Effect of cultivation on soil C contents and saturated hydraulic conductivity

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Abstract

The irrigation of pasture with saline, Na-contaminated industrial wastewater typically results in an increase in soil ESP. From current knowledge (derived largely from cultivated agricultural soils), although these sodic soils are likely to remain stable whilst irrigated with effluent (due to the effluent's large electrolyte concentration), during rainfall periods of low electrolyte concentration these soils would be expected to disperse. However, effluent irrigated pasture soils have been observed to maintain their structure even during intense rainfall events. Three soil types were collected (Sodosol, Vertosol and Dermosol), each with a cultivated/non-cultivated pair. The soils were equilibrated with various SAR solutions and then leached with deionised water to allow the measurement of saturated hydraulic conductivity (K_{sat}). At low SARs, K_{sat} tended to be greater in non-cultivated than cultivated soils and is attributable to a loss of structure associated with cultivation. In addition, as SAR increased, the reduction in relative K_{sat} tended to be significantly greater in cultivated than non-cultivated soils. The relatively rapid saturated hydraulic conductivity in the non-cultivated soils at large SARs is due to a greater aggregate stability due to greater soil C content. For the sustainable disposal of saline effluent, it is therefore necessary to ensure that soils remain undisturbed and preferably under pasture, thus maximising soil structural stability and hydraulic conductivity.

Key Words

Cultivation, effluent, hydraulic conductivity, organic matter, salinity

Introduction

Saline soils are of increasing importance both in Australia and world-wide. In Australia, approximately 2.5 M ha of arable land are affected by dryland salinity, costing A$200 M in lost production annually. In addition, the application to soil of poor quality irrigation water may result in an increase in soil salinity. The application of industrial wastes and effluents to land rather than to water is also becoming an increasingly popular alternative. Effluents resulting from the processing of cattle hides (such as from gelatine production or tanneries) are often characterised by large salinities (up to 16 dS m^{-1}), and large N contents (200 mg L^{-1}). These salts are typically dominated by Na, with the resulting effluents therefore of large sodium adsorption ratio (SAR) (up to 80 $(\text{mmol L}^{-1})^{0.5}$).

As the SAR of the effluent increases, the equilibrium exchangeable sodium percentage (ESP) of the soil also increases, with a general relationship between SAR and ESP given as: ESP = -0.0126 + 0.01475 SAR (Richards 1954). Although this empirical linear relationship was derived from 59 arid-zone soils from the Western United States it should be used with caution, as the SAR-ESP relationship will vary substantially depending upon solution ionic strength and the dominant clay mineral present in the soil (Shainberg *et al.* 1980).

The land-disposal of saline effluent is considered sustainable providing an adequate leaching fraction is maintained through the soil profile. If the effluent is applied to the land at a sufficiently high rate, salts will be leached as deep drainage, thereby limiting the accumulation salts in the rooting zone. However, the application of saline effluent increases soil ESP. This increase in soil ESP can potentially result in dispersion of the clay micro-aggregates, resulting in pore blockage and hardsetting, therefore reducing the soil hydraulic conductivity and hence reducing the capacity to leach salts through deep drainage. However, if the soil ionic strength (electrolyte concentration) is maintained above a certain critical level, an increase in soil ESP may not necessarily result in clay dispersion (Quirk and Schofield 1955). Therefore, whilst irrigated with high ionic strength effluent, these sodic soils are likely to remain stable. However, during periods of rainfall (low electrolyte concentration) these soils would be expected to disperse.

Current knowledge on soil dispersion has been derived largely through the study of the cultivated soils of agricultural systems. Cultivation has been observed to rapidly deplete the soil organic matter reservoir. Under saline conditions, this loss of organic matter may limit the soils ability to remain flocculated and maintain structure during periods of low electrolyte concentration (rainfall). In a saline land-disposal system, the loss of soil organic matter by cultivation may therefore increase soil dispersion during rainfall events, reducing soil hydraulic conductivity (and the ability to leach salts from the rooting zone), thereby reducing the sustainability of the system.

The objective of the current study was to investigate the effect of cultivation (with the concomitant loss of organic matter) on the structural stability and saturated hydraulic conductivity of saline soils.

Methods

Three sites were chosen (Gatton, Queensland, Australia) for which an accurate history of cultivation is known, and each of these sites contained a different soil type (a Sodosol, a Dermosol and a Vertosol (Isbell 1996)). At each site, a soil pair was collected (within 10 m of each other) from a depth of between 50-100 mm, one of the pair having been subjected to regular cultivation, the other being under pasture but never having been cultivated. The soil was dry when collected, and was then sieved (<2 mm). For the six soils (three soil types each with a cultivated/non-cultivated pair), soil solutions were extracted (Gillman 1976) after equilibration for 48 h (Menzies and Bell 1988), pH (TPS 901-CP) and electrical conductivity (EC) (Radiometer CDM210) determined, and were analysed for Na, Ca, S, Mg, K, and P by inductively coupled plasma atomic emission spectroscopy (ICPAES) (Table 1). Soil suspensions (1:5, soil:deionised (DI) water) were prepared, shaken for 60 min and pH and EC measured (Rayment and Higginson 1992). Total soil C was determined by combustion (LECO 2000). Exchangeable cations were determined as described by Richards (1954) from soil at field capacity, using 0.1 M $BaCl_2$/0.1 M NH_4Cl as an extractant.

Table 1. Selected properties of soil solutions extracted from cultivated and non-cultivated pairs of the Dermosol, Sodosol and Vertosol topsoils.

Soil	Cultivated	pH	EC	Na	Ca	S	Mg	K	P
			dS m^{-1}			mM			
Sodosol	Yes	5.75	0.637	2.96	1.34	0.73	0.81	1.18	0.25
Sodosol	No	7.17	0.393	1.25	0.66	0.50	0.56	3.04	0.55
Dermosol	Yes	7.33	0.851	0.03	<0.01	<0.01	<0.01	0.03	<0.01
Dermosol	No	7.30	0.370	1.10	0.47	0.24	0.47	1.31	0.07
Vertosol	Yes	7.49	1.17	0.02	<0.01	<0.01	<0.01	0.02	<0.01
Vertosol	No	7.47	0.460	0.01	<0.01	<0.01	<0.01	<0.01	<0.01

Table 2. Selected properties of cultivated and non-cultivated pairs of the Dermosol, Sodosol and Vertosol topsoils.

Soil	Cultivated	$pH_{1:5}$	$EC_{1:5}$ dS m^{-1}	ECEC $cmol_{(c)}$ kg^{-1}	Total C %	ESP %
Sodosol	Yes	5.29	0.072	5.1	0.90	1.5
Sodosol	No	6.42	0.104	10	1.6	0.5
Dermosol	Yes	7.13	0.121	25	1.7	3.8
Dermosol	No	6.75	0.144	28	2.4	0.5
Vertosol	Yes	6.81	0.196	42	2.9	2.8
Vertosol	No	6.64	0.127	44	4.4	2.4

Using NaCl and $CaCl_2.2H_2O$, five solutions of varying SAR (3, 6, 12, 18, and 24 $(mmol_c\ L^{-1})^{0.5}$) were prepared at a constant ionic strength of 50 mM. The six soil treatments (three soil types, each with a cultivated/non-cultivated pair) were placed in columns to a depth of 50 mm (approximately 300 g air-dry) to allow equilibration with these five SAR solutions, each treatment with three replicates (yielding a total of 90 columns). Solution was leached through each of the soils until the electrical conductivity (EC) of the leachate was similar to that of the initial equilibrating solution (approximately 10 times the estimated total soil porosity).

Following equilibration with the SAR solutions, two small sub-samples were removed from the surface of each leaching column and weighed. The first sub-sample (approximately 15 g) was oven-dried (105 °C) for 48 h to allow the determination of the gravimetric water content. The second sub-sample (approximately 7 g) was weighed, and placed into a pre-weighed 50 mL tube. Using the calculated gravimetric water content, the equivalent mass of air-dry soil in each tube was calculated. Total cation concentrations (exchangeable plus entrained cations) were then determined by ICPAES following extraction with 40 mL 0.1 M $BaCl_2$/0.1 M NH_4Cl (Gillman *et al.* 1982).

Deionised water was added to each column and a constant head of 70 mm maintained. After 18 h, the saturated hydraulic conductivity was determined for each column by measurement of the mass of leachate over a 30 min period. Relative K_{sat} was determined for each of the six soil treatments, and a logarithmic transformation was applied to the data to stabilise the variance. Using GenStat 6 (GenStat 2002), a one-way analysis of variance (completely randomised design) of the log K_{sat} at each of the SARs was performed. Comparisons between means were made using Fisher's protected least significant difference (LSD) test.

Results

Due to texture differences, K_{sat} was greatest in the Sodosol (approximately 40 mm h^{-1}), and least in the Vertosol (approximately 3 mm h^{-1}) (Figure 1). For both the Sodosol and Vertosol, cultivation had little effect on the absolute K_{sat} values at low SARs, with K_{sat} values for both cultivated and non-cultivated treatments similar in both soils (Figure 1). For the Dermosol, however, even at low SAR, K_{sat} was observed to be greater in the non-cultivated soil (21 mm h^{-1}) than the cultivated soil (3.8 mm h^{-1}) (Figure 1). This greater K_{sat} observed for the non-cultivated Dermosol is attributed to its greater aggregate stability, and is considered to result from its larger C content (2.4 %) relative to the cultivated soil (1.7 %) (Table 2) (Baldock and Nelson 2000).

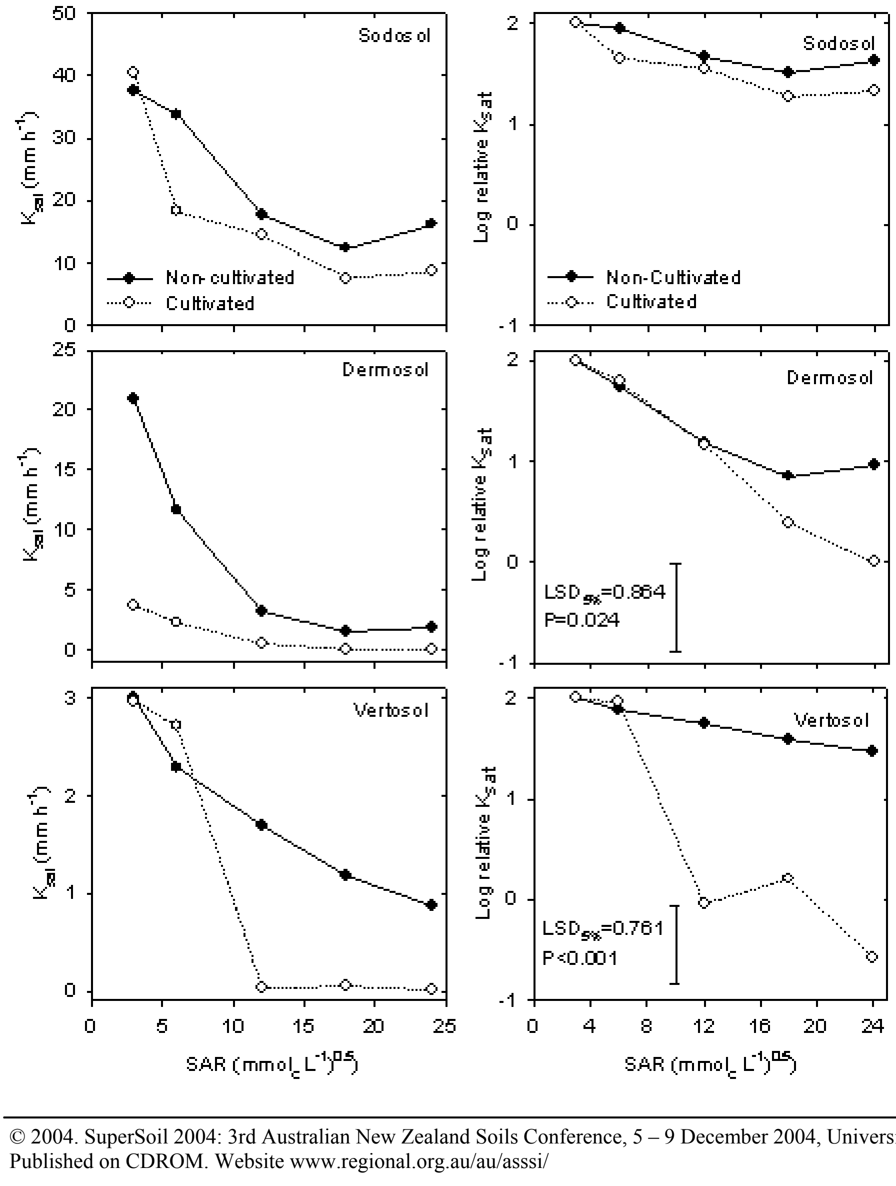

Figure 1. Effect of cultivation on the saturated hydraulic conductivity (K_{sat}) (left) and log relative K_{sat} (right) of three soil types (Sodosol, Dermosol and Vertosol) subjected to irrigation water of increasing sodium adsorption ratios (SAR).

As expected, K_{sat} decreased with increasing SAR solution for each of the soils (Figure 1). The decrease in K_{sat}, however, was not constant, but dependent upon both the soil type and cultivation. For the Sodosol, no significant interaction was found between cultivation and SAR (P=0.114)) (Figure 1). However, the pattern of response in K_{sat} was not the same for the cultivated/non-cultivated treatments in the Dermosol and Vertosol (significant interaction between K_{sat} and SAR; Dermosol P=0.024 and Vertosol P<0.001) (Figure 1). Saturated hydraulic conductivity was significantly less in the cultivated Dermosol than the non-cultivated Dermosol only at the greatest SAR (24 $(\mathrm{mmol_c\ L^{-1}})^{0.5}$) (LSD (5 %) = 0.864), while for the Vertosol, K_{sat} was significantly less in the cultivated treatment at SAR values ≥ 12 $(\mathrm{mmol_c\ L^{-1}})^{0.5}$ (LSD (5 %) = 0.761) (Figure 1). Although the cultivation of soil can potentially reduce K_{sat} through several mechanisms (reduced macro-porosity, slacking, dispersion etc.), in the current study measurements were conducted on repacked soil columns. Therefore, it is considered that the greater K_{sat} values observed for the non-cultivated Dermosol and Vertosol soils are due to their greater C content (Table 2), with aggregate stability increasing with increasing organic matter content (Lado *et al.* 2004).

The relationship between SAR and ESP was found to vary with soil type; at any given SAR, ESP tended to be higher in the Sodosol than either the Dermosol or the Vertosol (Table 3). This change in the SAR/ESP relationship is most likely due to clay mineralogy differences, with the dominant clay mineral known to affect the relationship between SAR and ESP (Marsi and Evangelou 1991; Evangelou and Marsi 2003). In addition, ESP was also found to change with the cultivation treatment, with ESP tending to be greater in the cultivated soil than the non-cultivated soil. It is considered that this is due to differences in soil C levels (Table 2), with organic matter reported to increase the soil's preference for Ca over Na (Levy and Hillel 1968; Nadler and Magaritz 1981).

Table 3. Effect of equilibrating solution sodium adsorption ratio (SAR) on the soil exchangeable Na percentage (ESP) for cultivated/non-cultivated soil pairs.

SAR $(\mathrm{mmol_c\ L^{-1}})^{0.5}$	Sodosol		Dermosol		Vertosol	
	Cultivated	Non-cultivated	Cultivated	Non-cultivated	Cultivated	Non-cultivated
	ESP (%)					
3	9.2	5.5	4.0	3.7	3.3	3.0
6	14	7.7	6.6	7.3	6.6	5.4
12	18	11	12	12	11	11
18	20	14	17	17	16	16
24	28	19	21	23	21	20

Conclusion

The sustainability of land-disposal of saline effluent is reliant upon the ability to maintain an adequate leaching of salts through the plant rooting zone, thereby limiting salt accumulation. However, deterioration in soil physical properties, and in particular the saturated hydraulic conductivity, will restrict infiltration of water into the soil, resulting in salt accumulation. The results of this study demonstrate the need to minimise soil disturbance so as to limit loss of soil organic matter reserves (and the associated decline in saturated hydraulic conductivity), thus ensuring greater sustainability of the effluent disposal system. Further study is required to investigate the contribution of other soil properties disturbed by cultivation (e.g. macro-porosity) to the soil K_{sat}.

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