximum water reserves were lower and ranged from 169 mm (profile 2.1) to 194 mm (profile 1.1).

During the vegetation season of 1998, which due to the precipitation total equal 378 mm may be described as medium wet, the role of runoff in the water balance for the 1 m layer of postmining soils was also noticeable. The highest runoffs were observed for profiles with smaller retention capacities (profiles 1.1

and 2.1), reaching the approximate value of 106 mm, which constituted 28% of the precipitation total in the vegetation season. Values of underground runoff for profiles composed of light and medium clays (profiles 3.1, 4.1, and 5.1) were lower in the 1998 vegetation season in comparison to the profile 1.1 with a lighter grain composition by 30 mm (profile 3.1), 34 mm (profile 5.1), and 45 mm (profile 4.1), respectively. Actual evapotranspiration reached values from 326 mm for the plot with natural plant succession (no. 1.1) and lucerne (no. 2.1) to 367 mm for the plot with winter rye. The mean value of actual evapotranspiration for the investigated plots equalled 345 mm, which constituted 91% of the corrected precipitation total for that period of time. Similarly to the previous wet vegetation season, i.e. 1997, water shortages, lasting 79 days, were observed for profiles with a lighter grain composition (profile 1.1).

Similarly, in the other examined plots with the fertilisation levels of 0 NPK and 2 NPK, the role of individual elements of water balance for the analysed layers of postmining soils was comparable in the testing period. Slight differences, which were observed in comparison to the experimental plots discussed above (fertilisation level of 1 NPK), i.e. in water reserves, capillary conduction, runoff and actual evapotranspiration, resulted from differing physical and hydrological properties of individual soil profiles, as well as the effect of plant cover. Summing up, it may be stated that the basic factor influencing water balances for the soils in that area are meteorological conditions, in terms of precipitation and evapotranspiration values. Thus, it is of great importance to determine the role of these factors in the water balances, as they have a decisive effect on the water economy in soils of postmining areas.

Conclusions

1. Detailed pedological examinations showed that upper layers of analysed soil profiles, representative of the experimental plots, are characterised by a differentiation in grain composition and basic physical and chemical properties. It results from the non-selective management of the overlayer, employed by the Polish opencast mining.

2. The differentiation in grain composition and physical and chemical properties of the upper layers of investigated soil profiles resulted in the differences in hydrological properties of the discussed postmining soils.

3. A primary factor influencing water balances for soils in that region are weather conditions, in terms of precipitation and evapotranspiration values. These elements have a decisive effect on water economy in the region.

4. In the dry vegetation season of 1994, the impact of capillary conduction was also observed in the water balance of the area. Upper layers of postmining soils were supplied by capillary conduction from perched ground water, accumulating periodically at various depths of the waste heap.

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BILANSE WODNE WIERZCHNIEJ WARSTWY GLEB POGÓRNICZYCH

S t r e s z c z e n i e

W pracy przedstawiono wyniki badań i obserwacji terenowych prowadzonych w latach hydrologicznych od 1992/93 do 1997/98 na zwałowisku wewnętrznym odkrywki „Pątnów", położonym na Pojezierzu Kujawskim (52°20' N, 18°14' E). Badania i obserwacje terenowe prowadzono na pięciu poletkach doświadczalnych poddanych rolniczej rekultywacji, o różnym użytkowaniu i jednakowym nawożeniu mineralnym. Wyniki badań wykazały, że wierzchnie warstwy rekultywowanych rolniczo gleb terenów pogórniczych charakteryzują się zróżnicowaniem składu granulometrycznego i właściwości fizyczno-wodnych, co ma wyraźny wpływ na kształt bilansów wodnych gleb tych terenów. Podstawowym czynnikiem wpływającym na bilanse wodne gleb pogórniczych jest jednak przebieg warunków meteorologicznych, wyrażony przez wielkość opadów atmosferycznych i parowania terenowego. Wpływa ona w decydujący sposób na gospodarkę wodną gleb tych terenów.