FACTORS AFFECTING CLAY DISPERSION AND AGGREGATE STABILITY OF ARID-ZONE SOILS

SABINE GOLDBERG, D. L. SUAREZ, AND R. A. GLAUBIG[1]

We investigated the stability of 34 arid-zone soil samples from 15 soil series, using clay dispersion and aggregate stability as structural indexes. The study evaluated clay dispersion and aggregate stability as affected by: pH, electrical conductivity, sodium adsorption ratio, soluble silica, cation exchange capacity, exchangeable sodium percentage, inorganic carbon, organic carbon, free iron oxide, free aluminum oxide, clay, surface area, quartz, kaolinite, illite, chlorite, vermiculite, and montmorillonite. The most significant single-variable linear regressions were obtained for percentage of clay dispersed versus log (montmorillonite) ($r^2 = -0.52$**) and for percentage of aggregate stability versus organic carbon ($r^2 = 0.27$**). Significant variables for multiple linear regression for percentage of clay dispersed were montmorillonite, exchangeable sodium percentage, and electrical conductivity ($r^2 = 0.67$**). For percentage of aggregate stability, significant variables in the multiple linear regression were quartz, montmorillonite, and surface area ($r^2 = 0.49$**). Principal factor analysis results indicated that the structural indexes were related most to the soil variables stabilizing structure by physically binding particles. These binding agents are aluminum and iron oxides and organic matter.

Maintaining adequate water infiltration rates is a major concern in the irrigation of arid-land soils. Infiltration rates are susceptible to reduction from the detrimental effect of sodium in the soil solution and on the exchange complex (Shainberg and Letey 1984). Clay dispersion resulting in subsequent clay migration and plugging of conducting soil pores is regarded as the dominant process restricting water intake of irrigated arid-land soils. Numerous studies have investigated solution and soil factors that cause or relate to clay dispersion (Shainberg and Letey

1984 and the references cited therein). Solution factors affecting clay dispersion include electrolyte concentration, sodicity (Shainberg and Letey 1984), pH (Suarez et al. 1984), and soluble silica concentration (Shanmuganathan and Oades 1983). Soil factors include exchangeable sodium percentage, carbonate content (Shainberg and Letey 1984), clay mineralogy, and clay content (Frenkel et al. 1978). The above studies have been restricted to characterization of arid-zone soils.

Maintaining stable soil structure is important for all cultivated soils. In the absence of sodic conditions, soil structure is usually evaluated by determining the stability of soil aggregates. Aggregate stability is related to the amount of various soil constituents, including organic matter, clay, iron oxide (Kemper and Koch 1966), and aluminum oxide (Giovannini and Sequi 1976). Cation exchange capacity and surface area are two soil properties that, being related to clay content and type, are also expected to influence aggregate stability and dispersion.

The objective of this study was to determine which of the above factors were the most important in affecting stability of arid-zone soils as measured by two structural indexes. We examined aggregate stability and clay dispersion of 34 California soil samples from 15 different soil series treated with distilled water. Distilled water treatment was considered by Rengasamy et al. (1984) to be qualitatively indicative of field dispersibility of bare soils during a rainfall event. The effect of all the variables enumerated above on the values of the soil structural indexes for the soil samples was investigated using single-variable regression, multiple linear regression, and factor analysis.

MATERIALS AND METHODS

The structural stability and chemical characteristics of 34 California soil samples were determined using the <2-mm fraction, unless otherwise indicated. Soil classifications, physical and chemical characteristics, and structural indexes are given in Table 1. Clay dispersion under gentle end-over-end shaking was meas-

TABLE 1

Classifications and physical and chemical characterization of soils

Soil series	Depth, cm	EC dS m⁻¹	pH	SAR	Si, g m⁻³	CEC, mmol_c kg⁻¹	ESP
Altamont (fine, montmorillonitic,	0–25	0.08	6.6	0.35	4.5	152	0.60
thermic Typic Chromoxerert)	25–51	0.06	6.6	0.52	4.7	160	0.84
Arlington (coarse-loamy, mixed,	0–25	0.08	8.1	0.19	5.1	107	0.44
thermic Haplic Durixeralf)	25–51	0.10	8.4	1.88	5.2	190	2.18
Bonsall (fine, montmorillonitic,	0–25	0.11	6.6	0.27	3.0	54	0.24
thermic Natric Palexeralf)	25–51	0.05	7.0	0.80	5.8	122	1.63
Fallbrook (fine-loamy, mixed,	0–25	0.05	7.5	0.47	3.8	112	0.74
thermic Typic Haploxeralf)	25–51	0.06	7.1	0.45	2.8	78	0.85
Imperial (fine, montmorillonitic (cal-	Surface clods	0.45	8.5	3.82	3.6	222	4.22
careous), hyperthermic Vertic Tor-							
rifluvent)	0–7.6	1.03	8.0	3.23	3.5	229	3.59
Twisselman (fine, mixed (calcar-	Surface	3.22	7.8	1.98	7.9	197	7.64
eous), thermic Typic Torriorthent)	15–46	4.90	8.0	4.11	7.3	204	19.6
Pachappa (coarse-loamy, mixed,	0–25	0.08	7.6	0.22	3.5	39	0.01
thermic Mollic Haploxeralf)	25–51	0.04	7.8	0.13	3.5	52	0.01
Ramona (fine-loamy, mixed, thermic	0–25	0.10	6.5	0.24	2.7	66	0.01
Typic Haploxeralf)	25–51	0.12	6.8	0.28	4.9	29	0.34
Wyman (fine-loamy, mixed, thermic	0–7.6	0.21	7.3	0.65	4.9	100	0.81
Typic Haploxeralf)	0–7.6	0.16	7.2	0.57	5.9	123	0.70
	0–7.6	0.16	7.2	0.29	6.2	144	0.29
	0–7.6	0.18	7.5	0.28	6.0	116	0.37
	0–7.6	0.06	7.1	0.25	5.9	74	0.55
Porterville (fine, montmorillonitic,	0–7.6	0.18	7.3	0.34	7.2	203	0.39
thermic, Typic Chromoxerert)							
Hesperia (coarse-loamy, mixed, non-	0–7.6	0.08	7.5	1.58	4.4	45	4.84
acid, thermic, Xeric Torriorthent)	0–7.6	1.07	8.1	11.7	5.4	91	44.5
Wasco (coarse-loamy, mixed, nona-	0–5.1	0.13	5.7	0.12	2.9	71	0.42
cid, thermic, Typic Torriorthent)	94–165	0.20	7.1	0.26	4.5	55	0.60
Arbuckle (fine-loamy, mixed thermic,		0.16	8.6	2.79	9.9	170	6.65
Typic Haploxeralf)		0.19	9.4	7.07	5.0	31	17.2
		0.19	8.8	2.85	10.1	196	9.04
		0.15	9.2	2.58	7.7	87	7.64
Panoche (fine-loamy, mixed (calcar-		0.24	8.2	1.48	6.4	208	1.54
eous), thermic Typic Torriorthent)		0.41	8.0	1.97	6.1	210	1.87
Wyo (fine-loamy, mixed, thermic	0–10	0.12	7.4	0.61	3.6	161	0.61
Mollic Haploxeralf)		0.09	7.1	0.21	4.1	155	0.17

IOC	OC	Fe	Al	Clay	SA	Q	Kaol	Ill	Chlor	Verm	Mont	Clay dispersed	Aggregate stability
	%				m² g⁻¹					%			
0.001	0.85	0.77	0.058	23.0	102.5	0.32	1.3	4.6	0.32	3.1	13.3	8.11	76.7
0.004	0.65	0.82	0.064	17.0	114.2	0.24	1.2	2.8	0.34	0.71	11.7	11.3	75.8
0.060	0.51	0.82	0.048	17.5	61.1	0.82	1.7	6.4	0.93	2.6	5.1	13.2	73.7
0.011	0.15	1.01	0.060	14.0	103.1	0.57	2.4	0.75	1.8	3.2	5.3	11.5	72.4
0.001	0.60	0.93	0.045	16.5	32.9	0.002	14.6	1.4	0.15	0.13	0.28	24.5	44.1
0.007	0.21	1.68	0.091	30.9	105.7	0.003	27.9	1.9	0.19	0.53	0.40	25.5	72.7
0.020	0.38	0.69	0.036	17.0	68.3	0.17	10.9	4.7	0.15	0.58	0.56	28.6	75.7
0.024	0.31	0.49	0.021	9.2	28.5	0.13	5.9	2.9	0.07	0.04	0.18	29.8	69.5
1.88	0.89	0.61	0.038	46.0	196.0	8.6	19.9	5.8	3.0	0.05	8.6	25.9	78.3

TABLE 1—*Continued*

IOC	OC	Fe	Al	Clay	SA	Q	Kaol	Ill	Chlor	Verm	Mont	Clay dispersed	Aggregate stability
		%			$m^2\,g^{-1}$					%			
1.76	0.83	0.67	0.043	44.0	191.4	5.5	15.8	2.9	1.8	3.1	14.9	0.39	78.0
0.170	0.56	0.30	0.063	33.0	182.4	1.6	11.3	5.0	2.8	1.6	10.8	1.19	69.0
0.166	0.41	0.27	0.063	30.8	159.3	0.74	9.5	3.2	1.8	1.2	14.4	1.83	32.4
0.010	0.49	0.76	0.067	13.0	36.3	0.29	1.8	8.2	0.62	0.36	1.7	24.2	36.0
0.038	0.12	0.72	0.038	7.0	41.0	0.11	0.99	4.5	0.25	0.18	1.0	29.8	65.0
0.002	0.56	0.45	0.042	12.0	27.9	0.06	1.5	9.8	0.10	0.17	0.36	28.9	31.9
0.025	0.21	0.59	0.040	12.2	38.8	0.31	1.5	9.9	0.09	0.28	0.18	42.1	42.4
0.044	0.72	0.65	0.064	21.9	86.5	0.96	7.2	11.2	0.35	1.0	1.2	12.2	89.6
0.021	0.64	0.77	0.074	31.0	122.2	1.6	11.8	14.8	0.37	0.87	1.6	11.6	87.8
0.011	0.79	1.04	0.082	26.9	107.8	0.59	12.9	11.3	0.56	0.35	1.2	11.8	91.7
0.016	0.79	0.96	0.077	26.9	105.6	0.86	11.3	12.4	0.59	0.48	1.3	3.46	86.4
0.014	0.67	0.83	0.072	23.1	84.3	0.65	10.8	8.8	0.37	0.44	2.1	15.0	86.3
0.023	0.84	1.07	0.090	38.5	172.2	3.1	15.8	13.6	1.1	0.89	4.0	2.96	87.3
0.001	0.44	0.32	0.034	8.4	30.9	0.03	1.7	6.1	0.12	0.14	0.34	22.2	57.2
0.068	0.20	0.38	0.036	13.4	48.7	0.12	1.7	10.9	0.25	0.04	0.39	45.1	56.2
0.001	0.40	0.24	0.042	13.4	55.9	0.20	3.5	6.0	0.11	0.58	3.0	20.0	70.4
0.016	0.21	0.24	0.035	14.6	48.2	0.31	3.6	7.9	0.25	0.42	2.1	6.10	56.7
0.017	0.69	0.40	0.058	23.8	138.1	3.7	3.8	5.3	0.98	2.5	7.6	18.6	82.7
0.013	0.35	0.32	0.022	9.2	19.5	1.8	2.4	4.0	0.17	0.37	0.48	31.2	74.1
0.019	0.60	0.40	0.071	26.6	165.1	5.0	5.3	7.1	2.7	1.0	5.5	20.8	82.6
0.013	0.32	0.28	0.032	11.7	44.7	3.4	2.1	3.9	0.26	0.50	1.5	27.7	77.2
0.075	0.80	1.27	0.098	29.3	154.0	1.2	11.8	2.5	5.9	0.26	7.5	2.11	78.6
0.081	0.75	1.25	0.095	26.6	151.0	1.1	11.7	2.6	5.8	0.003	5.3	0.63	79.4
0.005	0.86	1.00	0.085	21.9	80.9	0.55	9.3	6.0	2.4	0.24	0.3	24.5	93.3
0.015	1.37	0.95	0.089	15.7	78.2	0.93	7.1	4.2	2.2	0.002	1.1	21.3	89.3

ured in duplicate using the mechanical dispersion method of Rengasamy et al. (1984). Stability of the 1- to 2-mm aggregates was measured in duplicate after vacuum-wetting using the method of Kemper and Rosenau (1986). The stroke frequency of the sieving machine was 44 to 50 strokes per minute.

Electrical conductivity (EC), pH, sodium adsorption ratio (SAR = Na/(Mg + Ca)$^{1/2}$, solute concentrations in $mol_c\,m^{-3}$), and soluble Si concentration of the supernatants from the mechanical dispersion method were determined. Soluble Na, Mg, and Ca concentrations for calculation of SAR were determined using inductively coupled plasma (ICP) emission spectrometry. Soluble Si concentrations were obtained on a Technicon Auto Analyzer II with the heteropoly blue method (American Public Health Association 1976) using ascorbic acid as the reducing agent (Technicon Auto Analyzer II Industrial Method no. 105-71W/B).[2]

Cation exchange capacity (CEC) of each of the soils was determined using the method for arid-land soils described by Rhoades (1982). Exchangeable Na, K, Mg, and Ca concentrations for calculation of exchangeable sodium percentage (ESP = Na/(Na + K + Mg + Ca), concentrations in $mmol_c\,kg^{-1}$) were obtained as described by Knudsen et al. (1982). Inorganic carbon (IOC) and organic carbon (OC) analyses were conducted as described by Nelson and Sommers (1982). Free iron oxide (Fe) and free aluminum oxide (Al) were extracted using the method of Coffin (1963). Aluminum and Fe concentrations were determined by ICP.

Percentage of clay was determined using the hydrometer method of particle-size distribution described by Day (1965). Surface area (SA) was measured using ethylene glycol monoethyl ether (EGME) adsorption (Cihacek and Bremner 1979). Clay mineralogy was determined on Mg-saturated <2-μm fractions by x-ray diffraction analysis. Estimates of quartz (Q), kaolinite (Kaol), illite (Ill), chlorite (Chlor), vermiculite (Verm), and montmorillonite (Mont) were made by directly converting diffraction peak areas to

clay mineral contents using the method of Klages and Hopper (1982).

RESULTS AND DISCUSSION

Regression analyses for percentage of clay dispersed and percentage of aggregate stability versus each of the soil variables were carried out using linear, exponential, logarithmic, and power single-variable functions. The resultant correlation coefficients are presented in Table 2. There were highly significant ($P = 99\%$) relations between EC, CEC, IOC, OC, Al, clay, SA, Chlor, Verm, Mont, and percentage of clay dispersed. The relations between Si, Q, Kaol, and percentage of clay dispersed were significant ($P = 95\%$), while those between pH, SAR, ESP, Fe, Ill, and percentage of clay dispersed were not significant. The highest correlation coefficient ($r^2 = -0.52**$) was obtained for the logarithmic relation between Mont and percentage of clay dispersed.

For percentage of aggregate stability there were highly significant ($P = 99\%$) relations with CEC, OC, SA, and Q, as shown in Table 2. The relations between Fe, Al, clay, Kaol, Chlor, and

percentage of aggregate stability were significant ($P = 95\%$), while those between IOC, Ill, Verm, Mont, and percentage of aggregate stability were not significant. In the determination of percentage of aggregate stability, EC, ESP, and pH were considered to be constant, because the samples were immersed in the same large container of distilled water. The highest correlation coefficient ($r^2 = 0.27**$) was obtained for the linear relation between OC and percentage of aggregate stability.

It is apparent from the values in Table 2 that the clay dispersion index correlated with more factors and to a greater degree than did the aggregate stability index. This result provides no information on the predictive nature of either of these indexes for field conditions. It suggests, however, that if the physical and chemical variables listed in Table 1 are to be studied, it may be preferable to examine their effect on clay dispersion rather than on aggregate stability.

Multiple linear-regression analyses were carried out using all variables with the following exceptions. SAR and ESP, as well as, CEC, clay, and SA, were judged to be too closely related to

TABLE 2
Significant one-variable correlation coefficients[a]

Variable	Linear	Exponential	Logarithmic	Power
Percentage of clay dispersed				
EC		−0.48**	−0.37*	−0.60**
Si			−0.35*	
CEC	−0.61**	−0.64**	−0.61**	−0.58**
IOC				−0.47**
OC	−0.43**		−0.47**	−0.36*
Al	−0.53**	−0.42**	−0.55**	−0.42**
Clay	−0.58**	−0.62**	−0.62**	−0.61**
SA	−0.65**	−0.69**	−0.68**	−0.64**
Q			−0.37*	−0.39*
Kaol		−0.34*	−0.40*	−0.43*
Chlor	−0.46**	−0.58**	−0.58**	−0.61**
Verm	−0.44**	−0.36*		
Mont	−0.61**	−0.65**	−0.72**	−0.64**
Percentage of aggregate stability				
CEC	0.44**	0.40*	0.52**	0.48**
OC	0.52**	0.44**	0.45**	0.37*
Fe	0.36*		0.38*	0.34*
Al	0.43*	0.36*	0.38*	
Clay	0.38*		0.41*	0.36*
SA	0.40*	0.37*	0.49**	0.46**
Q			0.49**	0.45**
Kaol			0.40*	0.36*
Chlor			0.38*	0.34*

[a] Significance at the 95% (*) or the 99% (**) level of confidence.

be included together in the regression analyses. For this reason only the variable having the highest significance in the single variable regressions for percentage of clay dispersion from each group, ESP and SA, respectively, was used. Variables showing greater significance in a nonlinear single regression analysis were transformed in that manner.

Prior to the multiple linear-regression analysis of percentage of clay dispersed, logarithmic transformations were performed on Si, clay, OC, SA, Al, and Mont; square root transformations were performed on EC, IOC, Q, Kaol, and Chlor. The multiple correlation coefficient was $r^2 = 0.83^{**}$ for percentage of clay dispersed using 15 soil variables. Forward-selection regression analysis adds variables in order of significance of their contribution (highest F ratio) to a multiple linear regression. Maximum r^2 improvement regression analysis sequentially adds that variable to the multiple linear regression that provides the greatest increase in r^2 value. Unlike forward selection, it allows for the removal and replacement of a previously selected variable by the variable that most improves the overall r^2. For both procedures, only variables providing a significant (95% level) value of F-prime were added. Significant variables for forward-selection analysis of percentage of clay dispersed in order of addition were Mont, ESP, EC, and Al ($r^2 = 0.71^{**}$). Using maximum r^2 improvement analysis, only the first three variables in that order were significant ($r^2 = 0.67^{**}$) with the following regression equation

% clay dispersed = 34.3 − 4.7 log(10

$$\times \text{ Mont}) + 0.7\text{ESP} - 10.6\sqrt{\text{EC}} \quad (1)$$

The predictive ability of this equation is indicated in Fig. 1. In this case, maximum r^2 improvement analysis provided a smaller number of significant variables than forward-selection analysis. As shown in Fig. 1, reasonable predictions were obtained above 20% clay dispersion. Below 20% clay dispersion, predicted values did not increase with increases in measured percentage of clay dispersion. We do not consider this to be a serious limitation on the use of the equation, because our major interest is in predicting dispersive soils.

Prior to the multiple linear-regression analysis of percentage of aggregate stability, logarithmic transformations were performed on CEC, clay, SA, Fe, Q, Kaol, and Chlor. The multiple
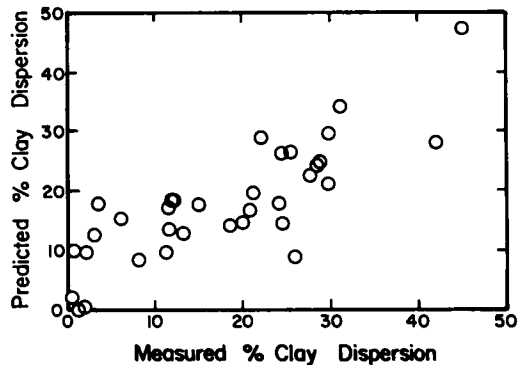

FIG. 1. Percentage of clay dispersed predicted with Eq. (1) using maximum r^2 improvement regression analysis.

correlation coefficient was $r^2 = 0.75^{**}$ for percentage of aggregate stability using 11 soil variables. The variables EC, pH, Si, and ESP were not measured in the percentage of aggregate stability determinations. Using forward-selection regression analysis, the significant variables for percentage of aggregate stability in order of addition were OC, Q, and Fe ($r^2 = 0.47^{**}$). Significant variables for maximum r^2 improvement, however, were Q, Mont, and SA in that order ($r^2 = 0.49^{**}$) with the following regression equation

% aggregate stability = −18.2 + 3.4Q

$$- 2.2\text{Mont} + 17.8 \text{ log(SA)} \quad (2)$$

The predictive ability of this equation is indicated in Fig. 2. As expected, maximum r^2 improvement analysis provided a better prediction (higher r^2 value) using the same number of variables than forward-selection analysis. As shown in Fig. 2, the eight values of aggregate stability below 60% were not predicted well. This result limits the usefulness of the equation, because we are primarily interested in predicting soils of low aggregate stability.

Multiple linear regression assumes that no significant interactions exist between the independent variables. Values for the correlation coefficients between the soil variables are given in Table 3 and indicate some significant interactions. The close relation between the two sets of variables discussed above (SAR and ESP, as well as CEC, clay, and SA), was affirmed by the high values of the correlation coefficients ($r > 0.90^{**}$). There was evidence for multicollinearity in our original set of variables as determined by

variance inflation factors, VIF. VIF for the ith regression coefficient is defined as VIF $= 1/(1 - R_i^2)$, where R_i^2 is the coefficient of multiple determination for the regression of variable x_i against the other variables x_j ($j \neq i$) (Myers 1986). Myers (1986) indicates that if any VIF exceeds 10 there is reason for some concern about multicollinearity, and either variables should be deleted or a technique, such as ridge regression, should be used to reduce the problem. We found, using a ridge trace, that a large value of the shrinkage parameter, k, would be required to stabilize the coefficients and therefore decided that ridge regression would introduce too much bias. The variables in our final regression equations, Eqs. (1) and (2), all had VIF values

FIG. 2. Percentage of aggregate stability predicted with Eq. (2) using maximum r^2 improvement regression analysis.

below 3, indicating that the forward-selection and maximum r^2 improvement analyses were successful in eliminating collinear variables using the partial F-test criterion.

Factor analysis was performed using the principal factor analysis program described in the SAS/STAT guide (SAS Institute 1985). Factor analysis is utilized for interpreting data sets with complex interrelationships. By clustering variables into factors that represent underlying processes, variable interrelations can often be sorted out. The data are initially transformed as needed to approximate a normal distribution. Each variable is assigned equal weighting (unit variance), because the procedure is based on the variance-covariance matrix (Davis 1986). The procedure assumes that the relationship within a set of variables reflects the relation of each of the variables with a set of uncorrelated (common) factors, in addition to unique factors representing the contribution of individual variables (Davis 1986). In contrast to a correlation matrix, the diagonal elements are the variances of the variables in the common factors. This also distinguishes the procedure from principal components analysis. This matrix is then considered to be the product of an $n \times f$ matrix of factor loadings multiplied by its transpose plus an $n \times n$ diagonal matrix of unique variances. The normalized eigenvectors are converted into factors that are weighted according to the total variance they represent. We utilized Kaiser's varimax rotation (SAS Institute 1985), a proce-
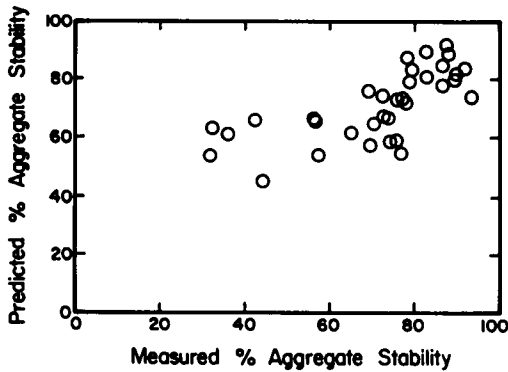
TABLE 3

Significant correlation coefficients between variables[a]

	SAR	Si	CEC	ESP	IOC	OC	Fe	Al	Clay	SA	Q	Kaol	Chlor	Verm	Mont
EC	0.34*		0.37*	0.45**						0.41*					0.55**
pH		0.58**	0.52**		0.43*							0.55**		0.36*	
SAR				0.95**			−0.35*								
Si			0.43*					0.38*	0.34*	0.52**					
CEC					0.44**	0.52**		0.54**	0.79**	0.93**	0.55**	0.46**	0.71**	0.41*	0.73**
ESP							−0.40*								
IOC								0.62**	0.51**	0.77**	0.41*				0.47**
OC								0.56**	0.51**	0.48**	0.34*		0.43*		
Fe								0.73**				0.58**			
Al									0.49**	0.53**		0.47**	0.54**		
Clay										0.91**	0.65**	0.76**	0.48**		0.58**
SA											0.63**	0.56**	0.63**	0.37*	0.72**
Q												0.35*			0.40*
Ill															−0.35*
Chlor															0.42*
Verm															0.62**

[a] Significance at the 95% (*) or the 99% (**) level of confidence.

dure that rotates the factor axes such that factor loadings are closer to either 1.00 or 0.0, facilitating interpretation of the factors. Criteria for determining how many factors to retain for rotation include the following: (1) sharp changes in eigenvector size as additional factors are added; (2) absolute eigenvector size; (3) whether a factor is a unique or common factor. The factor rotation is achieved by minimizing the variance of the loadings on the factors.

The factor analysis results for the percentage of clay dispersed data given in Table 4 are based on varimax rotation of two factors (only factor loadings above 0.5 are reported). The additional unrotated factors showed neither multiple variable loadings nor high factor loading for individual variables and had small eigenvectors. The first factor for the percentage of clay dispersion experiment contains relatively high factor loadings for EC, pH, SAR, IOC, Si, and Q. This factor accounted for 36% of the total variance in the data set and is related to solution chemistry and the soil variables that control it. Be-

TABLE 4
Rotated factor analysis

Variable	Factor 1	Factor 2
Clay dispersed, %		−0.66
EC	0.76	
pH	0.77	
SAR	0.77	
Si	0.62	
IOC	0.73	
OC		0.72
Fe		0.73
Al		0.89
Clay	0.50	0.75
Q	0.77	
Kaol		0.67
Ill		
Chlor	0.67	0.59
Verm		
Mont	0.65	
Aggregate stability, %	0.69	
IOC		0.55
OC	0.75	
Fe	0.59	−0.64
Al	0.82	
Clay	0.86	
Q		0.74
Kaol	0.72	
Ill		
Chlor	0.81	
Verm		
Mont	0.59	0.62

cause these soils were reacted without chemical pretreatment, the measurements should relate to interactions under native conditions. Increased clay content can reduce drainage and be associated with higher EC and SAR, as well as with greater precipitation of calcite. Reacting such a soil in distilled water would result in a higher laboratory pH value. The high factor loading for Q is presumed to be due to mineral association factors. The lack of association of percentage of clay dispersion with solution chemical factors is not too surprising, considering that the dispersion test is carried out with the addition of distilled water. As discussed earlier, the test indicates field dispersibility of bare soils during rainfall events. The lack of association of solution chemistry with this factor indicates that, in the dilute solutions resulting from the addition of distilled water, the effect of these variables is relatively minor. Factor 2 shows a negative loading of percentage of clay dispersion and a positive loading for OC, Al, Fe, and clay. This factor accounted for 32% of the total variance in the data set. The largest loading was found for the soil variables that stabilize structure by physically binding particles (see Table 4). Of the binding agents, Al was the one with the greatest factor loading, followed by clay, Fe, and OC. This factor represents the soil-binding agents and the component of clay dispersion associated with those processes.

The factor analysis results for the percentage of aggregate stability data shown in Table 4 are based on varimax rotation of two factors. The same selection criteria were used for this data set as were used for the percentage of clay dispersion data. The first factor is associated with percentage of aggregate stability, OC, Al, clay, Chlor, Kaol, Fe, and Mont. These variables are linked by their representation of binding processes in the soil. Percentage of aggregate stability increased as the amount of binding agents increased. The factor loadings are slightly lower than those for factor 2 in the clay dispersion data. That the factor represented 48% of the total variance does not imply better predictive ability than for the clay dispersion test. The higher percentage of total variance explained by factor 1 of this data set (as compared with factor 2 of the previous set) is due to the smaller number of variables. Except for the addition of Mont in the percentage of aggregate stability data set, both factor 2 for percentage of clay dispersed and factor 1 for percentage of aggre-

gate stability are similar. Factor 2 represented 26% of the total variance of the entire data set. The association of IOC, Q, Mont, and Fe is not readily interpreted, but appears to be related to mineral associations during deposition.

Differences between the results of multiple regression and factor analysis are not unexpected, because they are due to differences in optimization. Multiple regression optimizes to select variables with the best predictive ability. Factor analysis groups variables into common associations. If we can determine the link between the variables in these common factors, we can increase our understanding of the relationship of a variable (such as structure) to the processes (such as relative importance of solution chemistry and binding agents) explaining its variance. Variables loading onto several factors are related to several processes. As an example, Mont and Q are highly related to percentage of aggregate stability. We cannot explain why increasing Q should increase aggregate stability. Regression analysis provides no insight into the reasons for this association. Therefore, we have no confidence that Q could be a predictor of stability in other data sets. Factor analysis indicates that Q is associated with the binding process factor (loading 0.49) and factor 2. Quartz is not one of the major variables in factor 1, suggesting that it is not very important in binding and that its association may be due to mineral associations rather than a direct effect of Q on binding. Montmorillonite is a significant factor in the regression; however, an examination of Table 4 suggests that its variance is spread between factors 1 and 2. The association with percentage of aggregate stability is likely only partly through the binding factor. In their effect on aggregation, given quantities of montmorillonite are more effective than equal quantities of kaolinite (Kemper and Koch 1966).

From the factor analyses, we conclude that both stability tests relate to similar soil properties. Our results indicate that such binding agents as Al and Fe oxides and organic matter play an important role in the structure of arid-zone soils. The result that native Al relates best to the binding factor related to the structural indexes is consistent with previous research. Earlier results indicated that Al oxides, when added to soils, were more important in stabilizing dispersed and aggregated soil samples than

Fe oxides (El Rayah and Rowell 1973). Chemical variables, such as EC, SAR, and pH, have been shown to be important in affecting structural stability when they vary. However, this study indicates that, for the wide selection of arid-zone soils examined, where solution chemistry variables do not vary much, binding agents are dominant in determining stability under the distilled water test conditions pertaining to rainfall. Our results suggest that these chemical variables are insufficient for field prediction of different soils containing various amounts of binding agents.

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