CORRELATION OF SOIL DATA WITH TREATMENT PERFORMANCE OF SUBSURFACE EFFLUENT DISPOSAL SYSTEMS

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Abstract

The paper discusses research undertaken to contribute to providing long-term sustainable solutions for on-site sewage treatment based on soil physico-chemical evaluation. The study was conducted within the unsewered area in Logan City Council, Southeast Queensland. The unsewered areas were classified into four different zones based on the future development in the region and environmental sensitivity. Forty-eight sampling sites were identified and samples taken from the A and B horizons. The selected soil samples were analysed for a range of physico-chemical characteristics such as pH, electrical conductivity (EC), chloride ion, total nitrogen, total phosphorus, orthophosphate, cation exchange capacity (CEC), individual cations, particle size distribution, organic matter content and mineralogical composition. The soils at the different sites recorded pH levels ranging from moderately acidic to acidic. In the case of CEC, 50% of the sites reported values between 0 and 4 meq/100g, about 30% of the sites reported values from 10 to 47 meq/100g, and the remainder had values between 60 to 90 meq/100g. The data showed that based on location and intended land use, about 70% of the sites investigated had inadequate capability to renovate effluent discharged to the subsurface area from a conventional septic tank. In areas that have a very low cation exchange capacity and low organic matter content, the dominant clay has a low capacity to adsorb the wastewater pollutants. It can be surmised that septic tank/soil absorption systems based on conventional and typical designs would not be feasible. These sites would require extra care in designing and locating of the subsurface on-site disposal system or the use of alternatively designed systems.

Keywords

physico-chemical, mineralogical analysis, subsurface disposal area, cation exchange capacity, organic matter content.

1 Introduction

The project was formulated to solve serious environmental and public health problems resulting from the high failure rate of on-site sewage treatment systems. In general, the most common form of on-site sewage treatment in use is the septic tank-subsurface effluent disposal system, which was the focus of the study discussed in this paper. The septic tank is a water-tight receptacle, where settling of suspended solids and anaerobic digestion of organic matter takes place. The discharge of effluent to a subsurface disposal area results in further treatment processes taking place before its percolation into the groundwater.

The sewage effluent discharged to the subsurface area contains numerous pollutants, with significant amounts of nitrogen and phosphorus considered to be among the most important. Excessive application of effluent to the soil having a poor soil structure and chemistry could lead to the contamination of surface and/or groundwater resources.

The adverse impacts from on-site sewage treatment systems failure underlie the vital importance of employing reliable science based site suitability assessment techniques for the evaluation of effluent disposal areas. In the long-term, this approach is necessary to ensure the ecological sustainability of on-site sewage treatment, risk reduction and environmental best management practices to be implemented for the protection of environmental values and community well-being.

Scholes *et al.*, (1994) noted that soil was the most important factor in site suitability assessment for sustainable land management. In general, soil is a heterogeneous matrix which is difficult to evaluate based purely on physical factors or for that matter on soil chemistry alone. It is essential to integrate both physical and chemical factors together and to understand the correlations between these factors to be able to assess site suitability for on-site effluent application. Physico-chemical characteristics of soil are the foundation for site suitability assessment for conventional on-site sewage treatment. The capacity of natural soil to accommodate sewage effluent disposal will vary based on factors such as effluent characteristics, site vegetation, soil physico-chemical and biological characteristics, topography and depth to the groundwater table (Bouma *et al.*, 1972). Also, it is important that the physico-chemical characteristics of soil vary between types of soil and even within the same soil type due to interactions with relevant climate, parent material and location factors.

Different types of soils have varying capacities to adsorb pollutants contained in sewage effluent. Therefore it is important to investigate closely the soil physico-chemical factors and to correlate these factors in order to evaluate the ability of different soils to renovate sewage effluent. The effluent discharged from a septic tank contains variable, but significant amounts of nitrogen and phosphorus. Alloway (1995) investigated some of these relationships. White (1997) investigated the relationships between clay content and organic matter, which would provide the necessary surface area to adsorb pollutants. Sewage effluent can also replenish organic matter levels with beneficial effects on the physical and chemical condition of the soil (Hall *et al.*, 1986). Organic matter supports most of the important micro-flora in the soil. The breakdown of the organic matter interacts with other soil constituents and has a significant influence on the biological, physical and chemical processes in a soil.

The study discussed here was undertaken in the Logan City region, Queensland, Australia. This rapidly urbanising local government area encompasses a land area of about 250 km^2 and a current population of over 170,000. Over 50% of the land area is unsewered and the vast majority of on-site sewage treatment systems being used are septic systems. The primary aims of the project were to characterise the common soils in the region and to understand the relationships between different soil physico-chemical factors and thereby to investigate the influence exerted by these factors on the soil ability to renovate sewage effluent.

2 Field and experimental methods

The research undertaken involved extensive soil sampling and testing for a wide range of soil physical and chemical parameters. Forty eight soil sampling sites were identified from different suburbs in the project area and 158 soil samples collected from various soil horizons. Sampling sites were selected to reflect the geological and topographical settings in the region.

The soil samples were taken from locations which were away from effluent disposal fields and hence were not contaminated by sewage effluent. The soil profile changes through the different subsurface horizons were taken into consideration in the sampling process and samples were collected from each soil horizon accordingly. The tests undertaken to determine the required parameters are discussed below. All the collected soil samples were dried at 50^0C and sieved to< 2mm. pH and electrical conductivity (EC) were measured based on a soil/water ratio of 1:5 at 25^0C. The pH and EC tests were conducted according to the method (4A1 pH of 1:5 soil/water suspension) defined by Rayment and Higginson (1992). The cation exchange capacity (CEC) was measured using the ammonia selective electrode method developed by Borden and Giese (2001). The organic matter content (OM) was determined by adding 10mL of 50% hydrogen peroxide (H_2O_2) to 20gm of the soil samples and heated for 24 hours at 105^0C temperature. The dried soil samples was then crushed and subjected to 1300^0C temperature for 1 hour and the weight loss determined was taken as the organic matter content. Total nitrogen in the soil was measured by the wet oxidation method (Rayment and Higginson 1992). Organic nitrogen in the soil sample under analysis was converted to NH_3-N by digestion in the presence of a catalyst. The digestion method was adopted from the HACH (1988) manual, and the analytical method was adopted from APHA (1995). The ammonia selective electrode method developed by Borden and Giese (2001) was adapted to measure ammonia level in the digested solution. All ammonium standards were made by diluting freshly prepared 0.1M ammonium chloride according to method number 4500-NH_3 E as defined by (APHA, 1995). Phosphorus was measured according to method 4500-P defined in the APHA (1995). The chloride concentration was determined according to the method (5Al chloride 1:5 soil/water extracts, potentiometric titration) defined by Rayment and Higginson (1992). The soil mineralogical analysis was preformed using the X-ray diffraction machine over all the soil samples.

3 Results and Discussions

The physico-chemical data obtained from the soil sampling and testing formed the basis for investigating the ability of different soil types to renovate sewage effluent discharged from septic tanks. As septic tank effluent is usually discharged into a subsurface disposal area, the research focused primarily on the soil B-horizon. However, it was not possible to disregard the A-horizon completely as there were a number of locations where its depth was relatively high. All the soil types were classified in the field according to the Australian Soil Classification (Jacquier *et al*. 2000). Twenty different types of soils were noted within the project area as reported in Table 1. The following discussion will cover the most representative soils where a particular type was present in three or more sites.

Soil CEC, a measure of electrical charge available to hold nutrients on soil surface minerals and organic matter, is important in the analysis.. The crystalline framework of clay minerals such as kaolinite, illites and smectite act as a reservoir to hold the nutrients. The soil organic matter could increase the soil adsorption capacity by providing a large surface area, necessary for exchangeable cations between the soil particles surface area and nutrients (Morrás 1995). Therefore, CEC and organic matter content can be considered as among the most important parameters available to understand the soil's capacity to renovate discharged effluent.

One of the major soils recorded was Yellow Sodosol, which was present at four sites. The summary of data for these sites as given in Table1 shows a moderately acidic soil and generally low electrical conductivity with the lowest EC measurements recorded in the A-horizon. Chloride ion concentrations varied between the sites and the highest concentration was in the B-horizon. Phosphorus concentrations were low but the nitrogen concentrations were high in some sites due to the existence of some nurseries in around those sites. The dominant clay type was kaolinite and CEC was low. Consequently it could be surmised that this type of soil has weak capability to treat effluent.

Grey Chromosol was also common and the data summary shows an acidic soil. EC was low in the B-horizon. Cl^- and phosphorus measurements recorded were similar to the Yellow Sodosol but with generally lower nitrogen. CEC and organic matter content were low and the mineralogical analysis reported 73% of the soil was quartz. This soil has a weak capability to renovate effluent due to the sandy texture of the soil. Yellow Dermosol was found at four sites with relatively high pH. The salinities (as measured by EC) were generally similar to Yellow Sodosol with relatively low chloride ion concentration. Nitrogen concentrations were almost the same as in the Grey Chromosol and the highest nitrogen concentration was recorded in the first 100mm of the B-horizons for all sites. CEC values were low but were marginally higher than in the previous two soils. The XRD analysis reported the dominant clay type as kaolinite. This type of soil has weak capability to renovate sewage effluent based on the dominant clay type and the level of CEC provided by the clay surface charges.

Table 1 Summary of soil physico-chemical data

Soil Types*	Site Number	Parameter Range							
		pH	EC (µS/cm)	PO_4^{3-} (mg/Kg)	NH_3-N mg/Kg	CEC (meq/100g)	OM (%)	Cl^- (mg/Kg)	Dominant Mineral Type
Yellow Sodosol	1, 11, 43, 44	4.6-5.4	1-60	0.3-2.7	25-300	3-10	~0-9	2-150	Kaolinite
Grey Chromosol	2, 3, 4	4.9-5.5	10-70	0.4-2.2	33-160	1-6	~0-3	20-80	Quartz
Yellow Dermosol	8, 14, 15, 22	5.5-6.2	20-55	0.5-2.6	22-150	5-14	0.5-12	4-45	Kaolinite
Yellow Chromosol	9, 19, 24, 32, 39	4.3-5.9	2-90	0.4-9	10-68	3-60	~0-11	10-95	Illites & Smectite
Red Vertosol	10, 20, 35	4.6-5.9	10-115	0.7-1.2	10-100	2-20	1-12	21-65	Kaolinite
Yellow Kandosol	13, 18, 21, 28, 29,30	4.6-5.9	13-209	1-12	12-180	2-44	~0-7	10-100	Kaolinite & Illite
Red Kandosol	17, 25, 26, 27	4.3-5.9	30-90	0.9-3	35-180	10-88	2-11	10-80	Smectite
Red Sodosol	33, 36	4.3-5	1-60	~0-1	20-70	3-44	~0-2.2	6-260	Kaolinite & Illite
Brown Kandosol	34, 40	4.2-4.7	2-110	~0-1	38-130	2-71	3-8	87-400	Illites & Smectite
Red Dermosol	5, 47	4.7-5.9	15-48	~0-1.2	45-180	3-27	0.5-7.5	7-38	Kaolinite
Brown Dermosol	6	4.7-5.1	~25	1.3-3	80-130	16-25	5-8	20-60	Kaolinite
Grey Kurosol	7, 42	4.4-5.2	17-95	0.2-3.4	45-125	7-27	0.2-6	45-150	Kaolinite
Bleached-Leptic Tenosol	12	5.5-5.8	8-12	0.2-0.8	20-120	3-9	~0-2.2	20-80	Quartz & Kaolinite
Brown Vertosol	16, 46	4.7-5.9	3-36	0.6-4.6	10-170	1.5-12	0.2-9	44-70	Quartz & Kaolinite
Grey Dermosol	23	5-5.3	20-90	1-2	48-170	5-16	3-6	50-55	Kaolinite
Grey Sodosol	31	5.2	80-137	0.2-6	55-110	5-40	6-8	55-140	Kaolinite & Illite
Brown Kurosol	37	4.3-4.6	20-80	1	40-70	8-20	4.5-8	60-190	Kaolinite
Brown Chromosol	48	4.7-4.8	1-4	~0.5	50-120	6-7	7-8.5	4-6	Quartz
Spolic Anthoposol	45	4.3-4.5	2-100	~0.3	25-290	8-29	7.82	7-10	Kaolinite & Illite
Leptic Rudosol	38, 41	4.4-4.8	1-30	0.5	44-120	3.5-20	1.2-4	65-150	Kaolinite

* *Australian Soil Classification*

Yellow Chromosol was recorded at five sites as shown in Table 1. This soil was also acidic, and the EC was higher than the previously discussed soils. The phosphorus concentrations were among the highest values obtained when compared to the other soil types in the project area. CEC varied between the A and B-horizons with the A-horizon having values in the range of 3 to 22 meq/100g, and the B-horizon in the range of 27 to 60meq/100g. The dominant clay in the B-horizon was illite and smectite. The A-horizon had a relatively high CEC compared to the previously discussed soils due to the high organic matter content in this layer. This type of soil was determined to have a moderate effluent renovation capacity based on CEC available and the clay type.

Red Vertosol was recorded at three sites. This is a moderately acidic soil and the EC values were generally the highest when compared to the soil types discussed above. Nitrogen concentrations were in the medium range when compared to other soils and phosphorus concentrations were among the lowest between all reported types of soil in the region. CEC was in the low range and dominant clay type was kaolinite. Therefore, this soil has a weak ability for effluent renovation based on the CEC and mineralogical analysis

Yellow Kandosol was found at six sites. The soil was acidic with high EC values. Low values of nitrogen present were reported in the lower section of the B-horizons. CEC was measured in the range of 2 to 8meq/100g in the A-horizon and organic matter content was relatively high which could assist to improve the cation exchange capacity level for this layer. The CEC ranged from 9 to 45 in the B-horizon and the dominant clay types were kaolinite and illites. This type of soil has a moderate capability to renovate sewage effluent based on the dominate clay type and the level of cation exchange capacity available.

Red Kandosol was recorded at four sites. This soil is acidic and EC concentrations were in the medium range. CEC values were the highest among all soils and ranged from 10 to 88 meq/100g. XRD analysis indicated that the dominant clay type was smectite. In this type of soil, the CEC values in the A-horizon were higher than other soils due to the high organic matter present. This type of soil was considered a good soil for effluent renovation in terms of the dominant clay type, CEC and organic matter content.

In the context of sewage effluent renovation, clay minerals have a distinct advantage. The particle surface area is relatively large compared to its volume and thereby it enhances the adsorption capacity provided by the electrical charge on the particle surface. Therefore, clay minerals are considered very important for the chemical and physical processes inherent in the adsorption of contaminants crucial for sewage effluent renovation (White 1997). This highlights the role of specific surface area provided by the soil composition with regards to sewage effluent renovation capacity.

Overall for the samples tested, the CEC value varied from 1 to 90 meq/100g. The clay content is dependent on the clay mineralogy of the soil composition (White, 1997). For instance, soils with kaolinite clay provides CEC in the range between 3 and 20meq/100g, soil with illites as a dominant clay type provides CEC in the range between 20-60meq/100g and soils with smectite clay provides CEC in the range between 60 and 136meq/100g (Borden and Giese 2001). Smectites clay has a three layer crystalline structure and exhibits a high degree of swelling when wet. Other clays such as kaolinite have two layer crystalline structures with low CEC and show little swelling. In most cases kaolinite needs significant amount of organic matter to be able to provide a reasonable exchange capacity (White, 1997). According to the dominant clay type and their CEC for all the investigated soil types, the sites with quartz and kaolinite were considered to have poor soil based on their ability to renovate effluent. Soils with illites as dominant clay associated with the level of CEC available were considered to have a moderate capacity for effluent treatment. Soils with smectite or illites and smectite in combination as the dominant clay associated with the CEC level were considered to have a high capability for effluent renovation.

Similarly, the organic matter content in the soil also needs to be taken into consideration. Organic matter content levels in all soil types sampled were considered moderate at the soil surface and A-horizons and decreased rapidly with depth through the soil profile. The organic matter was found to contribute to improving the CEC especially in the A-horizon, which in turn would improve the soil capability for effluent renovation.

Chlorides are considered as the dominant salts in a leached soil profile. The Cl^- concentration at the different sites was in the range between 10 and 400 mg/kg. The chloride ion concentration was low in the A-horizons and higher in the B-horizons which indicate that most of the soils are not highly leached. Nitrogen in the soil was measured as NH_3-N_{org} and the concentrations were in the range between 60 and 400 mg/kg. Nitrogen levels in some of the investigated soils are high in A-horizon or the first 300 mm and that associated with level of organic matter content in this layer. However, other sites were reported high nitrogen levels in B-horizon due to the excessive application of nitrogen by the surrounding industries such as plant nurseries. The sites with low CEC and high permeability means that pollutants could leach through the soil profile and enter the surface or groundwater which could result in potential environmental problems in the future. Phosphorus was measured as orthophosphate (PO_4^{3-}) and the concentration was in the range between ~0 and 12mg/kg. Existing phosphorus levels in all investigated soils were considered low.. Nutrients (nitrogen and phosphorus) present in the soil are necessary for plant growth. Nutrients, if applied in excessive amounts, as in septic tank effluent, can lead to serious environmental problems such as nutrient enrichment of water resources. It is important that the amount of nutrients applied to the soil by septic tank effluent is within tolerable limits to avoid any potential problems in the future.

Clay type and content which controls CEC is an important factor along with organic matter and Cl^- concentration and was used as the basis to evaluate the ability of a soil to renovate effluent. Two common soil types are discussed in detail as examples to illustrate the analysis undertaken. Figure 2 shows the relationship between CEC, OM and Cl^-concentration for Yellow Sodosol. There is a clear influence on the soil CEC from the organic matter content. Secondly, there is an inverse relationship between CEC associated with OM and Cl^- concentration. The decrease of organic matter content and soil CEC result in an increase in Cl concentration in the soil and the increase of CEC level by small amounts has a considerable impact on the Cl^- concentration. Some selected sites are not highly leached according to their mineralogical analysis but reported a low Cl^- concentration at B-horizon which could be related to the drainage regime.

The data obtained for Yellow Chromosol are presented in Figure 3. Similar to the Yellow Sodosol, it shows a clear inverse relationship between CEC and Cl^-concentration. However the organic matter content does not have any effect on CEC. The mineralogical analysis showed that the dominant clay type is illite, which has a CEC in the range between 10 and 40meq/100g, providing a moderate ability to renovate effluent. The expected Cl^- concentration from the mineralogical type of clay involved in this soil was expected to be moderate. This means higher Cl^- concentration with increased clay content but Figure 3 doesn't show this. Thus, the sampled site drainage location will also need to be considered.

All the soil samples recorded pH levels ranging from 4.5 (extremely acidic) to 6.0 (moderately acidic). Acidic soils can become a problem when pH drops below 5.5, due to the rise in aluminium availability. Also, soils with low clay or low pH and toxic metal cations can eliminate some of the biological processes which are beneficial to sewage effluent renovation, such as nitrification or ammonia fixation (White, 1997). EC in all the sampled sites recorded in the range between 1 and 210 µS/cm. Soluble salts were very low and chloride ion was almost absent in the A-horizon. More soluble salts occurred in the B-horizon but levels were low in most sites. EC is an important parameter in evaluating the salt ion concentration in the soil. A high concentration of salts in soil can lead to salinity problems. Soils are considered to have a salinity problem when the total soluble salt concentration is high enough to affect plant growth. The soils can be classified as saline, saline-sodic or non saline-sodic, depending on the chemical composition of salts present in the soil (Shaw *et al.,* 1987). All the sample sites were classified as moderately saline.

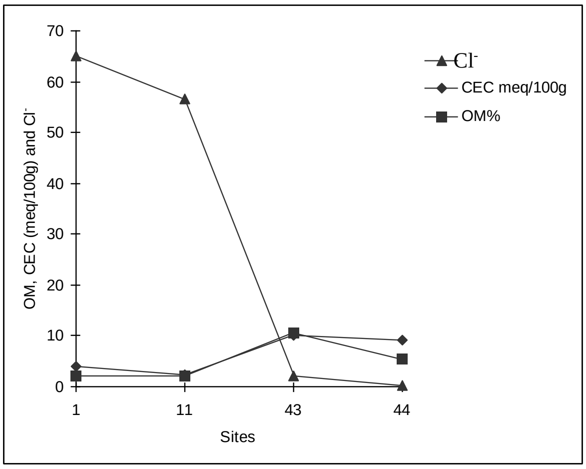

Figure 2 Correlation between CEC, OM and Cl^- in the Yellow Sodosol (Site No. 1, 11, 43 and 44)

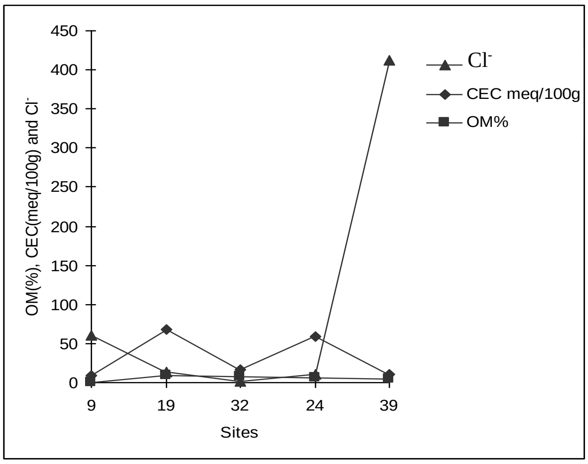

Figure 3 Correlation between CEC, OM and Cl^- in the Yellow Chromosol (Sites No. 9, 19, 32, 24 and 39)

Figure 4 shows a relationship between pH and phosphorus present in the soils. Soils rapidly adsorb phosphorus until their adsorbing capacity is reached and also phosphorus can be precipitated in the soil. Also, soil sorption may provide initial phosphorus removal but this is partly reversible storage as the soil is saturated. The linear relationship between ortho-phosphate and pH in Figure 4 shows that as pH reduces, phosphorus concentration reduces proportionately. Thus it could be surmised that the pH has an effect on phosphorus concentration in the soil. This means that as soil becomes acidic, the phosphorus concentration or orthophosphate in soils will reduce accordingly. It is important to note that for all the sites sampled, the soil had a pH value less than 6.0.

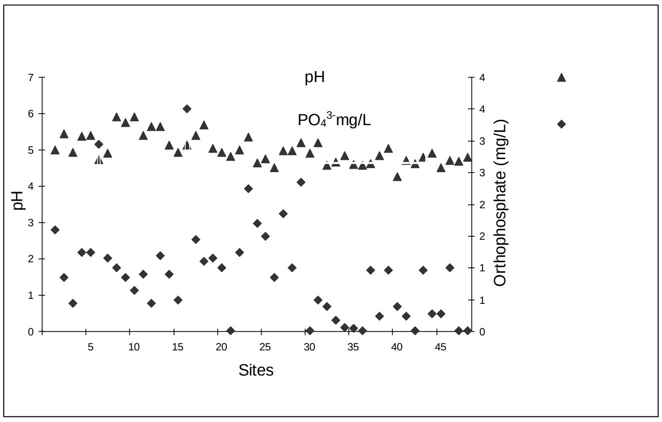

Figure 4 Relationship between pH and orthophosphate content in soil

4 Conclusions

The cation exchange capacity varies appreciably and depends on clay content, clay type and organic matter content in the soil structure. Soil CEC is expected to provide the necessary charges available on the clay surface area to adsorb the ion pollutants in the sewage effluent. Therefore, the cation exchange capacity and the soil mineralogical analysis were employed to evaluate the soil capacity to renovate effluent.

The soil physico–chemical analysis provided the necessary information to evaluate the renovation capacity of soil to handle effluent discharged from on-site sewage treatment systems based on the CEC associated with clay type and organic matter. For example, according to their CEC, sites with Yellow Sodosol were weak sites in their ability to renovate effluent and sites with Yellow Chromosol have a moderate ability. Based on the same criteria, sites with Red Kandosol were good sites to renovate sewage effluent.

The study also showed that in some soils such as Yellow Sodosol, there is an improvement in the CEC due to the presence of organic matter, whilst in the case of soils such as Yellow Chrromosol, the organic matter content has no effect on the CEC. Chloride ion concentration considers the dominant salts in leached profiles in the soil. The study showed in some soils that the decrease in soil CEC will increase the chloride ion concentration in some sites due to their topographic locations. In other soils the increase of CEC level by small amount affected the Cl^- concentration considerably. Therefore, it is important to define the drainage regime of a soil. Consequently, it is not sufficient to merely evaluate the soil based on the clay content.

The analysis indicated that pH reduction associated with phosphorus reduction. It could be surmised that the pH has an effect on phosphorus concentration in the soil. This would mean that as the soil becomes acidic, the concentration of phosphorus or the orthophosphate in soils would reduce accordingly.

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