SOIL WATER POTENTIAL - MOISTURE CHARACTERISTICS OF DIFFERENT AGGREGATE FRACTIONS OF EUTRIC CAMBISOL AND GLEYIC PHAEOZEM UNSTABILIZED AND STABILIZED WITH SOIL CONDITIONER (SOLACROL)

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A b s t r a c t. Changes in water retention caused by an addition of a soil conditioner (Solacrol), stabilizing soil aggregates, are presented in the paper. The investigations were carried out on two soils, i.e., Eutric Cambisol and Gleyic Phaeozem. Stabilization of different aggregate fractions with a soil conditioner was found to cause changes in the course of water retention curves, increasing or decreasing the amount of water bound by different forces. It was stated that the maximum changes in the amount of water did not exceed 16%.

K e y w o r d s : soil aggregation, soil conditioner (Solacrol), water retention

INTRODUCTION

Soil aggregation is intensively modified during application of various agrotechnical treatments. These treatments cause occurrence of quantitative relations of specific types between micro- and macroaggregates and their characteristic distribution in the profile undergoing dynamic changes. The use of soil conditioners for improving soil structure quality, i.e., its persistence, maintaining advantageous physical, physical-chemical and biological properties has been done for several years. It is determined not only by the neccessity for the intensification of agricultural production, but also by the importance of environmental protection, recultivation of postindustrial areas, utilization of waste lands and erosion control [2,4-6,9,10,18,22,26,31,32].

The aim of this paper is to show the impact of aggregate stabilization in different fractions of Eutric Cambisol and Gleyic Phaeozem on their water potential - moisture characteristics.

MATERIAL AND METHODS

The objects of investigation were Eutric Cambisol and Gleyic Phaeozem. Soil samples were taken from arable layer. Aggregation of the soils was determined by the standard sieve method and the following fractions of aggregates were separated: less than 0.25 mm; 0.25-0.5; 0.5-1; 1-3; 3-5 and 5-10 mm. Basic properties of the investigated aggregates are presented in Table 1. The aggregates of particular fractions of the two investigated soils were divided into two groups. The first group comprised the aggregates not subjected to stabilization, the second one - the aggregates, which were stabilized with Solacrol (20% aqueous solution of hydrolized polyacrylonitrile - HPAN, made in Hungary) [21]:

$$-\left[\begin{matrix} H & & H & H \\ | & & | & | \\ C & - & C & - C \\ | & & | & | \\ H & & CN & H \end{matrix}\right]_{(n-x)} - \left[\begin{matrix} H & H & & H \\ | & | & & | \\ C & - C & - & C - \\ | & | & & | \\ CO_2H & H & & CN \end{matrix}\right]_n$$

The unstabilized and stabilized aggregates of different fractions of Eutric Cambisol and

T a b l e 1. Basic properties of Eutric Cambisol and Gleyic Phaeozem aggregates

Soil	Fraction of aggregates (mm)	Grain size distribution (%) (diameter in mm)			Humus content (%)	Specific surface area $(m^2 g^{-1})$	$CaCO_3$ (%)	pH_{KCl}	Fe_2O_3 (%)	Organic matter (%)
		1-0.1	0.1-0.02	<0.02						
Eutric Cambisol (I)	natural state	3	58	39	1.01	39	4.0	7.4	1.6	3
	<0.25	4	62	34	0.4	32	4.4	7.8	1.6	4
	0.25-0.5	5	53	42	0.8	39	4.3	7.5	2.0	4
	0.5-1	4	50	46	0.6	44	4.3	7.7	2.1	3
	1-3	4	50	46	0.9	47	4.0	7.5	2.0	3
	3-5	3	54	43	0.8	41	4.1	7.6	2.1	2
	5-10	3	54	43	0.7	38	4.3	7.4	1.7	3
Gleyic Phaeozem (II)	natural state	34	44	22	-	138	0.19	4.2	0.4	26
	<0.25	14	65	21	-	115	0.16	4.1	0.6	18
	0.25-0.5	70	18	12	-	103	0.12	4.2	0.5	13
	0.5-1	51	29	20	-	142	0.12	4.0	0.6	24
	1-3	30	46	24	-	160	0.12	4.0	0.5	26
	3-5	29	47	24	-	147	0.16	3.9	0.4	25
	5-10	32	44	24	-	189	0.25	4.1	0.5	28

Gleyic Phaeozem were taken into standard Kopecky cylinders and initially compacted with a vibrator. Then, they were saturated with water and dried in subsequent cycles for stabilization of their aggregate distribution and bulk density [25,30]. In the case of the aggregates which did not stabilize with Solacrol, changes of aggregation were noticed as a result of water influence, while in the case of aggregates stabilized with Solacrol such changes were not observed. The final aggregate size and bulk density distribution of the investigated soil samples after 10 succeeding wetting-drying cycles are presented in Table 2. The water retention characteristics of the soil samples prepared in this way were determinated in the range of 98,1 - 15 x 10^5 MJ m^{-3}, i.e., pF0 - 4.2, for points of pF - 0; 0.4; 1; 1.5; 2; 2.2; 2.7; 3.7 and 4.2 in the drying process.

RESULTS

Water characteristics of the soil material studied, i.e., the relationship between soil water potential and moisture are presented, as an example, for 0.25 - 0.5 mm fraction of aggregates, in Fig. 1 for Eutric Cambisol and in Fig. 2 for Gleyic Phaeozem. Water characteristics of Eutric Cambisol and Gleyic Phaeozem aggregates differ. Distinct differences in moisture can be observed at various water potentials for the same soil aggregates unstabilized and stabilized with Solacrol. It results from the data presented in Fig.1 that the use of Solacrol in the case of the aggregates of the 0.25-0.5 mm fraction of Eutric Cambisol caused an increase in the water bound with the forces lower than pF 2 from 8 to 12%, v/v. The use of Solacrol practically did not influence the amount of water bound with the forces in the range of pF 2 - pF 3 and slightly decreased the bound water amount at pF 3.7 and pF 4.2. Fixation of the aggregates of 0.25-0.5 mm fraction of Gleyic Phaeozem with a soil conditioner resulted in the increase of water bound with the forces in the range of pF 0 - pF 1 from 5 to 10%, v/v and pF 2.7 - pF 4.2 - from 4 to 6%, v/v, while it caused a decrease of water bound with the forces corresponding to pF 1 - pF 2.7 from 3 to 13%, v/v.

The difference in the water content of the sample of Eutric Cambisol fixed and unfixed with Solacrol with respect to the investigated aggregate fractions is presented in Fig. 3. It results from this figure that the use of Solacrol caused an increase in the water bound with the forces smaller than pF 2.7 in the samples with aggregate fractions smaller than 0.25 mm; 0.5-1 mm and 1-3 mm. For the aggregates of the 0.25-0.5 mm fraction the increase of water content was noticed in the range of pF 0 - pF 2, and for the aggregates with the diameters of 3-5 mm only in the case of pF 0.4. The range of water content increase in the case of Solacrol application was from 2 to 12%, v/v, and its maximum and minimum values occurred for the fraction of 3-5 mm. A decrease of the soil water content in the soil after conditioner application was noticed in the whole range of pF for the 5-10 mm fraction (max. 16%, v/v), for the majority of pF points for the 3-5 mm fraction (max. 5%, v/v) and for pF values lower than 2.7 for the fractions smaller than 0.25 and 0.5-1 mm. For the aggregates of the 0.25-0.5 mm diameter a slight decrease in the water content, 2%, v/v, was noticed beginning from pF 2. Solacrol influence was not observed in the cases of pF 2.7 for the aggregate fraction of 0.25-0.5 mm, pF 4.2 for the fraction of 1-3 mm and for pF 2; 2.2 and 4.2 for the aggregates of the 3-5 mm diameters. Considering relative values, the maximum increase of water amount under the influence of the Solacrol applied on Eutric Cambisol was 34% (pF 0.4 - aggregate fraction of 1-3 mm) while the maximum decrease of the water content was 35% (pF 2.7 - the fraction of aggregates smaller than 0.25 mm).

Differences of the water content in the Gleyic Phaeozem samples fixed and unfixed with soil conditioner for the investigated aggregate fractions are presented in Fig. 4. It results from the data presented in this figure, that the application of Solacrol had different influence on the water retention for the Gleyic Phaeozem than for the Eutric Cambisol. Water

T a b l e 2. Aggregate size and bulk density distribution of the samples formed of aggregates of Eutric Cambisol and Gleyic Phaeozem

Soil	Fraction of aggregates (mm)	Aggregate size distribution (%) (diameter in mm)						Bulk density (g cm^{-3})	
		<0.25	0.25-0.5	0.5-1	1-3	3-5	5-10	not treated	Solacrol added
Eutric	<0.25	99	1	-	-	-	-	1.25	1.19
Cambisol /I/	0.25-0.5	52	47	1	-	-	-	1.18	1.01
	0.5-1	45	18	37	-	-	-	0.97	1.01
	1-3	30	14	14	42	-	-	0.93	0.92
	3-5	34	15	11	17	22	1	0.90	0.90
	5-10	31	20	12	13	8	16	0.88	0.84
Gleyic	<0.25	96	4	-	-	-	-	0.80	0.97
Phaeozem /II/	0.25-0.5	13	86	1	-	-	-	1.15	1.00
	0.5-1	7	25	67	1	-	-	0.56	0.56
	1-3	11	12	16	60	1	-	0.41	0.41
	3-5	11	14	5	23	45	2	0.39	0.43
	5-10	9	4	2	5	27	53	0.52	0.45

Fig. 1. Retention curves of the Eutric Cambisol aggregates unstabilized (line) and stabilized (points) with Solacrol.
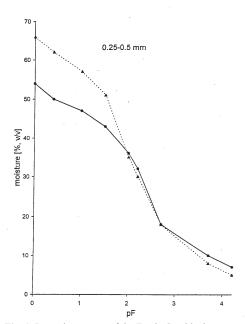

Fig. 2. Retention curves of the Gleyic Phaeozem aggregates unstabilized (line) and stabilized (points) with Solacrol.

retention increased practically in the whole range of the pF values for the aggregates of the 0.5-1 and 1-3 mm fractions. For the aggregate of the 3-5 and 5-10 mm fractions the increase of the water amount was noticed in the whole range of the pF values, except from pF 0 and pF 2 for the 3-5 mm aggregates and pF 4.2 for the fraction of 5-10 mm. An increase of the water content under the influence of the Solacrol applied was also noticed for the lowest and the highest pF values in the case of the aggregates smaller than 0.5 mm. For the aggregates smaller that 0.25 mm this increase referred to pF 1.5 and for the fraction of 0.25-0.5 mm to pF 1; 2.7 and 3.7, respectively. A significant decrease of water retention was noticed for the aggregates smaller than 0.25 mm in the range of pF 2-2.7 (max. 15%, v/v) and for the fraction of 0.25 -0.5 mm in the range of pF 1-2.7 (max. 13%, v/v). Considering relative values, the maximum increase of water amount under the influence of the Solacrol applied on the Gleyic Phaeozem was 50% (pF 4.2; the aggregate fraction of 0.25-0.5 mm) and the maximum decrease of water content - 29% (pF 2.2; the aggregates smaller than 0.25 mm).
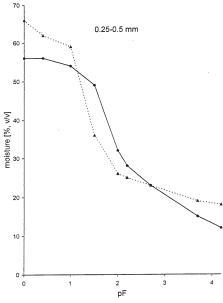
In the case of natural aggregates the course of water retention curves and the moisture content was related to the properties of the investigated soils, (see Table 1). The experimentally evaluated pF curves are typical for the aggregates of Eutric Cambisol (see Fig. 1) and Gleyic Phaeozem (see Fig. 2). An addition of the synthetic polymer, Solacrol into the soil, changes the shape of the retention curves (see dashed lines in Figs 1 and 2), as well as the amount of water confined by the aggregates stabilised by the polymer (Figs 3 and 4). Obviously, the properties of the soils decide on the processes of polymer adsorption and soil aggregation and about water stability of the formed aggregates. To explain the observed experimental effects, it is necessary to consider the following problems: adsorption of polymers and factors influencing the polymer adsorption process, structure of the polymer particles, role of the soil properties and its structure, as well as the interactions in the polymer-water-soil system. We shall briefly discuss some of the above mentioned points.
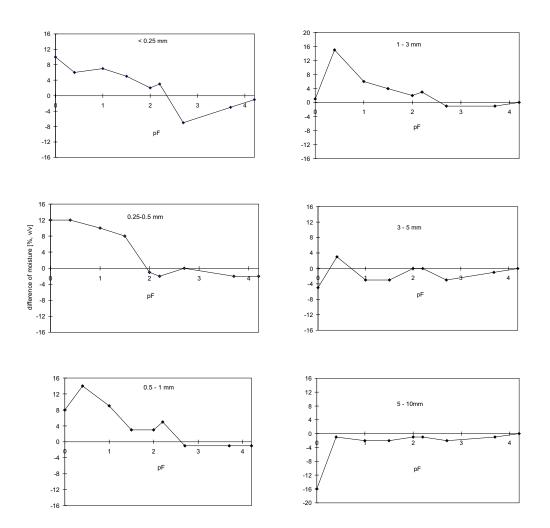
Fig. 3. Differences of moisture between stabilized and unstabilized Eutric Cambisol aggregates for some chosen soil water potentials.

DISCUSSION

Polymer exert impact on the soil physical properties. The impact seems be the function of its adsorption and desorption by the soil material. In the case of pure clays, this adsorption is strongly connected with the electrostatic charge of the polymers. Other important polymer characteristics that affects adsorption is molecular size and molecular conformation. In addition, the external surface area, structure, pore size distribution of clay packages and clay type, affect adsorption of the polymers as well. The next factors are related to the electrolyte composition and concentration of the solution.

Polymer adsorption occurs mainly on the external surface of the clay packages. The polymers with high molecular weights do not penetrate soil aggregates, and adsorption on the soil material is related to the soil aggregate size and molecular conformation of the polymer. The adsorption of uncharged polymers by clays is largely "entropy-driven". Polymer conformation changes from a random coil in the solution
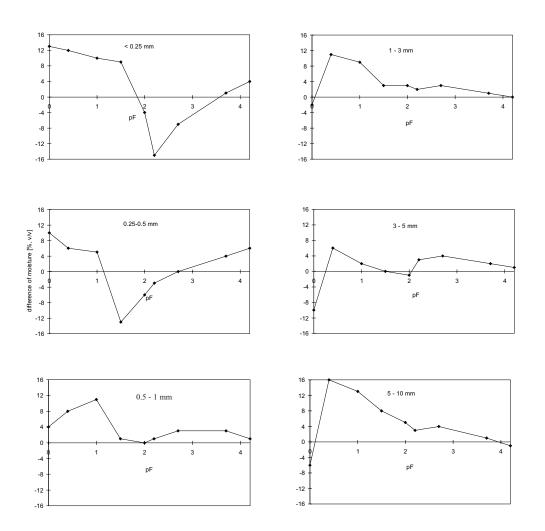
Fig. 4. Differences of moisture between stabilized and unstabilized Gleyic Phaeozem aggregates for some chosen soil water potentials.

to an extended form at the surface, where the adsorbed polymer segments or trains alternate with loops and tails extending away from the surface.

Polycations are adsorbed largely through electrostatic interaction between the cationic groups of the polymer and the negatively charged sites at the clay surface. Because of the negative charge of the clay surface, negatively charged polymers tend to be repelled from the clay surface and their adsorption occurs only to a small extent. However, appreciable uptake can take place under acid conditions and at the high ionic strength, when a negative charge on the polyanion becomes effectively neutralized by the protonation and screened by the electrolyte. Adsorption of the polyanions can be also promoted by the presence of polyvalent cations. These cations act as bridges between anionic groups on the polymer and the negatively charged sites on the clay. Possible mechanisms of interaction between polymer and clays have been discussed in reviews [1,3,8, 11-13,16,23,24,28,29].

In our case two completely different soils, that is Eutric Cambisol and Gleyic Phaeozem, were used in the experiments with Solacrol. Polymeric soil conditioner, Solacrol, is a modified hydrolysed polyacrylonitrile (HPAN). Polymeric substances are well-defined synthetic polymers or copolymers - linear chains built of one or two monomer types. To characterise them one should give the types of monomers and the molecular weight or chain length of polymer. In the solution, polymeric chains are coiled and free flying at low concentration, but entangled at high concentration [24]. Conformation and aggregation performance of a given polymer depends also on the reaction of the solution. The best pH is about 7.5 [1,23]. The Eutric Cambisol indicated very similar reaction to the mentioned above (see Table 1), and additionally, it contains a high amount of clay particles. These conditions are optimum for the soil aggregation. In contrast, the reaction and amount of clay particles in the Gleyic Phaeozem are significantly lower (Table 1). When the reaction of Solacrol decreases to pH =3-4, as in the case of the Gleyic Phaeozem, polymerization is going down, macromolecules of the polymer change conformation and aggregation is difficult. Gleyic Phaeozem contains also big soil particles and a lot of organic matter. In a natural soil, all kinds of particles are held together by humus. It is common knowledge in the soil science that organic matter helps to form and to stabilize aggregates built of mineral particles. Stabilizing mechanisms of organic matter come into action only when some water is present [17]. Humic substances consist largely of negatively charged polymers that possess different kind polar and apolar functional groups, which exhibit affinity to inorganic ions and water molecules rather than to macro-molecules of polymer. Steric effects and mobility of the species play also some role in the adsorption and aggregation processes.

Solacrol was added to soils as a completely saponified sodium-amonium aqueous solution. Addition of surfactants lowers the surface tension of water. If a surfactant molecule is adsorbed by the soil with the hydrophobic end of the molecule attracted to the soil, leaving the hydrophilic end exposed, the soil can be converted from water repellent to a wettable system [19]. Eutric Cabmisol consists of calcium carbonate. Polymer and calcium ions at alkaline pH may form insoluble compounds, which may eventually act as cementing agents for the soil aggregate.

The use of synthetic polymers as soil conditioners is of particular relevance to the clay-soil system in improving the physical conditions of the soils, which, in turn, influence soil fertility and crop production [7]. It should be pointed out that the polymer here is added to an already aggregated system in which the soil-clay particles are in close proximity. Soil conditioners thus act more as an aggregate stabilizing or strengthening agent than as a flocculent. The amount of polymer adsorbed by the aggregated material is much lower than the adsorption maximum by the dispersed soil. This can be attributed to the fact that the polymer is adsorbed to form a lining along the walls of the pores entering the aggregates, which are thus partially or completely blocked, and adsorption does not occur on the surfaces inside the aggregates. It has been reported that changes in the specific surface area and pore size distribution result from the adsorption of polyvinyl alcohol by the aggregates of the clay soil [33]. These results are interpreted in terms of "peripheral pore occupation" by the polymer. In our previous papers [14,15,27,34], we pointed out that the difference in aggregate distribution and in density became distinct in the analysis of pore size distribution. In the case of the Eutric Cambisol, stabilization of the structure resulted in an increase of the number of pores of all the groups, but in the Gleyic Phaeozem only a slight increase in the large pores was observed. The above discussion may explain the difference between moisture content and water retention curves for both kinds of the investigated aggregates: natural and with Solacrol (Figs 1 and 2). Additionally, organic matter and polymer are two agents, which sorb and keep water, what is well seen in the case of Gleyic Phaeozem.

CONCLUSIONS

The performed investigations on the influence of Solacrol utilization on the soil water potential - moisture characteristics of Eutric Cambisol and Gleyic Phaeozem aggregates led to the following conclusions:

- Fixation of the aggregates with soil a conditioner causes differentiated influence on their water retention; this influence depends not only on the aggregate sizes and soil type, but also on the soil water potential values.

- In the case of Eutric Cambisol an increase of water retention after Solacrol utilization was noticed for low soil water potential values for the aggregates smaller than 3 mm and its decrease was observed practically in the whole range of the soil water potential for the aggregates larger than 3 mm as well as in the case of high soil water potential values for the aggregates smaller than 3 mm.

- In the case of the Gleyic Phaeozem, an increase of the water amount bound by the soil after Solacrol was noticed practically for the aggregates larger than 0.5 and for the aggregates smaller than 0.5 mm for the low and high soil water potentials; a significant decrease of the water content was observed for the aggregates smaller than 0.5 mm for the medium values of the soil water potential.

- The maximum absolute value of the increase as well as the decrease of the water amount retained by the soil aggregates was 16%, whereas the maximum relative values of the increase as well as the decrease of the amount of retained water ranged from 35 to 50%.

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