An alternative index to ESP to explain dispersion occurring in Australian soils when Na content is low

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Abstract

Re-use of industrial and agricultural wastewater for irrigation can increase the concentration of potassium in soil and affect soil structure. However, investigations of clay dispersion have traditionally focused on soils with high exchangeable sodium, therefore exchangeable sodium percentage (ESP) has been used to assess soil structural stability. Currently, Australian soils have been considered non-sodic or non- dispersive when the soil ESP <6. However, a few studies have demonstrated that potassium (K) ions in the exchange complex of soil can also assist clay dispersion even when the exchangeable sodium (Na) levels are minimal.
The dispersion (as turbidity) and ESP were measured on 74 Australian soils. 17 of those soils showed a considerable level of dispersion, despite ESP <4.5. In all of these soils the Na to K ratio was <1. The relationships between ESP and turbidity were poor (R^2= 0.23) indicating limitations of using the ESP for identifying potentially dispersive soils when K is present on the soil exchange sites. Therefore, we used exchangeable cation ratio (ECR), as an index alternative to ESP, but which takes into account effects of exchangeable K on clay dispersion. The good correlation obtained between ECR and the parameters like turbidity and zeta potential support its use in assessing soil structural stability when the appreciable amount of K present on exchange sites.

Key words: ESP, clay dispersion, ECR, soil structure.

Introduction

Sodium adsorption ratio (SAR) and exchangeable sodium percentage (ESP) are currently used as indices for assessing soil structural stability upon interaction with water. Whilst these indices are used to predict clay dispersion in soils, the controlling mechanism of dispersion in both cases is presumed to be exchangeable sodium. However, the chemical component of clay structural integrity is primarily a function of ionic valence and hydrated radius. This work considers the latter in terms of the impact of potassium, which has the largest hydrated radius of the major exchangeable cations, on dispersion. Even though most Australia soils are low in potassium, there are some soils with sufficient K to affect structure, and there is increasing interest in the use of industrial wastewaters for irrigation, which may have an elevated concentration of sodium, potassium and magnesium. Such solutions will likely affect the level of both, soluble and exchangeable cations and lead to soil structural deterioration due to clay dispersion and swelling (Arienzo *et al.*, 2009; Jayawardane *et al.*, 2011, Rengasamy et al. 1986). Rengasamy and Marchuk (2011) proposed a new ratio "CROSS" (cation ratio of soil structural stability) analogous to SAR, but incorporating the effects of potassium and magnesium on soil clay dispersion.

In Australia, soil with an ESP greater than 6 % is considered to be sodic. However, soil structural problems can occur at a lower ESP depending upon the cations present on exchange sites There is an issue when a ratio of exchangeable Na to K is <1 and K is not considered as a dispersive factor in the exchange ratio. Rengasamy and Marchuk (2011) proposed exchangeable cation ratio (ECR) instead of ESP to indicate a tendency of the soil to disperse. In this paper we proposed to modify ECR to take into account the difference in effects of Na to K on clay dispersion. The primary aim of this study is to investigate if the ECR can be used as an index more accurately than ESP in assessing soil structural stability and clay dispersion when potassium is present in appreciable amount on exchange sites.

Material and Methods

Soil samples from 17 locations around Australia, which exhibited high clay dispersion with ESP less than 5%, were selected for this study. The soil properties (Table 1) were determined as described in (Marchuk and Rengasamy, 2012). The clay mineral composition of all soils was illite and kaolinite.
The exchangeable cations (Na^+, K^+, Ca^{2+} and Mg^{2+}) were extracted using 1M of NH_4Cl pH adjusted (Rayment and Lyons, 2011) and all extracts analysed by inductively coupled plasma atomic emission spectroscopy (ICP AEM). The exchangeable cation ratio and the exchangeable sodium percentage were calculated as:

ECR %= [(Na +0.56K)/ [exch (Na+K+Ca+Mg)] x100 (1)

ESP % = (Na)/[exch (Na+K+Ca+Mg)] x100 . (2)

In the ECR formula the distinction between dispersive effect of K was taken into account by multiplying the reading's for exchangeable K by 0.56 (Marchuk and Rengasamy, 2011). Turbidity, Zeta potential and visual dispersion tests were done using standard procedures (Marchuk *et al.*, 2013).

Table 1 Selected soil properties

	Soil Location	pH	EC (dS/m)	Organic C%	Clay %
		1:5 soil water			
1	Lake Cargelligo NSW	4.9	0.185	0.75	22
2	Forbes NSW	7.9	0.293	0.90	44
3	Melbourne, Victoria	5.0	0.178	2.48	40
4	Kew East, Victoria	6.1	0.119	2.43	30
5	Temora NSW	5.4	0.041	0.49	18
6	Temora NSW	5.1	0.035	0.46	21
7	Temora NSW	5.0	0.035	0.49	22
8	Salisbury Plain Vic	6.7	0.069	1.16	39
9	Salisbury Plain Vic	8.1	0.064	0.40	73
10	Salisbury Plain Vic	8.8	0.162	0.56	65
11	Sutton Forest. Victoria	6.3	0.101	0.91	58
12	West Essendon Vic	7.7	0.192	0.95	43
13	Balaklava SA	9.0	0.099	1.27	53
14	Balaklava SA	8.5	0.132	0.69	33
15	Balaklava SA	8.9	0.144	1.19	48
16	Jamestown SA	5.6	0.151	0.70	23
17	Jamestown SA	6.0	0.148	1.19	33

Results and Discussions

The results of analysis for exchangeable cations, clay dispersion as turbidity, visual assessment of the intensity of soil clay dispersion after 48 hours and Zeta potential are presented in Table 2. Turbidity was highly related to ECR; increasing ECR leading to increased turbidity. Values of Zeta potential (Table 2) confirm that the net charge of dispersed clays depend on the dominant exchangeable cation.

The extent of soil clay dispersion in investigated soils was influenced by K rather than Na presence on the exchange sites, confirming earlier reports on the effects of K on soil structural changes (Marchuk and Rengasamy, 2011; Rengasamy and Marchuk, 2011).

Table 2 Exchangeable cations, ESP, ECR, Turbidity and Zeta Potential of selected soils.

	Soil Location	Ca	Mg	Na	K	CEC	ECR	ESP	Turbidity	Zeta	Level of dispersion
		mg/100g					%	%	NTU	mV	
1	Lake Cargelligo NSW	3.58	1.51	0.06	1.80	7.0	15.43	0.92	3970	-51.6	Very high
2	Forbes NSW	13.49	6.35	0.58	1.15	21.6	5.66	2.67	2580	-39.7	High
3	Melbourne, Victoria	3.98	1.49	0.08	1.42	7.0	12.53	1.13	3480	-40.4	Very high
4	Kew East, Victoria	6.73	2.14	0.13	0.54	9.5	4.53	1.33	1860	-37.7	Medium
5	Temora NSW	2.17	0.22	0.05	0.44	2.9	10.19	1.60	3240	-44.6	Very high
6	Temora NSW	2.02	0.24	0.04	0.40	2.7	9.78	1.49	3510	-46.8	Very high
7	Temora NSW	2.22	0.25	0.04	0.40	2.9	8.95	1.33	3260	-49.0	High
8	Salisbury Plain Vic	7.75	2.74	0.16	1.09	11.7	6.57	1.36	2890	-37.4	High
9	Salisbury Plain Vic	11.25	11.25	0.85	1.52	24.9	6.82	3.41	2820	-38.3	High
10	Salisbury Plain Vic	19.75	7.44	0.90	1.00	29.1	5.02	3.08	2130	-37.5	Medium
11	Sutton Forest. Victoria	1.54	3.10	0.14	0.93	5.7	11.64	2.51	2970	-37.9	High
12	West Essendon Vic	8.25	7.67	0.65	0.92	17.5	6.66	3.71	2560	-36.1	High
13	Balaklava SA	9.25	2.28	0.15	1.12	12.8	6.08	1.18	2810	-38.0	High
14	Balaklava SA	11.25	1.95	0.24	1.84	15.3	8.31	1.55	3300	-42.9	High
15	Balaklava SA	13.50	4.69	0.86	1.41	20.5	8.05	4.18	2780	-37.1	High
16	Jamestown SA	4.18	1.20	0.06	0.99	6.4	9.61	0.97	3510	-47.8	High
17	Jamestown SA	5.75	2.05	0.09	0.92	8.8	6.84	1.02	2870	-36.7	High

Figure 1 Relationships between turbidity and a) Exchangeable Cation Ratio and b) Exchangeable Sodium Percentage

Figure 1 demonstrates the ECR as superior to ESP as an index to predict soil structural deterioration when sodium is low on soil clay exchange sites. Importantly, the modification of ESP to create ECR has incorporated the Na factor of the function as Na is clearly common and a well-documented issue in the Australian landscape. Further work must be completed to investigate the relationship as sodicity, measured as traditional ESP, increases. In the present study clay mineral composition of the investigated soils was similar with different proportion of illite-kaolinite phases by design; i.e. mineralogy has been suggested as an important factor controlling soil structural behaviour, so to explore the current phenomena we attempted as best possibly to limit mineralogy as an extraneous variable. Hence, while K has clearly had a dominant effect on clay dispersion, as compared to Na, the extent of this effect is likely to differ with changes in mineralogy.

Threshold cation concentrations

Our results present good argument for continuing to explore clay structural behaviour under cation dominant environments other than Na, but also raise an interesting discussion about threshold cation concentrations controlling the dominant effect. For example, Rengasamy et al. (1986) have clearly shown that Mg can have a deleterious effect on soil structure, but the question remains about how this can be incorporated into an ECR type of calculation. Consideration of Mg in the above ECR equation yielded poor relationships with turbidity (results not shown). Further work considering anisotropy of Mg in its role of flocculating and dispersing clays in the presence of other cations should be undertaken to produce a single useful index of soil structure. Similarly, an understanding of how a cation's role changes in defining soil structure as the concentrations of other cations increase and decrease – that is to say, what threshold cation concentrations exist for a soil – is vital to being able to accurately predict soil structural behaviour under differing solutions.

Conclusion

While ESP as a measure of soil structural stability is highly applicable to Na-dominated soils, the ECR is better suited explaining structure in soils containing K in appreciable amounts. The ECR is a new concept and its accurate reflection of roles of cations in inducing clay dispersion must be further clarified taking into account the physical and chemical aspects of soil structural behaviour governed by mineralogy, organic matter and pH. The interpretation of the results in this study has been restricted to soils with illite and kaolinite based clays. Finally, this iteration of ECR does not take into account Mg effects, or the concept of threshold cation concentrations on the dispersive behaviour of soils. Future iterations should continue to explore and incorporate these concepts.

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