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EFFECTS OF WATER SOFTENER USE ON THE PERMEABILITY OF SEPTIC TANK[1/] SEEPAGE FIELDS

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The proper functioning of the septic tank soil-absorption field system depends on maintenance of sufficient soil hydraulic conductivity (HC) to dispose of the waste water. High-Na waters are known to adversely affect the HC of irrigated soils, and questions have been raised about possible hazards associated with disposal of water softener waste in a soil absorption field. Therefore, the purpose of this study was to determine the conditions under which these effluents might pose a threat to the proper functioning of the disposal system and whether there is any justification for banning disposal of wastes from water softener regeneration in soil absorption fields.

REVIEW OF LITERATURE

The deleterious effects of high exchangeable sodium percentage (ESP) on HC of soils have long been recognized (Scofield and Headley, 1921). Over the years, researchers have identified the factors responsible for these deleterious effects, but much work remains to be done on quantitative aspects of the problem.

The two parameters receiving the widest use in predicting effects of salt additions on HC are the ESP of the soil and the soluble salt concentration (m_o) in meq/liter. A third parameter used in predicting effects of Na-bearing waters on HC is the sodium adsorption ratio (SAR). The relationship between SAR and ESP is given by the equation of Gapon (1933) which for the Na-Ca system is

$$NaX/Ca_{1/2}X = k_G(Na^+)/[(Ca^{2+})/2]^{1/2} \quad (1)$$

where NaX and $Ca_{1/2}X$ represent the adsorbed Na and Ca in meq/100 g, k_G is the Gapon "constant," and (Na^+) and (Ca^{2+}) are the activities of dissolved Na and Ca in meq/l. $NaX/Ca_{1/2}X$ is the exchangeable sodium ratio from which the ESP can be derived and $(Na^+)/[(Ca^{2+})/2]^{1/2}$ is the SAR. In practice, the sum of the activities of the divalent cations is used in place of Ca alone. The Gapon equation has been shown by Bolt (1955) to agree with the double layer equation at < 50% Na-saturation, and Bower (1959) found it to give a reasonable description of Na-exchange reactions in soils. Observed deviations of k_G from soil to soil have been attributed primarily to differences in charge density of the adsorbing surfaces.

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Factors Influencing HC in Salt-Affected Soils

ESP, SAR and m_o: Rowell et al. (1969) state that, as m_o is lowered in a soil of high ESP, HC begins to decrease at the point the soil aggregates start to swell and that changes in permeability are directly controlled by swelling of clay until clay dispersion and movement begins. Swelling decreases the average size of pores which causes the drop in HC even though total pore space may be increased. As m_o is lowered, bond weakening occurs, and swelling increases until aggregates are broken into discrete particles that can be transported and lodged in pore constrictions blocking some of the pores. Decreases in HC due to swelling are at least partially reversible (Reeve and Tamadonni, 1965), but those due to dispersion and pore blockage are not (Singh and Jaswal, 1973).

Critical ESP and electrical conductivity (EC) levels for saline-sodic soils (ESP > 15, EC > 4 mmhos/cm) and nonsaline-sodic soils (ESP > 15, EC < 4 mmhos/cm) proposed in Handbook 60 (U.S. Salinity Laboratory Staff, 1954) have been widely accepted as maximum limits for agricultural use. Electrical conductivity is used as a routine method for estimating m_o. Subsequent research, however, has shown that the critical ESP may vary quite widely among soils of different physical and mineralogical makeup. This has led to the determination of "threshold values" of ESP (or SAR) and m_o for individual soils. If a soil is equilibrated with a solution of high m_o (> 300 meq/liter) and a high enough constant SAR to lower HC at low m_o, HC will remain relatively constant at first as m_o is lowered and then it will decrease quite rapidly as m_o is lowered further (McNeal, 1968). The value of m_o at which the HC is 85% of maximum has been named the "threshold" value for that SAR (or for the resulting ESP) by Quirk and Schofield (1955). Other investigators have used relative HC values as low as 75% (McNeal and Coleman, 1966). If threshold values at various SAR's are plotted, a curve such as that in Fig. 2 describes the m_o-ESP range over which the soil is stable. Similar curves can be constructed using ESP in place of SAR. Threshold SAR values determined from data of a number of different investigators (Hamid and Mustafa, 1975; Johnston, 1975; McNeal and Coleman, 1966; McNeal et al., 1966; Quirk and Schofield, 1955; Vander Pluym et al., 1973) for m_o = 20 and m_o = 50 meq/l show wide differences between soils (Fig. 2). The reasons for these differences must lie in the factors other than SAR, ESP and m_o mentioned previously.

Soil Mineralogy: Swelling and dispersion at high ESP and low m_o appears to be associated with the presence of significant quantities of montmorillonite (McNeal and Coleman, 1966; McNeal, 1968). Iron oxides tend to stabilize the structure of montmorillonitic systems and reduce swelling and dispersion (McNeal and Coleman, 1966; McNeal, 1968; Rowell, 1965; El Rayeh and Rowell, 1973).

Organic Matter and pH: Many investigators have noted that organic matter is one of the major factors promoting aggregate stability in soils. However, once high-Na soils are dispersed, the presence of organic matter seems to make flocculation more difficult (Quirk and Schofield, 1955). Theoretically, the higher charge density at high pH due to pH-dependent charge of organic matter and clay edges should encourage swelling and dispersion. This could explain the negative effects of organic matter on clay flocculation because Na-saturated soil systems at low m_o generally exhibit a high pH. Rowell (1965) found that the swelling of montmorillonite at pH 6 was twice that at pH 2 with no increase in swelling above pH 6. Increased swelling was attributed to decrease in the number of positive charges at the edges of the plates and therefore a decrease in the attractive forces between the negative faces and positive edges of the plates.

Mechanical Stress

In interpreting laboratory studies of HC experiments, particularly with disturbed soils, it is important to note that adverse effects of Na will be found at lower ESP values if soils are agitated or mechanically puddled (McNeal and Coleman, 1966; Rowell et al., 1969).

Calculation of Swelling Pressures and HC

Swelling and dispersion of montmorillonite systems results when the concentration of ions midway between two montmorillonite plates exceeds the concentration of ions in the surrounding solution. The surface negative charge attracts cations and prevents them from escaping to the solution so that an osmotic system is set up in which water flows from the bulk solution to the region of higher ion concentration between the plates, resulting in pressure build-up. Monovalent cations cause greater pressures at equivalent normalities because there are twice as many cations in the interlayer solution as with divalent cations.

Mixed-ion Model: Lagerwerff et al. (1969) and McNeal (1970) have derived equations for calculating swelling pressures for a montmorillonite system in which exchangeable Na and Ca are uniformly distributed over all of the charged surfaces (mixed-ion model). Lagerwerff et al. also derived equations based on this model for calculating HC. In McNeal's approach, the distance, D, from an imaginary capacitor plate located a distance δ behind the surface of the montmorillonite layer to the midplane between adjacent clay layers is calculated from the equation:

$$D = \frac{1}{\sqrt{\beta N_o}} \cdot \sqrt{\frac{2}{f}} \cdot \frac{2}{\sqrt{\alpha_1(\alpha_2 - \alpha_4)}} \cdot F(\phi, K) \qquad (2)$$

where $\beta = 1.06 \times 10^{15}$ cm/mmole at 25°C; N_o = total electrolyte concentration in meq/ml; f is the equivalent fraction of divalent cations in the soil solution; $F(\phi,K)$ is an incomplete elliptic integral of the first kind; and α_1, α_2 and α_4 are roots of a fourth order polynomial. The α terms are related to ψ_d, the electrical potential midway between the plates, and to f. The reader is referred to the original paper for the detailed equations.

In most cases, neither D nor ψ_d are experimentally determinable so that values of one must be assumed in order to calculate values for the other. Once ψ_d is determined or assumed, the swelling pressure can be calculated from the following equation:

$$P = nRT\, M_o[\cosh(ze\psi_d/KT) - 1] \qquad (3)$$

where P is the swelling pressure (atm); n the weighted number of ions per mole (2 for NaCl, 3 for $CaCl_2$); R the gas constant and M_o the equilibrium salt concentration in moles/liter.

Demixed-ion Model: McNeal (1968, 1970) used the following equation to predict interlayer swelling for a "demixed-ion" model assuming that "the behavior of mixed Na-Ca-clays can be described adequately by considering such clays to consist of a mixture of homoionic Ca-saturated and Na-saturated interlayers with only the latter exhibiting interlayer swelling as the salt concentration of the ambient solution is decreased:"

$$X = (f_{mont})(3.6 \times 10^{-4})(ESP^*)(d^*) \qquad (4)$$

where X = interlayer swelling (g/g); f_{mont} = weight fraction of montmorillonite in the soil; ESP* = ESP - (1.24 + 11.63 log C_o) and d* = [1.2 + 356.4 $(C_o)^{-1/2}$] for C_o < 300 meq/liter and 0 for C_o > 300 meq/liter. For the above relationships C_o is the salt concentration of the equilibrium dialysate (meq/liter); ESP and ESP* are the experimental and "adjusted" ESP's; d* is the increase in interlayer spacing (Å) beyond the stable 19.8-Å spacing observed for Ca-montmorillonite and for Na-montmorillonite at high salt concentrations.

McNeal (1968) then proposed the following empirical equation to describe HC as a function of the swelling factor, X, derived from Eq. (4):

$$1 - y = Ck^n/(1 + CX^n) \tag{5}$$

where y - relative soil HC; n = 1 for ESP < 25, = 2 for ESP 25-50, and = 3 for ESP > 50; C varies with soil characteristics but average values are 25 for ESP < 25, 1000 for ESP 25-50, and 45,000 for ESP > 50.

<u>HC Experiments with Septic Tank Effluent</u>

As indicated by Weikart (1976), very little research has been done on the relationship between the chemical composition of septic tank effluent and the HC of the soil under the seepage field. Winneberger and Weinberg (1976) state: "A search of the literature disclosed that losses of permeabilities of Na-labile soils occurred when infiltrating fresh waters contained high concentrations of Na, but when the same high concentrations of Na were in sewages, permeabilities of the soils were not much changed." Unfortunately, the authors did not cite specific references to substantiate their statement.

The only study found that dealt directly with the problem of water-softener salts on HC was by Weibel et al. (1954) who approximated the composition of the softener wastes by dissolving the appropriate salts in 47 gallons of water and discharging this into a 455-gallon laboratory septic tank each Monday morning. The tank also received 250 gallons of raw sewage per day in eight feeds daily. Effluent from the normally-operating tank receiving softener-waste salt was passed through columns of Brookston silt loam as was effluent from a tank receiving no softener waste. The salt effluent caused less clogging and maintained higher HC than the regular septic-tank effluent. However, they tested aggregate stability and concluded that the brine effluent caused more damage to the soil structure. The test for structural stability was not valid because they used distilled water which would naturally cause swelling and structural breakdown in soils of high ESP such as those receiving the high-salt water. The authors' conclusion that "soil structure is more damaged by the salt effluent" is not only in direct contradiction to their preceding statement that "percolation rates are maintained at a higher value under salt effluent than normal effluent" (which would require a less-swelled condition) but it is based on a method of measurement which would be valid only if the seepage field were to be flushed with water of very low m_o such as rainwater.

To obtain further information about the effects water softeners may have on the HC in soil absorption beds, a study relating analysis of septic tank effluents with calculated soil conductivities was conducted.

MATERIALS AND METHODS

Septic tanks from eleven households were sampled to determine SAR and m_o. Five of the households used water softeners and discharged the regeneration waste into the septic tank on a regular basis. Each of the systems was sampled from one to five times for a total of 38 samples. In homes with conventional systems, the samples were taken near the surface of the tank but below any scum layer. For mound systems, the effluent was taken from the pumping chamber on the outflow side of the septic tank.

Samples were analyzed for Na and K by flame emission spectrophotometry, Ca and Mg by atomic absorption spectrophotometry after suppression of phosphate interference by addition of $SrCl_2$, and NH_4 by the microkjeldahl method. SAR values were calculated from these data. Values for m_o were determined from the sum of cations and also from electrical conductivities (U.S. Salinity Laboratory Staff, 1954).

Theoretical HC values for various levels of SAR, m_o and montmorillonite were calculated from Eq. (5) (McNeal, 1968) for a demixed-ion system. These values were used to construct a threshold value curve for soil containing 10% montmorillonite so that effects of the effluent compositions on HC could be estimated. Eqs. (2) and (3) (McNeal, 1970) for a mixed-ion system were used to calculate swelling pressures as a function of the thickness of the water layers separating two montmorillonite plates for hypothetical Na-Ca systems.

RESULTS AND DISCUSSION

The results of the effluent analyses are shown in Table 1. The estimates of m_o by EC are generally lower than estimates derived from summing the cations. This might be caused by the presence of large organic anions or ion-pairs. Because the lack of anion analyses prevents estimation of these factors, m_o values derived from EC data were used in Fig. 3.

Table 1. Chemical Characteristics of Septic Tank Effluent Samples from Systems With and Without Water Softeners

System no.	Softener	SAR	m_o EC	m_o Σ cations	System no.	Softener	SAR	m_o EC	m_o Σ cations
1	No	5.5	11.6	11.8	6	No	3.1	8.9	11.8
		3.1	7.3	7.0			3.5	8.9	14.4
2	No	2.8	7.3	7.3			10.4	13.0	16.1
		8.1	11.2	12.1			6.4	13.0	16.5
		5.3	11.8	14.6	7	No	8.0	11.2	13.5
		3.0	9.4	11.6		Yes	12.6	21.4	27.7
		7.4	9.4	11.3			7.7	11.8	14.9
3	No	3.0	8.9	13.0			12.7	21.2	26.0
		2.5	7.7	7.0	8	Yes	7.6	9.4	9.7
		2.7	7.7	8.8			5.9	5.9	7.4
		3.6	6.5	8.1			4.5	7.7	7.5
4	No	4.8	11.8	13.3			8.0	7.9	10.0
		4.8	11.8	18.2			3.0	5.9	7.5
		3.5	14.2	17.7	9	Yes	7.2	17.1	15.1
5	No	4.3	11.2	12.8			7.5	15.3	12.1
		5.6	9.4	10.1			8.1	21.8	22.9
		2.5	7.1	8.1			7.3	23.6	29.5
		6.7	9.0	12.2	10	Yes	16.4	21.2	24.7
							5.0	10.0	13.2
					11	Yes	7.4	14.2	17.1

Because of the almost complete absence of experimental data on effects of effluent composition on HC, the possibility of using Eq. (5) for prediction purposes was investigated. Threshold-value curves of % montmorillonite vs. SAR at m_o values of 20 and 50 meq/liter were calculated and plotted in Fig. 1. The threshold values derived from the literature are also plotted. In general, the McNeal equation appears to overestimate the threshold SAR at high percentages of montmorillonite and underestimate it at low montmorillonite. However, the agreement is reasonably good considering the experimental errors associated with montmorillonite estimates and HC determinations, and it tends to give near-minimum threshold values in the critical 0 to 15% montmorillonite range.

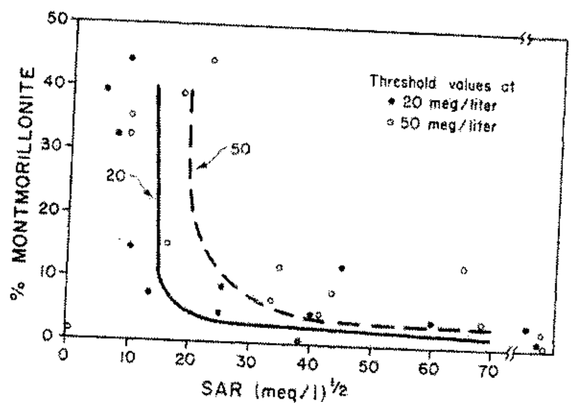

Fig. 1. Threshold Values of HC for Selected Values of m_o as Affected by SAR and Montmorillonite Concentrations

In many states, soils are considered unsuitable for septic tanks if the percolation rate is greater than 60 min/in. Bartelli (1962) as reported by Olson (1964) shows that the 60 min/in. limit generally falls in the silty clay loam textural class which contains between 27 and 40% clay. For Wisconsin soils, Jackson (personal communication) has estimated that montmorillonite comprises approximately 30% of the clay fractions of soils derived from loess and considerably less than 30% for some of the more clayey soils derived from shales. In the case of a subsoil containing 40% clay at 30% montmorillonite, the total soil montmorillonite content would be only 12%. Therefore the 10% figure used in subsequent calculations appears reasonable as an approximate upper limit for soils underlying septic tank seepage fields, at least for Wisconsin conditions.

Since the McNeal equation appeared to be useful for predicting minimum threshold values over the range of montmorillonite contents of interest for septic-tank seepage fields, a threshold-value curve of m_o vs. SAR at 10% montmorillonite was derived using Eq. (5). This curve is shown in Fig. 2 along with SAR-m_o data for the septic-tank effluents from systems with and without water softeners. All of the septic tank effluents fall within the stable HC range. In general, effluents with low SAR and low m_o are from systems without softeners while those of high SAR and high m_o are from systems with softeners. There is considerable overlap in the intermediate SAR-

m_o range. In some of the systems there are wide fluctuations in both m_o and SAR from one sampling to another; but in no case do the effluents exceed the calculated threshold values.

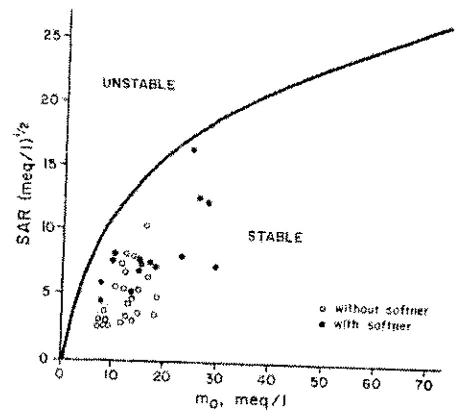

Fig. 2. Composition of Septic-Tank Effluents Compared with Threshold Values Calculated from Eq. (5) for 10% Montmorillonite

In order to look in another way at possible swelling problems associated with the additional Na added during the softening process and in the regeneration waters, calculations of swelling pressures as a function of the thickness of the water layers separating the montmorillonite plates were performed using Eqs. (2) and (3) (McNeal, 1970) for the mixed-ion model. In these calculations, we assumed that the average (Ca + Mg) content of the waste water was not affected by the softening process (all of the Ca and Mg taken out is put back during regeneration) so that any effect on HC would be due to addition of NaCl to the normal effluent. In order to determine swelling pressure for a particular distance between plates, the midpoint potential, ψ_d, at that spacing must be known. The ψ_d values at the desired spacings were obtained by assuming values of ψ_d (at desired levels of m_o and f) and plotting ψ_d as a function of spacing. The graphically determined ψ_d values at the desired spacings were then used to calculate swelling pressures at those spacings. The results are shown in Fig. 3 where swelling pressure is plotted against Na concentration for selected spacings. In these figures a (Ca + Mg) concentration of 5 meq/liter was assumed along with Na values of 0, 10, 20, 40, 80, 160 and 320 meq/liter. Similar graphs were prepared for (Ca + Mg) concentrations of 1, 10 and 20 meq/liter but they are not shown as the trends are similar in all of the systems.

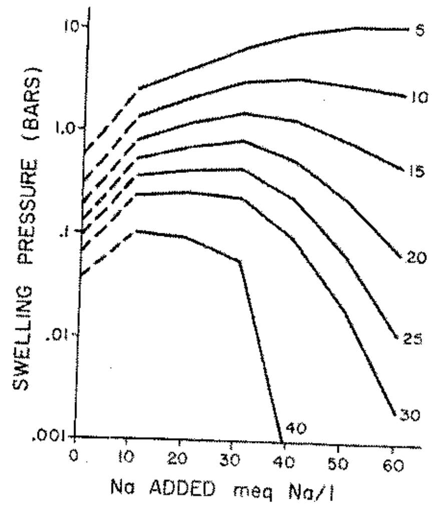

Fig. 3. Swelling Pressure as a Function of Na Concentration for Different, Half-distance Spacings (D - δ) in a Montmorillonite System Containing 5 meq/liter of (Ca + Mg). [Values of (D - δ) in Å are shown for each curve].

The graphs show a marked increase in swelling pressure at all spacings on addition of 10 meq/liter of Na to the pure (Ca + Mg) system. This would not be of great concern as far as water softener wastes are concerned, however, because normal septic tank effluent frequently contains this much Na. Addition of the second Na increment of 10 meq/liter of Na increases swelling pressure at midpoint spacings of 30 Å or less but decreases swelling pressure at 40 Å. This indicates that interlayer swelling would be increased up to an interlayer spacing between 60 and 80 Å but that the resulting spacing would be stable, i.e., there would be no tendency to disperse. As more Na is added, the spacing at which the additional Na causes a decrease in swelling pressure becomes smaller. Therefore, if this model correctly predicts the trends in swelling pressure, the addition of NaCl to normal septic tank effluent might or might not cause some additional swelling depending on the interlayer distances already existing, but it should not cause dispersion.

CONCLUSIONS

1. Reduction of hydraulic conductivity (HC) of soils receiving water with high sodium adsorption ratio (SAR) and low salt concentration (m_o) is due at first to the swelling of aggregates, which reduces the average pore size and thus HC, and subsequently to aggregate breakdown and dispersion. 2. If aggregates are not broken down during the swelling process, lowering the SAR or increasing m_o will at least partially restore the HC. 3. Once aggregate breakdown or dispersion has occurred, the effects will not be reversible. In coarse-textured soils, particularly, the dispersed particles may be

transported downward and become lodged in pore constrictions thereby irreversibly reducing HC.

4. Swelling and dispersion appear to be associated primarily with the expanding 2:1 layer silicate, montmorillonite. 5. The presence of sesquioxides tends to limit swelling of montmorillonite and increase stability of the aggregates. 6. Organic matter appears to stabilize aggregates at low SAR but to destabilize them at high SAR. 7. Swelling and dispersion for a given soil are probably greater the higher the pH. 8. Any mechanical stress will cause aggregate breakdown and dispersion at SAR values lower than where breakdown would normally occur.

9. The HC equation of McNeal (1968) based on a demixed-ion model appears to predict threshold values with reasonable accuracy. 10. Comparison of SAR and m_o values of a number of septic effluents with calculated threshold values indicates that salts in the waste waters from regeneration of water softeners create no HC problems in septic-tank seepage fields. 11. Lowered HC might result from water softening if all of the house water were softened and if the regeneration wastes were not allowed to enter the seepage field because almost all of the divalent cations would be removed resulting in high SAR and relatively low m_o. 12. Reduced HC might result if water of low m_o such as rainwater were to enter the system in which the soil under the seepage bed had a relatively high SAR because a soil that is stable at the relatively high m_o of the sewage effluent might swell and disperse under low m_o conditions.

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