USING SOIL PROPERTIES TO PREDICT LONG-TERM EFFLUENT TREATMENT POTENTIAL

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Abstract

The capacity of a particular soil to treat wastewater will change over time. The physical properties influence the rate of effluent movement through the soil and its chemical properties dictate the ability to renovate effluent. This study presents the outcomes of an investigation to identify the major controlling soil properties that influence the renovation processes. By monitoring changes in these properties will permit improved prediction of the treatment potential of a soil. The changes within soil properties of the disposal area due to effluent application were directly related to the subsurface drainage characteristics including permeability, clay content and clay type. The major controlling soil physical and chemical attributes were found to be moderate drainage, significant soil cation exchange capacity and dominance of exchangeable Ca or exchangeable Mg over exchangeable Na, low exchangeable Na, clay type and a minimum depth of 0.4m of potential unsaturated soil before encountering a restrictive horizon. An in-depth knowledge of the local soil characteristics and associated soil hydrology is essential for a better prediction of treatment potential of subsurface effluent disposal systems. The study confirmed that both the physical properties and chemistry of the soil can be valuable predictive tools for evaluating the effective long-term operation of sewage effluent disposal systems.

Keywords

laboratory assessment, physical soil properties, soil chemistry, subsurface drainage

1 Introduction

Approximately 13% of the Australian population, or more than two million people, are not serviced by reticulated sewerage facilities (Whitehead and Geary, 2000) and rely wholly on on-site systems for the treatment and disposal of domestic wastewater. Septic tanks are by far the most common form of on-site wastewater treatment and the associated sub-surface effluent disposal area is a crucial part of the treatment train. The efficiency of the disposal area and the adjoining buffer zones are essential to prevent the contamination of surface and groundwater resources by sewage effluent. This is especially of concern in areas where there is a high density of such systems. Despite the seemingly low technology of septic systems, failure is common. In many cases this can lead to adverse public health and environmental impacts. A primary factor that contributes to failure is the inadequate consideration of site and soil characteristics in the design of the sub-surface effluent disposal area (Whitehead and Geary, 2000).

On-site domestic wastewater treatment systems have traditionally relied on soil properties to remove specific contaminants as effluent percolates through the soil. Soil can be an excellent treatment medium provided the duration of effluent/soil contact is sufficient. However the ability of the soil to purify effluent is not completely understood.

Researchers such as Schipper *et al*. (1996) and Seigrist (2001) have noted the current lack of in-depth knowledge of the processes taking place within the soil matrix. This paper presents the outcomes of research undertaken to identify the influential soil properties and their use as predictive tools for evaluating the effective long-term operation of sewage effluent disposal systems.

2 The Project

2.1 Site selection and sampling

The research project was based in the urban fringe of the local government area of Brisbane City Council in Queensland, Australia. This area is currently undergoing significant urbanisation with the development of extensive rural residential allotments that are not serviced by a reticulated sewerage system. A representative sample of sixteen study sites having septic tanks and sub-surface effluent disposal areas was selected for detailed investigations. The site selection was based on the proportionate area of urban development in the region and located within different sub-tropical soil types common to South East Queensland. Five sites were subsequently rejected due to the inability to obtain sufficient soil water samples and/or lack of reliable historical information

Homogeneous paired soil samples were collected from each site. The soil samples were collected from installed piezometer locations at 1 m and 3m downstream from the edge of the subsurface disposal area and control soils that had not received effluent in order to determine background soil parameters. The piezometers were installed to a maximum depth of 1.5m or to a clay layer of very low permeability. Site and soil classifications derived are given in Table 1. Detailed soil descriptions were used to qualitatively assess the hydrology of the soil profile. Soil samples collected were classified, noting features such as parent material and profile description. Soil profile descriptions including colour, texture, structure and biological activity were recorded in depth increments of 100mm. The dominant soils were Red and Brown Chromosols, which generally exhibit a strong texture and contrast between the A and B horizons (Isbell, 1996).

Site conditions such as topography, slope and drainage characteristics were described in detail at the soil sampling points. Drainage information collected included the presence of preferential flow paths, redoximorphic features, hydraulic conductivity and porosity. Additionally, information on water table depth, presence of effluent flows, depth of soil horizons and depth to the impermeable soil layer were also recorded.

2.2 Analytical Program

The soil samples were air dried within 24 hours of collection. Each sample was then ground to pass a 2mm sieve and sub-sampled for the following tests: (i) electrical conductivity (EC) and pH in a 1:5 soil:water suspension; (ii) Exchangeable cations were measured using displacement with NH_4Cl and analysed by Inductively Coupled Plasma (ICP); (iii) concentration of chlorides and nitrates in aqueous solution by colorimetry; and (iv) concentration of soluble cations Ca, Mg, and Na by Inductively Coupled Plasma (ICP).

The soil parameter selection was based on the suite of tests generally carried out in land resource evaluation (Rayment & Higginson, 1992). These tests have been developed through extensive agricultural research and are designed to distinguish between deficient, adequate and toxic supply of elements in soil and between degraded and non-degraded soil conditions. They are being increasingly used in environmental monitoring (Peverill *et al*., 1999).

Parameters such as exchangeable sodium percentage (ESP), Ca:Mg ratio, cation exchange capacity (CEC) or effective cation exchange capacity (ECEC) and Sodium Adsorption Ratio (SAR) were derived from the data obtained. In the case of acidic soils which cover a significant area of South East Queensland, it is ECEC that is relevant where the summation also includes exchangeable acidity (Peverill *et al.*, 1999). Particle size analysis was measured by hydrometer analysis including sample pre-treatment for removal of organic matter where necessary. The type of clay was interpreted using published values of CEC and clay activity ratio (CCR = CEC/clay %) (Shaw *et al.*, 1997) and random samples were validated using X-Ray Diffraction.

Table 1 Sewage effluent disposal area soil classification

Site No.	System age (yr)	Australian Soil Classification[a]	Soil Texture[b] A – A horizon B – B horizon	Soil Drainage[c]	*Slope* (deg.)
1	4	Red Chromosol	A – Sandy loam B – Clay loam	Moderately well drained	>15
2[d]	8	Red Chromosol	Sandy clay loam	Moderately well drained	>10
3	5	Brown Chromosol	A - Sandy loam B – Light Clay	Imperfectly drained	<10
4	3	Brown Chromosol	A - Sandy loam B- Clay loam	Imperfectly drained	<5
5[d]	1	Brown Chromosol	Sandy clay loam	Imperfectly drained	<5
6[d]	11	Red Dermosol	Sandy clay	Poorly drained	<5
7	2.5	Red Chromosol	A - Sandy loam B – Sandy clay loam	Moderately well drained	>10
8	4	Red Sodosol	A - Clay loam B – Heavy clay	Poorly drained	<5
9	17	Grey Sodosol	A – Clay loam B – Heavy clay	Poorly drained	<5
10[d]	14	Red Kandosol	Sandy loam	Moderately well drained	>10
11	4.5	Red Kandosol	A - Sandy loam B – Sandy clay loam	Well drained	>15
12	19	Brown Kurosol	A -Loamy sand B – Sandy clay loam	Moderately well drained	>10
13[d]	16	Brown Kurosol	Loamy sand	Imperfectly drained	<10
14	14	Brown Chromosol	A - Loam B – Medium clay	Moderately well drained	>15
15	3	Red Ferrosol	A - Sandy loam B- Light clay	Moderately well drained	>5
16	4	Red Ferrosol	A - Clay loam B- Medium clay	Poorly drained	<5

a Australian Soil Classification after Isbell (1996)
b soil texture based on McDonald *et al*. (1990)
c the classification used complies with AS/NZS 1547:2000 (Standards Australia, 2000), McDonald *et al*. (1990).
d sites abandoned due to insufficient soil water sample and reliable historical site information

3 Results and Discussion

3.1 Physical Characteristics

The physical properties of a soil profile, particularly texture, structure and moisture regime can be employed to determine the effect of movement of water into and through the soil (Baker and Eldershaw, 1993). The sub-surface characteristics of the disposal area are among the most important factors governing the performance of effluent treatment processes. Purification of effluent will occur within a minimum depth of unsaturated soil beneath the disposal trenches. In this context, effective depths ranging from 0.6m to 2m have been quoted in research studies (Johnson and Atwater, 1988, Seigrist and Van Cuyk, 2001).

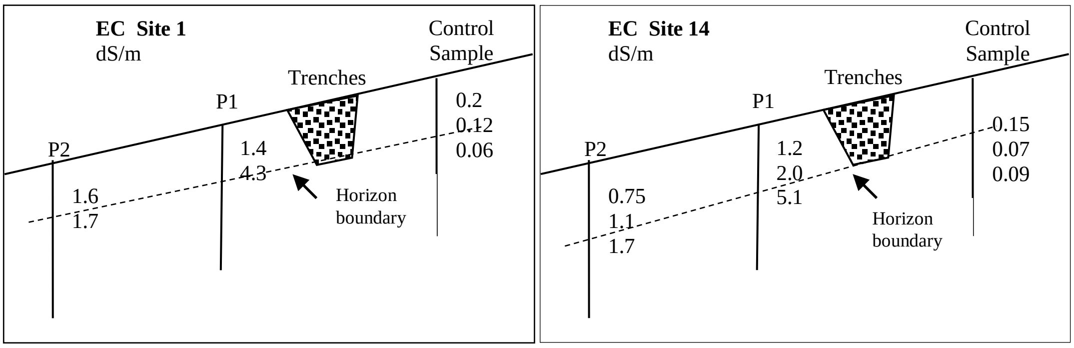
The drainage characteristics result from a complexity of factors such as layering or stratification of the soil, permeability of soil horizons, presence of restrictive layers, position in the landscape catena, and weather conditions (White, 1997). Table 2 presents the drainage observations noted in relation to the sub-surface disposal areas at the study sites. It illustrates that lateral seepage of effluent from the disposal field can occur independent of whether the sites are well drained or poorly drained. Table 3 presents results from the sampling and testing program.

Table 2 Sub-surface drainage characteristics

Site No.	Soil profile observations at piezometer sites	Drainage Class[a]	Observed Drainage[b]	Depth to restrictive layer[c]
1	Significant lateral seepage at 0.5m. Saturated zone at top of B horizon	Moderately well drained	mainly downward minor ponding observed	0.6
3	Significant lateral seepage at 0.5m. Saturated A horizon	Imperfectly drained	lateral minor ponding observed	0.5
4	Minor lateral seepage at 0.4m. Saturated profile throughout	Imperfectly drained	mainly downward	0.6
7	No lateral seepage observed. Saturated A horizon	Moderately well drained	downward	0.7
8	Significant lateral seepage at 0.3m. Saturated A horizon. High water table	Poorly drained	lateral ponding observed	0.3
9	Significant lateral seepage at 0.4m. Saturated profile throughout	Poorly drained	lateral ponding observed	0.3
11	No lateral seepage observed. Uniformly saturated profile	Well drained	downward	0.7
12	Minor lateral seepage at 0.4m. Saturated zone at top of B horizon	Moderately well drained	downward	0.7
14	Significant lateral seepage at 0.3m. Saturated zone at top of B horizon	Moderately well drained	mainly downward ponding observed	0.4
15	No lateral seepage observed. Well drained A horizon	Moderately well drained	mainly downward	0.7
16	No lateral seepage observed. Saturated at top of B horizon	Poorly drained	lateral ponding observed	0.4

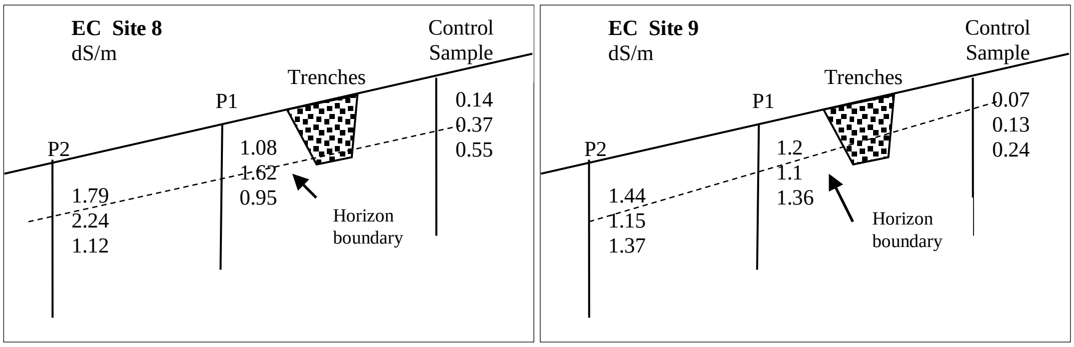
a the classification used complies with AS/NZS 1547:2000 (Standards Australia, 2000), McDonald et al. (1990).
b derived from soil moisture profiles and soil chloride profiles to determine drainage flow
c based on soil profile description and field measurements

Several of the study sites had slowly permeable soil at the top of the 'B' horizon indicating lateral flow to be prevalent. A medium to heavy clay 'B' horizon effectively acts as an impermeable barrier to vertical flow through the soil. Therefore as the 'A' horizon becomes saturated, lateral flow of effluent is preferred rather than downward movement. This was further confirmed by the fact that the 'B' horizon showed signs of redoximorphic features such as free water, presence of mottling and iron accumulation. This indicates a seasonal groundwater table during wet periods. Under these circumstances, flow of effluent into surface water bodies is a distinct possibility. The lateral flow rate is dependent on the slope and hydraulic conductivity of the soil. The soil electrical conductivity profiles shown in Figures 1 and 2 also confirmed the lateral movement of effluent through the more permeable surface layers. Where effluent ponding was observed, salt accumulation in the soil significantly increased independent of drainage class (Sites 1, 8, 9 and 14 in Figures 1 and 2). This would mean that structural breakdown of the soil has led to restricted water entry and changed the moisture regime of the soil.



P1 – Piezometer 1 at 1m
P2 – Piezometer 2 at 3m

Figure 1 - Soil sampling for electrical conductivity (well drained sites)



P1 – Piezometer 1 at 1m
P2 – Piezometer 2 at 3m

Figure 2 - Soil sampling for electrical conductivity (imperfectly/poorly drained sites)

As part of the analysis undertaken, each of the study sites was located on a hydrological sequence based on the drainage characteristics, landscape position and profile description. Physical soil properties that influence soil structure and stability including soil permeability, clay content and clay type were compared at each site with observed treatment performance. Treatment performance was defined by field observations, soil water sampling results and detailed site history obtained from the householder. Shaw *et al*. (1994) found that soils with mixed mineralogies are the most sensitive to sodium and will form the least permeable matrix if the clay content is around 40 to 50%. Sites 3, 8 and 9 exhibited these characteristics as illustrated in Table 3. Subsurface effluent disposal involves a series of wetting and drying cycles which would align the clay and restructure the soil. In soils with minimal shrink swell characteristics (kaolinite and illite clay), a dense soil matrix will form, whereas in soils with appreciable shrink swell properties (smectite clay), some regeneration of soil properties and porosity would result. Thus soils with a predominance of smectite clays have the ability to efficiently renovate effluent even with moderately high exchangeable sodium. Sites 1, 7 and 11 display these characteristics.

A strong correlation between the depth to the restrictive horizon measured at a site, and observed treatment performance was noted from the study results. Observed performance was defined by field observations, soil water sampling results**,** detailed site history obtained from the householder and surface and sub-surface site conditions noted during the study. In cases where the restrictive horizon was less than 0.4m from the surface, inadequate purification of effluent was the general outcome. The data given in Table 3 illustrates these conclusions.

3.2 Chemical properties

Chemical data such as exchangeable cations, Ca:Mg ratio and ESP were employed as possible indicators to investigate the likely deterioration of the soil structure due to sewage effluent disposal. Influential soil parameters were identified and correlations between these parameters and drainage factors were investigated. These parameters included cation exchange capacity (CEC) or Effective Cation Exchange Capacity (ECEC), dominance of exchangeable Ca or exchangeable Mg over exchangeable Na concentration, Ca:Mg ratio and ESP.

Significant changes in exchangeable cations Ca, Mg, Na as well as in parameters such as pH, EC and CEC (or ECEC) were found due to the sub-surface application of sewage effluent. These changes in chemical characteristics were comparable with other findings relating to New Zealand and Southern Australian soils (Falkiner and Smith 1997, Speir *et al.* 1999, Stewart *et al.* 1990).

Table 3 Soil Properties from Top of B Horizon

Site No.[a]	Observed Performance[b]	Particle size			Clay type	pH	EC dS/m	Ex Na meq/100g	ESP %	CEC meq/100g	Ca:Mg
		Sand	Silt	Clay							
1C		41	28	31		6.7	0.12	1.55	3	43	0.95
1ED	Satisfactory	26	43	34	S	6.9	1.54	2.40	5	48	0.54
3C		44	21	35		5.1	0.09	1.95	18	10	1.29
3ED	Fail	35	24	41	K/I	5.7	0.25	2.01	20	12	0.06
4C		51	19	30		4.2	0.08	0.68	4	9	0.94
4ED	Satisfactory	48	18	34	I	4.5	0.14	0.84	10	14	0.50
7C		66	14	20		7.3	0.17	0.41	2	34	4.00
7ED	Satisfactory	62	15	23	S	7.2	0.24	0.49	2	36	1.72
8C		13	30	57		5.7	0.46	4.84	26	7	0.59
8ED	Fail	11	25	64	K/I	6.3	1.93	5.20	28	11	0.13
9C		8	34	58		5.5	0.37	0.47	6	8	0.79
9ED	Fail	12	21	67	K/I	6.4	1.25	1.41	16	11	0.19
11C		45	35	20		5.4	0.11	1.80	4	42	1.05
11ED	Satisfactory	40	42	18	S	6.9	0.17	2.10	8	45	0.84
12C		49	30	21		4.7	0.07	0.12	13	10	1.38
12ED	Satisfactory	41	33	26	K/I	5.2	0.07	0.28	15	12	0.61
14C		38	30	32		4.8	0.07	0.33	5	10	0.47
14ED	Satisfactory	32	32	36	I	6.4	1.10	0.42	6	11	0.38
15C		33	30	37		4.8	0.11	0.09	1	7	1.42
15ED	Satisfactory	30	30	40	K	5.2	0.16	0.15	1	5	2.60
16C		16	25	59		4.3	0.10	0.40	6	6	0.38
16ED	Fail	20	21	59	K	5.4	0.19	0.52	7	7	0.09

a missing numbers are sites abandoned due to insufficient soil water sample and unreliable historical site information
b based on field observations, soil water sampling results, detailed site history
ED - Effluent disposal soil, C - Control soil
S – Smectite, K – Kaolinite, I – Illite, K/I - Mixed mineralogy

So and Aylmore (1993) suggested using exchangeable sodium content (ESC), measured on a dry soil basis, as a means of eliminating the texture factor in defining an index for sodicity. This was supported by Cook and Muller (1997) who concluded that ESC explained soil behaviour better than ESP and hence was a preferable index of sodicity. As Figure 3 shows, comparisons of performance observed at satisfactory and failed sites support this contention.

The Ca:Mg ratio in the soil was employed to indicate cation distribution, particularly in the case when the subsoil is dominated by Mg^{2+}. An excess of one cation may inhibit the uptake of another. Emerson (1977) found that ratios less than 0.5 are associated with soil dispersion.

This is supported by Shaw *et al*. (1997) who postulated that low Ca:Mg ratios in conjunction with high ESP indicate enhanced dispersion. Soil dispersion will limit treatment potential in the long-term.

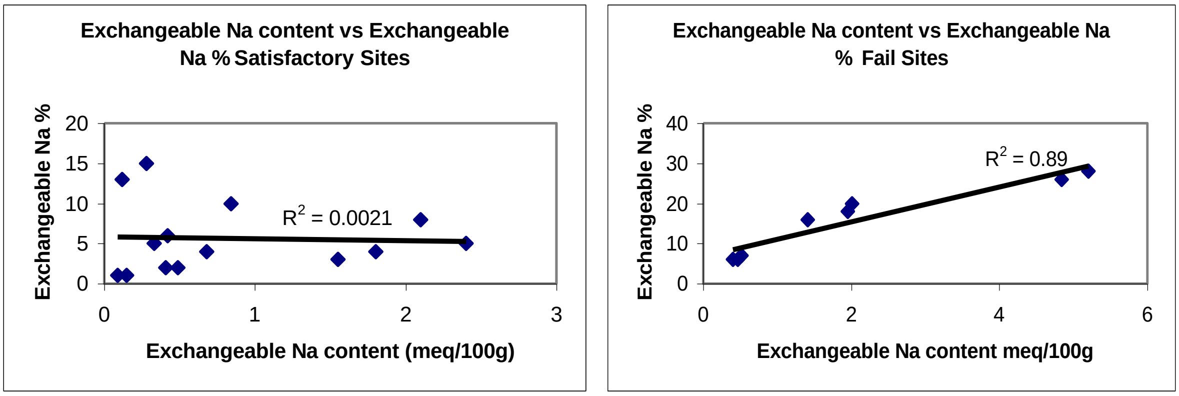


Figure 3 – Regression analysis of exchangeable Sodium Indices

4 Summary

Soils with moderate to high CEC (or ECEC), Ca:Mg >0.5, dominance of exchangeable Ca or exchangeable Mg over exchangeable Na concentration and thus low ESP have the ability to treat effluent without major soil structure deterioration. In some cases such as Sites 1 and 11, moderate to high exchangeable Na concentration was offset by the presence of swelling clays and the co-dominance of exchangeable Ca and exchangeable Mg. These characteristics have the ability to aid the adsorption of cations at depth and confirm that soils with swelling clays can be stable even at high exchangeable sodium levels. Curtin *et al*. (1994) study on prairie soils in Saskatchewan, Canada supports these conclusions.

The physical and chemical properties of a soil, which can be considered as suitable for long-term effluent disposal include:

1. Moderate to slow drainage (permeability) to assist the movement of effluent (percolation) through the soil profile and allow adequate time for treatment to occur. With longer percolation times, the opportunities for exchange and transport processes increases;
2. Significant soil cation exchange capacity and dominance of exchangeable Ca or exchangeable Mg over exchangeable Na. Although a soil dominated by Mg is found to promote dispersion of soil particles to some extent, its impact is far less than that of Na. A stable soil would have a Ca: Mg ratio > 0.5;
3. Low exchangeable Na content to maintain soil stability;
4. Minimum depth of 0.4m of potentially unsaturated soil before encountering a restrictive horizon to permit adequate purification to take place; and
5. Clay type having appreciable shrink-swell properties causing some regeneration of soil properties.

This paper supports that an in-depth knowledge of the local soil characteristics and associated soil hydrology is essential for a better prediction of long-term treatment potential of subsurface effluent disposal systems. It is important to be aware of the need to integrate the factors described above in understanding soil structure stability and predicting long-term sustainability of effluent disposal areas.

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