

Hydrophysical characteristics and evaporation of Haplic Luvisol and Mollic Gleysol aggregates

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A b s t r a c t. The influence of the size of Haplic Luvisol and Mollic Gleysol aggregates on soil water potential-moisture characteristics, saturated water conductivity, diffusivity and evaporation at different external conditions are presented. It has been found that size of aggregates strongly influenced hydrophysical characteristics and evaporation of investigated soils. The size of Haplic Luvisol and Mollic Gleysol aggregates had an impact on significant differentiation of the water bounded with the potential less than 10 kJ m^{-3} (pF 2). The saturated water conductivity increases significantly with the increase of aggregate size. The diffusivity coefficients of all the investigated aggregate fractions increased with the increase of moisture and they were higher for Mollic Gleysol aggregates than for Haplic Luvisol ones. The increase of evaporation under steady-state conditions was determined by the soil aggregation, i.e., the evaporation was always higher for fine- and medium-aggregated soil samples than for coarse-aggregated ones. This increase was very high and for the investigated soils it reached eleven times (Mollic Gleysol, $E_p=4.5 \text{ mm day}^{-1}$).

K e y w o r d s: water, evaporation, soil aggregates

INTRODUCTION

The soil aggregation determines not only water capacity and water conductivity, but also has an impact on evaporation from its surface. It was proved that under stable external conditions the amount of water evaporating from soil mainly depends on the structure of its upper layer. With improving of quality of soil aggregation the possibility of utilisation of water supplied to the soil profile by plants increases from 15 to 85% [2–8,12,14,19,20,25].

Evaporation, in the absence of vegetation and when the soil surface is subject to radiation and wind effects, occurs entirely from the soil. Under traditionally managed annual field crops, the soil surface often remains largely bare

throughout the periods of tillage, planting, germination and early seedling growth, periods in which evaporation can deplete the moisture of the surface soil and thus hamper the growth of young plants during their most vulnerable stage. The problem can also be acute in young orchards, when the soil surface is often kept bare continuously for several years. Evaporation of soil moisture involves not only loss of water but also the danger of soil salination [1,9–11,13,16–18,23].

The purpose of this study was to determine the effect of aggregate size of Haplic Luvisol and Mollic Gleysol on their hydrophysical characteristics, i.e., water retention, diffusivity and evaporation at the different external conditions.

MATERIALS AND METHODS

The object of investigations were Haplic Luvisol (I) and Mollic Gleysol (II), samples of which were taken from arable layer. Following drying up of the soil samples in the laboratory to the air-dry state, the aggregation of the soils was determined by standard sieve method without sand correction. Then, soil cylinders (for determining the hydrophysical properties) and columns (for determining the evaporation) were filled with aggregates of the particular fractions: <0.25, 0.25–0.5, 0.5–1, 1–3, 3–5 and 5–10 mm treating them by means of a vibrator to ensure uniform density. When the cylinders and columns were filled with aggregates, they were subjected to successive wetting-drying cycles. This procedure allowed soil materials with stable physical characteristics to be obtained [21,22]. The basic properties of the six soil aggregate fractions of the investigated soils, which were determined using the methods commonly applied in the soil science are presented in Table 1.

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Table 1. Basic properties of Haplic Luvisol and Mollic Gleysol aggregates

Soil	Fraction of aggregates (mm)	Grain size distribution (%)			C_{org} (%)	Specific surface area (H ₂ O vapour) (m ² g ⁻¹)	pH in KCl	Bulk density (g cm ⁻³)
		1–0.1	0.1–0.02	< 0.02				
Haplic Luvisol (I)	< 0.25	7	63	30	2.3	28	4.9	1.20
	0.25–0.5	48	33	19	1.9	24	5.0	1.39
	0.5–1	47	35	18	2.0	26	4.8	1.22
	1–3	44	34	22	2.3	24	4.5	1.13
	3–5	40	36	24	1.7	27	4.6	1.05
	5–10	43	34	23	1.8	22	4.7	1.14
Mollic Gleysol (II)	< 0.25	10	64	26	3.2	58	6.5	1.15
	0.25–0.5	64	17	19	2.8	43	6.1	1.20
	0.5–1	63	20	17	2.4	47	6.6	1.02
	1–3	46	33	21	3.0	50	6.6	0.92
	3–5	45	35	20	3.1	52	6.5	0.89
	5–10	45	34	21	3.0	47	6.5	1.06

The characteristics of soil water potential-moisture were obtained with the use of pressure chambers. Water conductivity in the saturated zone was determined according to de Wit method. The water diffusivity was calculated with Mualem method on the basis of the retention curves and data of saturated water conductivity [15]. Measurements of evaporation were conducted using the apparatus described by Walczak and Witkowska-Walczak [24,26] in which the thickness of aggregate soil samples was about 32 cm and water table was on the bottom of the soil column. It means that at the start of the experiments the water potential on the upper surface of soil samples was equal to 3.16 kJ m⁻³ (pF 1.5). The external conditions of the experiment were as follows: variant 1 – radiation – 11.6 W m⁻², air temperature: 20±0.5°C, air humidity: 50±3%; variant 2 – radiation – 163 W m⁻², 27.5±0.5°C and 33±3%, respectively. The potential evaporation (Ep) for the variant 1 of the experiment was equal to 4.5 mm day⁻¹ and for the variant 2 – 11 mm day⁻¹. Stabilisation of the evaporation rate was noticed between 7 and 10 days of the experiment.

RESULTS AND DISCUSSION

The water content at chosen soil water potential for different size aggregates of Haplic Luvisol and Mollic Gleysol in the drying process is presented in Table 2. It can be seen that Haplic Luvisol aggregates bigger than 1 mm in the whole range of soil water potentials bound more water than those less than 1 mm. In the case of Mollic Gleysol aggregates the opposite relationship was observed, i.e., soil aggregates less than 1 mm bounded much more water than those bigger than 1 mm (except fraction 3–5 mm for pF>1.5). Analysing the moisture values at chosen soil water potentials, it can be noticed that they rapidly decreased between saturation (pF 0) and pF 0.4 for the all fractions of

Haplic Luvisol aggregates and for aggregates bigger than 1 mm of Mollic Gleysol. It means that there is the high amount of very large pores (9–23% v/v.) of Mollic Gleysol aggregates less than 1 mm. The amount of the very large pores does not exceed 6%. At the soil water potential 16 kJ m⁻³ (pF 2.2), which corresponds to field water capacity, the differences of moisture for several fractions of Haplic Luvisol aggregates reach 12% v/v. and for Mollic Gleysol aggregates – 8% v/v., except the smallest ones. For the soil water potentials higher than 50 kJ m⁻³ (pF 2.7), the effect of aggregate sizes for Haplic Luvisol and Mollic Gleysol aggregates bigger than 0.5 mm on the water content was practically insignificant.

The results of the investigation of saturated water conductivity show that it increases with the increase of the aggregates size for both investigated soils. The lowest values of the saturated water conductivity were noticed for the smallest aggregates of Haplic Luvisol and Mollic Gleysol, i.e., 0.3 and 0.9 m day⁻¹, respectively. The highest values of K_{sat} were observed for aggregates bigger than 3 mm of both soils. They equal to 11.5 m day⁻¹ for Haplic Luvisol and 45.4 m day⁻¹ for Mollic Gleysol.

The water retention data and the values of saturated water conductivity were a basis for calculation of the diffusivity, which determines the water movement in the uniform soils in unsaturated zone. The results of diffusivity calculations for the investigated soil material are presented in Fig. 1. It can be seen from this figure that the diffusivity coefficients for all the investigated aggregate fractions increased with the increase of moisture and they were higher for Mollic Gleysol aggregates than for Haplic Luvisol ones. For the low water content, in the case of Haplic Luvisol less than 15% v/v. and Mollic Gleysol less than 20% v/v., the increase of diffusivity coefficients values was very rapid, and above them, till the highest moisture (about 50% v/v.), slight. In the case of Haplic Luvisol the lowest diffusivity was noticed for

Table 2. Moisture (% v/v) at chosen soil water potential for investigated soil aggregates

Soil	Fraction of aggregates (mm)	Soil water potential (kJ m ⁻³)							
		0.1 (pF 0)	0.25 (pF 0.4)	1 (pF 1)	3.16 (pF 1.5)	10 (pF 2)	16 (pF 2.2)	50 (pF 2.7)	1500 (pF 4.2)
Haplic Luvisol (I)	<0.25	49	28	26	26	22	20	12	8
	0.25–0.5	37	27	26	24	17	14	10	9
	0.5–1	50	38	25	18	13	12	10	8
	1–3	56	47	40	35	28	24	14	8
	3–5	55	39	36	32	26	23	13	7
	5–10	51	39	37	32	26	23	12	8
Mollic Gleysol (II)	<0.25	55	54	52	49	44	37	20	8
	0.25–0.5	51	51	49	39	23	20	17	8
	0.5–1	57	51	47	24	18	16	13	7
	1–3	60	41	31	24	18	15	12	6
	3–5	60	37	33	28	22	19	14	6
	5–10	53	30	25	21	15	12	9	7

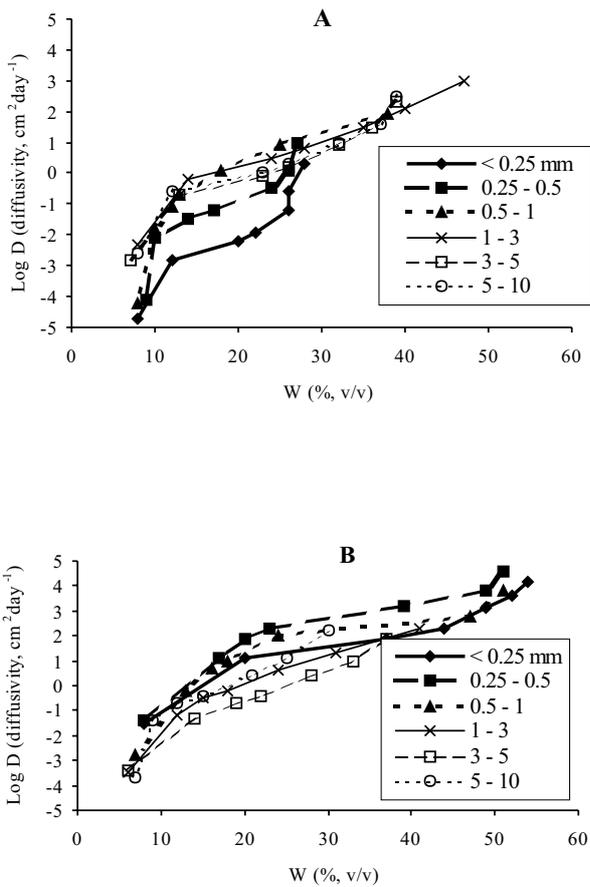


Fig.1. Relationship between the moisture and diffusivity for different fractions of Haplic Luvisol (A) and Mollic Gleysol (B) aggregates.

the smallest aggregates (less than 0.5 mm) whereas for Mollic Gleysol aggregates the lowest diffusivity was observed for the largest aggregates (bigger than 1 mm). The maximum diffusivity values reached $0.1 \cdot 10^4$ – $0.33 \cdot 10^3$ cm² day⁻¹ for 1–3 and 5–10 mm aggregates of Haplic Luvisol at 0.25 kJ m⁻³ soil water potential (pF 0.4) and $0.14 \cdot 10^5$ – $0.4 \cdot 10^5$ cm² day⁻¹ for Mollic Gleysol aggregates less than 0.5 mm at the same potential. The minimum diffusivity values were noticed at 1500 kJ m⁻³ potential (pF 4.2) and they varied from $0.2 \cdot 10^{-4}$ to $0.79 \cdot 10^{-4}$ cm² day⁻¹ for the smallest aggregates of Haplic Luvisol and from $0.18 \cdot 10^{-3}$ to $0.4 \cdot 10^{-3}$ cm² day⁻¹ for Mollic Gleysol aggregates bigger than 1 mm.

The results of the laboratory investigations of the evaporation rate from the different aggregated soil surface of Haplic Luvisol and Mollic Gleysol are presented in Fig. 2 for low radiation – 11.6 W m⁻² (A) and high radiation – 164 W m⁻² (B), respectively. It can be seen that in the both studied cases the evaporation decreased successively with the increase of aggregates size. At low radiation for Haplic Luvisol the evaporation rate decreased slightly from 1.6 mm day⁻¹ for the aggregates less than 0.25 mm to 1.0 mm day⁻¹ for the aggregates of diameter 5–10 mm. The sharper fall of evaporation was observed for Mollic Gleysol aggregates, i.e., from 2.2 mm day⁻¹ for aggregates less than 0.25 mm to 0.2 mm day⁻¹ for 5–10 mm aggregates. At the high level of radiation the highest evaporation was noticed for the smallest aggregates of Haplic Luvisol – 6.3 mm day⁻¹ and it decreased slightly till 0.5–1 mm aggregates (5.7 mm day⁻¹) whereas for the biggest aggregates the evaporation reached only 3.4 mm day⁻¹. It means that in this case evaporation fell nearly twice. The influence of aggregates size on evaporation is more significant for Mollic Gleysol. In this case, the evaporation rate reaches 4.4–4.2 mm day⁻¹ for the

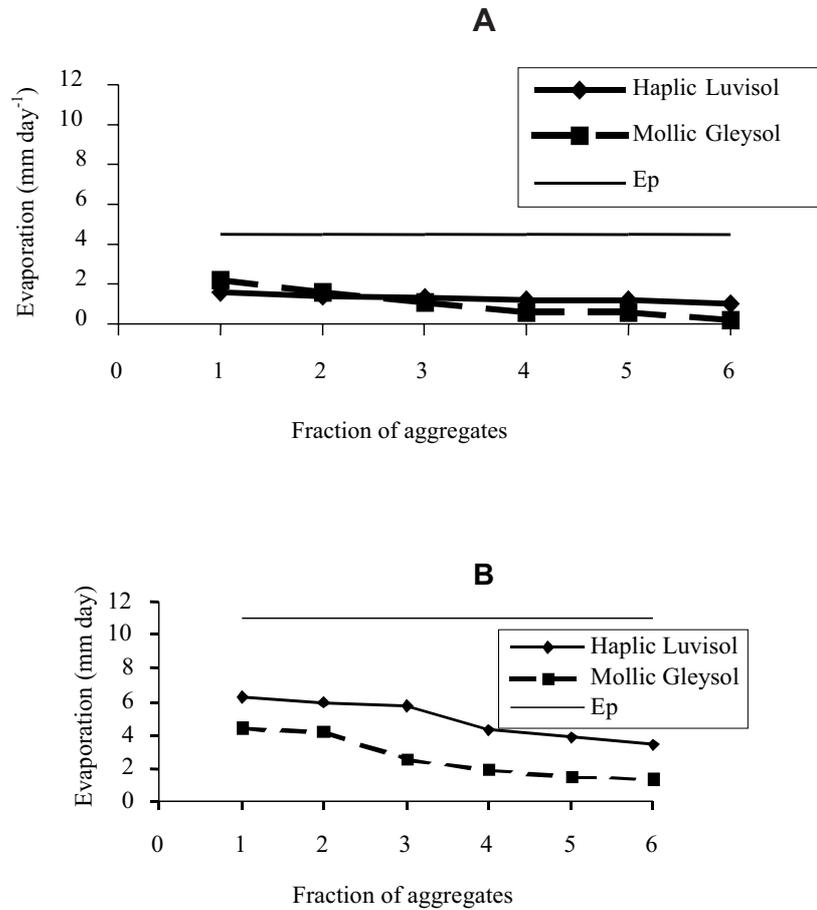


Fig. 2. Relationship between the size of aggregates (1 corresponds to 0.25 mm; 2 to 0.25–0.5; 3 to 0.5–1; 4 to 1–3; 5 to 3–5 and 6 to 5–10 mm, respectively) and evaporation for low (A) and high (B) evaporativity.

aggregates of diameter less than 0.5 mm and 1.4–1.3 mm day^{-1} for aggregates bigger than 3 mm day^{-1} , i.e., the decrease of about 3.4 times is observed.

It is known that evaporation rate is determined either by the external evaporativity or by the water-transmitting properties of the soil, depending on which of the two is lower and therefore limiting. When the soil water potential at the soil surface is low, the evaporation rate is forced by external conditions. However, when the soil water potential at the soil surface increases, the evaporation approaches a limiting value regardless of how high external evaporativity may be. The results of the presented investigations showed that the evaporation increases with the increase of the moisture and diffusivity coefficient. The increase of evaporation under steady-state conditions is determined by the soil aggregation, i.e., the evaporation is always higher for fine- and medium-aggregated soil samples than for coarse-aggregated ones. This increase is very high and for the investigated soils it reached eleven times (Mollic Gleysol, $E_p=4.5 \text{ mm day}^{-1}$).

CONCLUSIONS

The obtained results can lead to the following conclusions:

1. The aggregate size of Haplic Luvisol and Mollic Gleysol strongly determines the course of their water characteristics and evaporation.

2. The size of Haplic Luvisol and Mollic Gleysol aggregates has an impact on significant differentiation of the water bounded with the potential less than 10 kJ m^{-3} ($pF 2$).

3. The saturated water conductivity increases significantly with the increase of aggregate size.

4. The diffusivity coefficients for all the investigated aggregate fractions increase with the increase of moisture and they are higher for Mollic Gleysol aggregates than for Haplic Luvisol ones. For the low water content, in the case of Haplic Luvisol less than 15% v/v. and Mollic Gleysol less than 20% v/v., the increase of diffusivity coefficients values is very steep, and over them, till the highest moisture (about 50% v/v.), slight.

5. The aggregate size as well as external evaporativity strongly influence evaporation from the soil surface of the investigated soils. At low evaporativity for Haplic Luvisol the evaporation decreases 1.6 times with the increase of aggregate size whereas for Mollic Gleysol – 11 times. In the case of high evaporativity this impact is not so significant and it reaches for Haplic Luvisol – 1.9 times and for Mollic Gleysol – 3.4 times.

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