Dispersion of Clay From Some Salt-Affected, Arid Land Soil Aggregates[1]

M. YOUSAF, O. M. ALI, AND J. D. RHOADES[2]

ABSTRACT

The dispersion characteristics of five arid land soils were determined upon reaction with solutions having various levels of electrolyte concentration, C (C = 0, 1, 4, 10, 30, 50, and 100 mmol$_c$L^{-1}), and sodium adsorption ratios, SAR (0, 5, 10, 20, and 40) with either Ca or Mg as the divalent counter-ion. With either divalent cation, clay dispersion increased as SAR increased and C decreased. Greater dispersion was observed with Mg as the divalent counter-ion due to the higher SAR and lower C levels, which resulted in the Mg systems compared to the Ca systems when the soils were reacted with comparable SAR and C treatment solutions. Dispersion threshold relations are concluded to be a useful criterion for screening soils for their sodicity hazard potentials.

Additional Index Words: **soil salinity, soil sodicity, aggregate stability.**

Yousaf, M., O.M. Ali, and J.D. Rhoades. 1987. Dispersion of clay from some salt-affected, arid land soil aggregates. Soil Sci. Soc. Am. J. 51:920–924.

CALCIUM AND MG HAVE, for practical purposes, been considered nondeleterious and equivalent for assessing the sodicity hazards of soils and irrigation waters (U.S. Lab. Staff, 1954). However, some researchers have concluded that Mg may be deleterious to soil structural stability in certain situations. Quirk and Schofield (1955) observed a greater decrease in the hydraulic conductivity (HC) of a Mg-saturated illitic soil compared to its Ca counterpart when leaching was carried out with distilled water and ascribed the difference to greater clay dispersion with Mg. Bakker et al. (1973) and Emerson and Chi (1977) also observed that an illitic soil was more likely to disperse and block soil pores in Na–Mg systems than in Na–Ca systems. Recently, Alperovitch et al. (1981, 1986) observed that in *noncalcareous* soils, exchangeable Mg caused greater reductions in HC and greater clay dispersion when they were leached with distilled water than did their Ca counterparts. On the other hand, Abder-Rahman and Rowell (1979) observed swelling, dispersion, and HC behaviors at the same levels of exchangeable sodium, E_{Na}, and electrolyte concentration, C, in both Na–Ca and Na–Mg systems. However, Mg was found to be more deleterious, in this regard, with vermiculite, illite, illitic soils, and mixed illitic-montmorillonitic soils than was Ca at equivalent levels of E_{Na} and C.

Rowell and Shainberg (1979) concluded that exchangeable Mg had no "specific effect" (i.e., different effect compared to Ca at equivalent E_{Na}, on the HC of a sodic, sandy loam soil that was dominated by kaolinitic and montmorillonitic clays at an electrolyte concentration of ≥ 10 mmol$_c$ L^{-1}. McNeal et al. (1968) and Abder-Rahman and Rowell (1979) pointed out that a part of the "specific" effect of Mg is that E_{Na} levels are higher in Mg–Na systems compared to Ca–Na systems at a given sodium adsorption ratio [SAR $=$ Na/(Ca $+$Mg) $^{1/2}$, with concentrations expressed in mmol L^{-1}].

The above brief review shows that the effect of exchangeable Mg on the stability of soil aggregates is controversial and not fully understood at present. This study reports data on clay dispersion from aggregates of arid land soils upon reaction with solutions of different divalent cation composition, SAR, and electrolyte concentration, in order to improve this understanding.

MATERIALS AND METHODS

The selected physical and chemical characteristics of the five soils studied are given in Table 1. These soils are representative of the many soils found in Californiia derived from granite-diorite parent material. A 50-g sample of each soil (<4 mm) was placed in a bottle, the air was evacuated, and a 400-mL aliquot of 500 mmol$_c$ L^{-1} chloride solution of the desired SAR (0, 5, 10, 20, or 40) was carefully introduced to avoid disaggregation. The bottle was gently inverted. After the aggregated soil (<4 mm) settled for a reference time (taken as the time when the supernatant appeared clear in the SAR 0, 500 mmol$_c$ L^{-1} solution; this time was different for each soil), each clear supernatant was siphoned off and the sediment was successively reacted twice more with the 500 mmol$_c$ L^{-1} solution and then successively with solutions of identical SAR but of lower electrolyte concentrations (100, 50, 30, 10, 4, 1, and 0 mmol$_c$ L^{-1}). At the reference settling time only particles of dispersed clay size remained in suspension and they were separated with the

---

[1] Contribution from the U.S. Salinity Lab., USDA-ARS, Riverside, CA 92501. This research was supported by a grant from the United States-Israel Binational Agricultural Research and Development Fund (BARD). Received 29 May 1985.

[2] Graduate student, Postdoctoral fellow, and Research Leader, respectively. The permanent address of the senior author is Associate Professor, Soil Science, Barani Agricultural College, Rawalpindi, Pakistan. The permanent address of the junior author is Assistant Professor, Suez Canal Univ., Ismailia, Egypt.

Table 1. Selected physical and chemical characteristics of experimental soils.

Soil	Particle size			pH	CEC	$CaCO_3$	Organic matter	Clay mineralogy†	Soil classification
	Sand	Silt	Clay	1:1					
	g kg^{-1}				$mmol_c$ kg^{-1}	g kg^{-1}			
Bonsall	540	282	178	7.1	95	0	9	S, M, and K	Fine, montmorillonite, thermic Natric Palexeralfs
Fallbrook I	556	185	259	7.9	143	0	6	K, V, S, and M	Fine-loamy, mixed thermic Typic Haploxeralfs
Fallbrook II	405	309	286	7.6	157	0	5	K, V, S, and M	Fine-loamy, mixed thermic Typic Haploxeralfs
Pachappa	646	216	138	7.5	92	0	9	S, M, and K	Coarse-loamy, mixed thermic Mollic Haploxeralfs
Arlington	364	442	194	7.6	184	0	15	V, ML, M, and K	Coarse-loamy, mixed thermic Haplic Durixeralfs

† S = smectite, M = mica, K = kaolinite, V = vermiculite, ML = mixed-layer.

Table 2. Comparison of cumulative clay dispersion in Ca–Na and Mg–NaCl solutions.

	Soil									
	Bonsall		Fallbrook I		Fallbrook II		Pachappa		Arlington	
C	Ca	Mg	Ca	Mg	Ca	Mg	Ca	Mg	Ca	Mg
$mmol_c$ L^{-1}	g kg^{-1}									
	SAR, 40									
100	--	--	--	--	--	--	--	--	0.2	--
50	1.1	4.3	2.8	11.1	0.2	4.0	1.4	7.4	0.5	--
30	13.7	13.1	12.7	19.5	12.1	4.0	4.9	10.4	1.2	1.5
10	31.6	26.0	23.8	26.1	24.1	5.2	14.4	13.4	18.2	22.7
4	49.3	47.4	33.3	39.5	114.6	60.7	22.1	15.6	57.4	71.7
1	54.6	63.4	38.4	49.8	165.0	151.4	28.0	18.6	69.8	83.3
0	59.3	86.5	42.3	62.2	196.7	227.7	32.7	30.3	101.0	111.2
	SAR, 20									
100	--	--	--	--	--	--	--	--	0.2	--
50	0.4	4.4	0.4	4.1	0.2	--	0.4	4.6	0.3	--
30	3.3	10.6	2.7	18.7	0.5	--	1.8	8.3	0.8	--
10	18.7	19.4	16.9	25.0	3.0	--	11.9	11.7	4.8	9.2
4	28.7	26.5	23.1	29.7	37.7	25.2	17.2	15.1	26.4	41.1
1	30.7	33.3	26.2	35.4	58.4	58.6	20.2	18.6	35.5	53.3
0	31.9	55.6	28.2	53.0	97.6	193.0	21.6	24.7	65.9	94.2
	SAR, 10									
100	--	--	--	--	--	--	--	--	--	--
50	0.2	--	0.3	--	0.1	--	0.3	3.8	0.2	--
30	1.2	2.4	0.8	1.7	0.4	--	0.7	6.7	0.4	--
10	6.6	15.8	9.9	14.4	0.8	--	5.0	11.0	3.5	2.3
4	14.1	23.7	16.8	23.1	19.8	4.5	11.1	14.6	19.4	23.9
1	15.4	28.7	19.8	26.2	33.7	35.2	13.6	17.4	23.7	30.2
0	16.3	35.9	21.1	36.1	40.3	119.7	14.5	23.9	30.4	48.8
	SAR, 5									
100	--	--	--	--	--	--	--	--	--	--
50	0.2	--	0.3	--	0.2	--	0.2	--	0.2	--
30	0.5	--	0.6	--	0.3	--	0.5	4.2	0.4	--
10	3.8	3.4	2.0	6.1	0.6	--	1.2	10.8	0.7	--
4	9.1	16.7	13.3	16.0	3.8	4.0	8.0	12.9	11.1	14.4
1	12.7	21.3	17.8	19.9	28.2	31.7	11.2	15.7	18.2	22.3
0	13.6	27.0	18.9	25.7	32.7	56.1	12.1	22.2	23.9	34.9
	SAR, 0									
100	--	--	--	--	--	--	--	--	--	--
50	--	--	--	--	--	--	--	--	0.1	--
30	--	--	--	--	--	--	--	--	0.4	--
10	--	--	--	--	--	--	--	--	0.5	--
4	--	3.8	0.1	6.0	--	2.5	--	1.6	0.8	--
1	6.2	13.3	7.1	15.0	0.3	5.8	5.0	6.3	5.1	6.2
0	7.5	20.2	8.5	19.9	5.0	31.4	6.4	10.4	22.7	29.9

Table 3. Comparison of cumulative clay dispersion relative to total soil clay in Ca–Na and Mg–NaCl solutions, g kg^{-1}.

	Bonsall		Fallbrook I		Fallbrook II		Pachappa		Arlington	
SAR	Ca	Mg	Ca	Mg	Ca	Mg	Ca	Mg	Ca	Mg
40	0.333	0.486	0.163	0.240	0.688	0.796	0.237	0.220	0.521	0.573
20	0.179	0.312	0.109	0.205	0.341	0.675	0.157	0.179	0.340	0.486
10	0.092	0.202	0.081	0.139	0.141	0.419	0.105	0.173	0.157	0.252
5	0.076	0.152	0.073	0.099	0.114	0.196	0.088	0.161	0.123	0.180
0	0.042	0.113	0.033	0.077	0.017	0.110	0.046	0.075	0.117	0.154

supernatant. The clay so dispersed was separated from the supernatant by centrifugation and its amount was determined by pipette and gravimetric techniques and its type(s) was determined by x-ray diffraction analysis (Ali et al., 1987). The composition of each supernatant solution was characterized by laboratory analysis with respect to pH, SAR, and electrical conductivity, σ. In order to evaluate the effect of Mg on clay dispersion from these mixed clay soils; analogous disaggregation determinations were made using $MgCl_2 \cdot 6H_2O$ and NaCl salts instead of $CaCl_2 \cdot 2H_20$ and NaCl salts in the preparation of the SAR solutions.

Threshold values of SAR and *C* for disaggregation were computed in three different ways for comparison and evaluation of appropriateness: clay dispersion of an amount equivalent to 3 and 5% of the total clay contents of the soils and dispersion of 5 g clay kg^{-1} soil. The "3 and 5%" threshold values are referred to as "relative" threshold values; the "5 g" threshold values are referred to as the "absolute" threshold values. The threshold lines given in Fig. 1, 2 and 3 were fitted by linear regression analysis.

RESULTS AND DISCUSSION

The amounts of clay dispersed from all of the soils increased as SAR increased and *C* decreased with either Ca or Mg as the divalent counter-ion (Tables 2 and 3).

Although SAR level had a dominant effect on the amounts of clay dispersed from all the soils irrespective of divalent cation type (Table 3), all soils were more dispersive, especially at lower SAR levels, with Mg compared to Ca as the divalent counter-ion, except Pachappa at SAR 40 (Table 2). The relative amounts of cumulative clay dispersed (relative to the total clay contents of each soil) at SAR 0 were 2.7, 2.3, 6.5, 1.7, and 1.3 times higher with Mg relative to Ca as the divalent counter-ion for Bonsall, Fallbrook I, Fallbrook II, Pachappa, and Arlington soils, respectively. Similar relative increases in clay dispersion occurred at the higher SAR levels with Mg as the divalent counter-ion as well. For example, for Bonsall soil, the amounts of clay dispersed in the Mg–NaCl solutions were 2.7, 2.0, 2.2, 1.7, and 1.5 times those in the equivalent Ca–Na solutions at SAR levels of 0, 5, 10, 20, and 40, respectively. These data show that

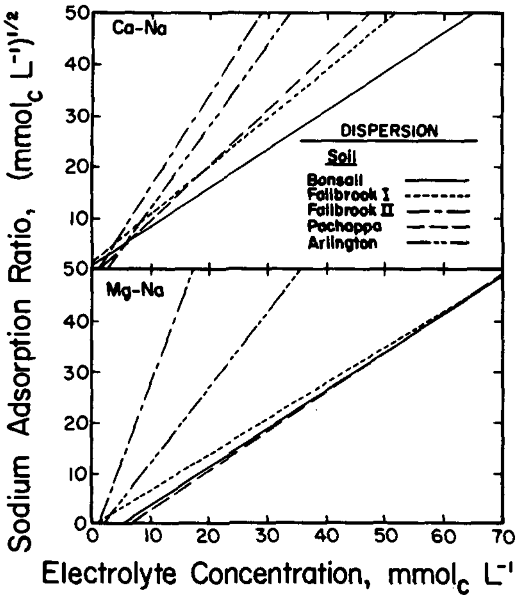

Fig. 1. Comparison of Ca–Na and Mg–Na clay dispersion threshold (SAR, C) relations based on 5% (50 g kg^{-1}) of total soil clay dispersed.

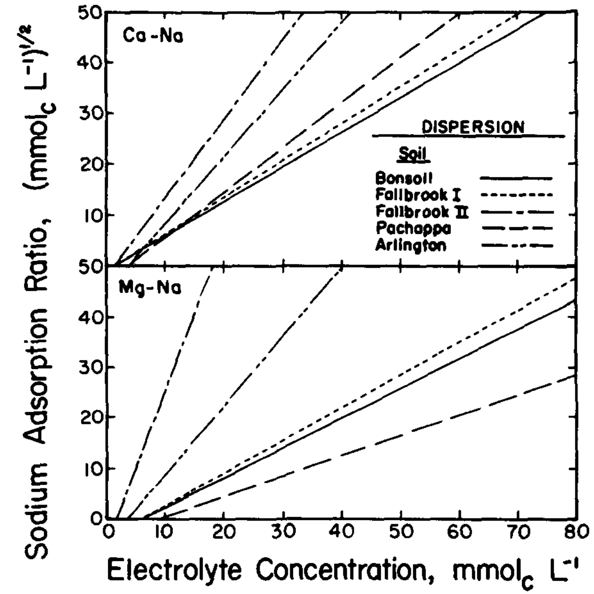

Fig. 2. Comparison of Ca–Na and Mg–Na dispersion threshold (SAR, C) relations based on 3% (30 g kg^{-1}) of total clay dispersed.

with Bonsall soil, the effect of Mg decreases as the SAR level increases. Since other soils displayed similar results, this observation may be true for arid land soils in general.

The influence of salt composition and concentration on clay dispersion for the various soils can be more readily compared and summarized by plotting the data as threshold values of SAR and C associated with the occurrence of significant dispersion. The concept of such a threshold relation was introduced by Quirk and Schofield (1955), and is a useful way to distinguish between those combinations of SAR and electrolyte concentration that result in reduced hydraulic conductivity and those that do not.

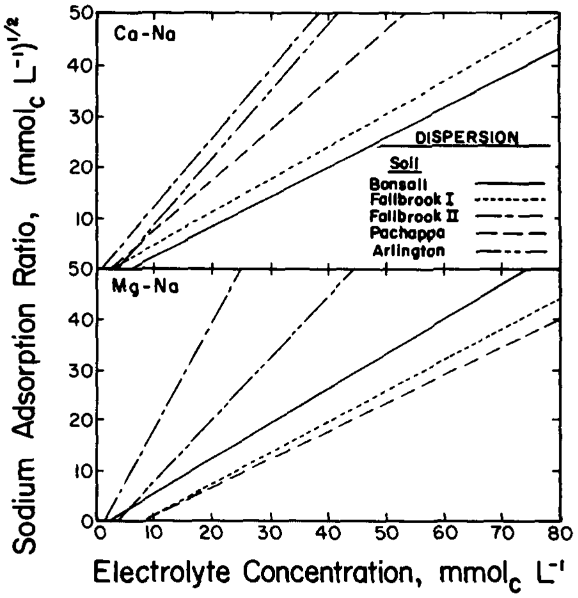

Fig. 3. Comparison of Ca–Na and Mg–Na dispersion *absolute* threshold (SAR, C) relations based on 5 g of clay dispersed kg^{-1} soil.

Three different methods of expressing the threshold relations were evaluated and compared. Threshold values based on clay dispersion equivalent to 5% (50 g kg^{-1}) of each soil's total clay content are shown in Fig. 1. These relations indicate that all the soils, with the exception of Pachappa and Bonsall soils with Mg as the divalent counter-ion, were rather similar in their threshold values at SAR levels of 0 and 5. However, differences among the soils are evident at higher levels of SAR. At SAR 0, the C threshold values for the various soils varied from <0 to 3 mmol$_c$ L^{-1} with Ca as the divalent counter-ion and from nearly 0 to 7 mmol$_c$ L^{-1} with Mg as the divalent counter-ion. Similarly, at SAR 40, the range was 27 to 52 mmol$_c$ L^{-1} for Ca and 13 to 58 mmol$_c$ L^{-1} for Mg. These results indicate that a greater variability in threshold relations exists with Mg as the divalent counter-ion. A greater sensitivity for clay dispersion with Mg compared to Ca as the divalent counter-ion was noted for all soils studied, except Fallbrook II.

With both divalent cations, Arlington and Fallbrook II were the least sensitive to clay dispersion among the soils studied. Yet these two soils were very dispersive at low electrolyte levels (<4 mmol$_c$ L^{-1}) and the highest amounts of cumulative clay dispersion were obtained for them.

It may be that clay dispersion of a lesser amount than 5% (50 g kg^{-1}) may be sufficient to reduce soil permeability. For this reason, relative clay dispersion threshold values were also calculated on the basis of 3% (30 g kg^{-1}) dispersion of the total clay content of each soil. The 3% relative threshold relations are given in Fig. 2. Again, the C threshold values were similar at low SAR levels (0 and 5) with either divalent counter- ion, with the exception of Na–Mg Pachappa. Pachappa was far more sensitive with Mg as the divalent counter-ion on the 3% basis. However, a greater variation in C threshold values among the soils was observed at the higher levels of SAR. On the 3% relative threshold basis, Bonsall, Fallbrook I, and Pachappa soils were more sensitive with Mg as the divalent counter-ion, whereas Fallbrook II and Arlington soils were more sensitive with Ca as the divalent counter-ion. With either divalent cation, all soils were slightly more dispersive on the 3% relative basis compared with the 5% relative basis, with the exception of the Na–Mg, Arlington soil, which was about equally sensitive according to both references.

These relative threshold relations are similar to those used by Rhoades (1982) to assess the sodicity hazards of irrigation waters, which were based on hydraulic conductivity data. They also are informative in that they show that the threshold relations are dependent on the percentage of clay chosen as the basis of expression. However, they do not interrelate dispersion sensitivity and the *absolute* amount of clay dispersed. For this reason absolute threshold relations were computed using 5 g of total clay dispersed per kilogram of soil as the threshold reference. These threshold relations are given in Fig. 3. Similar to the 5 and 3% threshold findings, the C threshold values increased as SAR increased from 0 to 40. The absolute C threshold values at SAR 15 were 27, 29, 13, 17, and 15 mmol$_c$ L^{-1} for the Na–Ca system and 33, 34, 8, 36, and 16 mmol$_c$ L^{-1} for the Na–Mg system for Bonsall, Fallbrook I, Fallbrook II, Pachappa, and Arlington soils, respectively. These absolute C threshold values are higher in the Na–Mg system compared to the Na–Ca system for all soils except Fallbrook II.

Based on the above, it is concluded that, in general, clay dispersion occurs more readily in arid land soils reacted with Na–Mg solutions compared with their Na–Ca counterparts, especially at low C and low SAR levels, when evaluated with reference to treatment levels per se. Threshold relations have often been established and expressed with reference to the levels of SAR and C (or σ) in the treatment solutions. However, the composition of the solution may be different *after* the reaction. It is debatable whether the treatment or reacted solution composition should be used in this regard. The resultant levels of SAR and σ in the reacted solutions (supernatants) are higher and lower, respectively, in the Na–Mg systems, especially in the higher SAR and C treatments (see Table 4). McNeal et al. (1968) also observed that E_{Na} is higher at a given SAR treatment in Na–Mg compared to Na–Ca systems. The pH data in Table 4 indicate that hydrolysis occurred upon reaction in both systems; pH is an additional factor affecting dispersion, as has been shown by Suarez et al. (1984) with high pH enhancing dispersion. However, pH was generally lower in the Na–Mg system compared to the Na–Ca system at equivalent treatment levels, probably because Mg is a slightly stronger acid than is Ca. Specific adsorption of Mg may also alter the surface potential of clay and affect the dispersion characteristics of soils.

The clay minerals that dispersed from these soils were determined by x-ray diffraction analysis and are given in Ali et al. (1987). A comparison of these clay dispersion results with the hydraulic conductivities of these same soils under similar conditions of SAR and C and the use of clay dispersion as an index for assessing the sodicity hazard sensitivities of soils are given in Yousaf et al., 1987.

Table 4. Compositions of supernatant solutions.

		Supernatant solution					
Reacting solution		Ca–Na system			Mg–Na system		
SAR	C	SAR	σ	pH	SAR	σ	pH
(mmol L^{-1})$^{1/2}$	mmol$_c$ L^{-1}	(mmol L^{-1})$^{1/2}$	dS m^{-1}		(mmol L^{-1})$^{1/2}$	dS m^{-1}	
			Bonsall				
40	50	35.0	6.5	6.5	39.0	6.1	6.4
	0	2.8	0	7.3	0.2	0	7.2
20	50	23.0	6.4	6.5	22.0	6.0	6.5
	0	3.0	0	7.2	1.7	0	6.8
10	50	14.0	6.4	6.5	11.0	5.9	6.1
	0	2.4	0	7.2	1.6	0	7.0
5	50	6.0	6.2	6.4	7.0	5.8	6.4
	0	2.3	0	7.1	1.4	0	6.9
0	50	0.7	6.3	6.0	0	5.8	6.3
	0	0.4	0	6.9	0.3	0	6.6
			Fallbrook I				
40	50	34.0	6.4	6.8	36.0	6.0	6.4
	0	4.8	0	7.3	1.9	0	7.2
20	50	22.0	6.7	6.8	31.0	6.0	6.5
	0	5.0	0	7.3	1.9	0	7.2
10	50	14.0	6.6	6.6	11.0	5.9	6.3
	0	3.7	0	7.3	1.6	0	7.1
5	50	6.0	6.2	6.5	7.0	5.9	6.4
	0	3.1	0.1	7.3	1.3	0	7.0
0	50	0.5	6.3	6.8	0	5.8	6.3
	0	0.8	0	7.1	0.2	0	6.7
			Fallbrook II				
40	50	33.0	6.7	6.8	37.0	6.2	6.3
	0	3.9	0	7.6	13.1	0	7.4
20	50	22.0	6.6	6.7	25.0	6.1	6.5
	0	4.0	0.1	7.5	1.4	0.1	7.3
10	50	14.0	6.7	6.7	15.0	6.1	6.3
	0	4.1	0.1	7.4	1.4	0	7.1
5	50	7.0	6.4	6.6	7.0	6.0	6.4
	0	2.8	0	7.4	1.3	0	7.0
0	50	0.9	6.5	6.4	0.3	5.8	6.5
	0	0.3	0	7.1	0.2	0	6.7
			Pachappa				
40	50	35.0	6.4	7.0	37.0	6.1	7.0
	0	4.5	0.1	7.4	2.8	0.1	7.3
20	50	23.0	6.5	6.9	30.0	6.0	6.9
	0	1.9	0.1	7.2	2.6	0.1	7.3
10	50	14.0	6.3	6.8	22.0	5.9	6.8
	0	3.8	0.1	7.4	2.0	0.1	7.2
5	50	6.0	6.1	6.8	7.0	5.8	6.6
	0	3.1	0.1	7.2	1.4	0.1	7.0
0	50	0.4	6.4	6.7	0	5.7	6.5
	0	0.3	0	7.0	0	0.1	7.0
			Arlington				
40	50	38.0	6.1	7.7	40.0	6.4	7.9
	0	1.1	0	7.5	1.0	0	7.8
20	50	18.0	6.1	7.7	25.0	6.5	7.8
	0	1.3	0	7.5	1.0	0	7.4
10	50	9.0	6.1	7.3	11.0	6.2	7.5
	0	1.9	0	7.2	0.9	0	7.3
5	50	5.0	6.0	7.6	7.0	6.1	7.7
	0	1.4	0	7.5	1.0	0	7.0
0	50	0	5.7	7.2	0	5.8	6.8
	0	0.4	0	7.3	0.2	0	6.9

CONCLUSIONS

More clay dispersion occurred from the studied soils with Mg as the divalent counter-ion compared to Ca, when compared on the basis of equivalent *treatment* levels of SAR and C, but SAR was higher, and σ was lower in the supernatants (reacted solutions) in the Na–Mg system. At equivalent levels of exchangeable Na and electrolyte concentrations, little difference exists between the Na–Mg and Na–Ca systems. However, because of the disparity in resultant levels of

SAR and σ, Na–Mg waters have a higher sodicity hazard than equivalent Na–Ca waters when compared at the same level of reacted electrolyte concentration.

REFERENCES

Abder-Rahman W., and D.L. Rowell. 1979. The influence of Mg in saline and sodic soils. A specific effect or a problem of cation exchange. J. Soil Sci. 30:535–546.

Ali, O.M., M. Yousaf, and J.D. Rhoades. 1987. Effect of exchangeable cation and electrolyte concentration on mineralogy of clay dispersed from aggregates. Soil Sci. Soc. Am. J. 51:896–900 (this issue).

Alperovitch. N., I. Shainberg, and R. Keren. 1981. Specific effect of magnesium on the hydraulic conductivity of sodic soils. J. Soil Sci. 32:543–554.

Alperovich, N., I. Shainberg, and J.D. Rhoades. 1986. Effect of mineral weathering on the response of three California sodic soils to exchangeable magnesium. Soil Sci. Soc. Am. J. 50:901–904.

Bakker, A.C., W.W. Emerson, and J.M. Oades. 1973. The comparative effect of exchangeable calcium, magnesium and sodium on some physical properties of red brown earth subsoils. I. Exchange reactions and water contents for dispersion of Shepparton soil. Aust. J. Soil Res. 11:143–150.

Emerson, W.W., and C.L. Chi. 1977. Exchangeable calcium, magnesium, and sodium, and the dispersion of illites. II. Dispersion of illites in water. Aust. J. Soil Res. 15:255–263.

McNeal, B.L., D.A. Layfield, W.A. Norvell, and J.D. Rhoades. 1968. Factors influencing hydraulic conductivity of soils in presence of mixed salt solutions. Soil Sci. Soc. Am. Proc. 32:187–190.

Quirk, J.P., and R.K. Schofield. 1955. The effect of electrolyte concentration on soil permeability. J. Soil Sci. 6:163–178.

Rhoades, J.D. 1982. Reclamation and management of salt affected soils after drainage. p. 123–197. *In* B.L. Colgan Annu. West. Provincial Conf., Rationalization of Water and Soil Res. and Manage. 1st "Soil Salinity", Alberta, Canada. 29 Nov.–2 Dec. Province of Alberta, Lethbridge, Alberta, Canada.

Rowell, D.L., and I. Shainberg. 1979. The influence of magnesium and of easily weathered minerals on hydraulic conductivity changes in a sodic soil. J. Soil Sci. 30:719–726.

Suarez, D.L., J.D. Rhoades, R. Lavado, and C.M. Grieve. 1984. Effect of pH on saturated hydraulic conductivity and soil dispersion. Soil Sci. Soc. Am. J. 48:50–55.

U.S. Salinity Laboratory Staff. 1954. Diagnosis and improvement of saline and alkali soils. USDA Handb. 60. U.S. Government Printing Office, Washington, DC.

Yousaf, M., O.M. Ali, and J.D. Rhoades. 1987. Clay dispersion and hydraulic conductivity of some salt-affected arid land soils. Soil Sci. Soc. Am. J. 51:905–907 (this issue).