Comparison of capillary pressure curves and hydraulic conductivity functions of water and vinasse using evaporation method

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ABSTRACT: Vinasse is a by-product of the production of sugar and alcohol which is used as a fertilizer. Its use in large quantities, however, is problematic due to environmental problems resulting from its use in irrigation, which may contaminate surface and groundwater with high concentrations of ammonia, aluminum, iron, manganese, chloride, magnesium, sodium, potassium and calcium. It also reduces the hydraulic conductivity, which may cause flooding and increase runoff. In order to evaluate possible changes in the hydraulic properties of the soil, the present paper uses the evaporation method to compare soil retention curves and hydraulic conductivity functions for both water and vinasse in unsaturated lateritic soils. No significant differences were found, although the hydraulic conductivity of vinasse may be somewhat less than that of water in soils with more clay, probably due to the larger number of cations in the vinasse, which encourage the displacement of smaller particles, thus contributing to the clogging of the pores in the soil.

1 INTRODUCTION

Since Brazil is the largest producer of sugar and ethanol in the world, it also generates large quantities of vinasse. This by-product is often used as a fertilizer, since it can partially replace chemical fertilizers. Not only does it bring economic advantages, but it is sustainable and can help reduce dependence on external input, especially potassium. However, excessive use is questionable due to the high organic content (DBO/DQO), low pH, and high corrosivity, as well as the presence of cations and metals in solution, which can cause contamination of groundwater and salination of aquifers.

In addition to the problems of contamination, various authors (including Ribeiro and Sengik 1983; Ribeiro et al. 1983, Uyeda et al. 2013, Basso et al. 2017) have observed a reduction in saturated hydraulic conductivity when vinasse percolates columns of the soil typical of the region of São Paulo, in Brazil. Dispersion in latosoils depends on the nature of the clay fraction, the concentration of cations present in the vinasse, and the quantity sprayed on the field (Ribeiro et al. 1983). According to Uyeda et al. (2013), the large quantity of the monovalent cation potassium in vinasse may cause the dispersion of clay particles in the soil, thus, as with sodium, provoking the clogging of voids and making the soil less permeable. According to the problems related, these paper presents a comparison of the performance of water and vinasse in relation to soil-water retention curve and hydraulic conductivity in unsaturated lateritic soil.

2 MATERIALS AND METHODS

The selection of the soils chosen for this study was based on their different textures and the fact that both are typical of the state of São Paulo, in Brazil, where fertilization with vinasse is common. Soil 1 is classified as a red/ yellow latosoil from the city of Rio Claro, while Soil 2 is a purple latosoil from the city of São Carlos.

The vinasse used was a sample provided by a sugar and alcohol plant located in the city of Araras, in the state of São Paulo, where vinasse is used as a fertilizer in agriculture.

Direct measurements of water retention and hydraulic conductivity were made over a wide range of pressure values using the evaporation method (Peters and Durner 2008; Schindler et al. 2010, Peters et al. 2015) and a HYPROP © measuring system. This system plots capillary pressure versus time measurements at two depths within a small sample of soil as water evaporates from the surface; the rate of evaporation is measured by successive weighings of the sample. Figure 1 provides a schematic diagram of the Hyprop system.

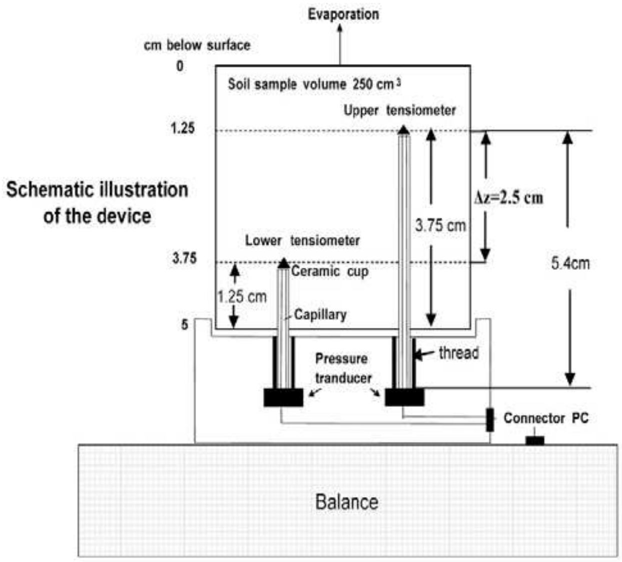

Figure 1. HYPROP system of measurement (Schindler et al. 2010).

The samples used in the tests were obtained by static compaction using the same density and humidity found in situ.

As required by Hyprop system, drying was used for measurement. Thus, the samples, with natural humidity of compaction were pre-saturated with water or vinasse for 24 hours. The hydraulic properties of the soils were described using the van Genuchten-Mualem formulation (van Genuchten 1980):

$$S(h) = \frac{\theta(h) - \theta_r}{\theta_s - \theta_r} = \frac{1}{\left[1 + |\alpha h|^n\right]^m} \qquad (1)$$

$$K(S_e) = K_s S_e^{\,L} \left[1 - \left(1 - S_e^{\,1/m}\right)^m\right]^2 \qquad (2)$$

where S(h) is effective saturation, θ_s and θ_r are the saturated and residual water contents, respectively [L^3L^{-3}], K_s is the saturated hydraulic conductivity [LT^{-1}], α [L^{-1}] and n are semi-empirical shape parameters, m=1-1/n, and L is a pore-connectivity parameter.

3 RESULTS AND DISCUSSIONS

Table 1 summarizes the percentages of sand, silt and clay in the soils used and their textural classification. Table 2 shows the characteristics of the water and vinasse. As can be observed in Table 1, there is a significant variation of texture between the coarser soil (Soil 1), with sand predominating, and the finer one (Soil 2), with clay predominating. Table 2 shows that at the same temperature, the vinasse is almost twice as viscous as water, with a 50% lower surface tension.

Table 1. Percentages of sand, site and clay in soils and their classification according to texture

Soil	Sand (%)	Silt (%)	Clay (%)	Texture Classification
1	65,6	7,3	27,1	Sandy clay loam
2	30,5	17,3	52,2	Clay

Table 2. Water and vinasse characteristics

Characteristic	Unit	Water	Vinasse
Temperature	Celsius	15	15
Density	g/cm^{-3}	1,00	1,02
Viscosity	cP	1,14	2,24
Surface tension	mNm^{-1}	74,7	40,3

3.1 *Capillary pressure curves*

Figures 2 and 3 show the capillary pressure curves obtained for the two soils, initially saturated with water and vinasse. Figures 2 and 3 shows that, for a given volumetric content, no significant difference in pressure head for water and vinasse is found, regardless of soil texture.

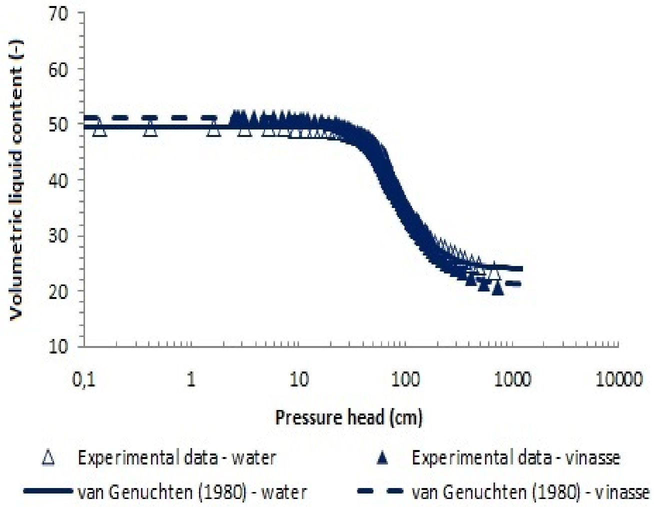

Figure 2. Capillary pressure curves of Soil 1 saturated with water and with vinasse.

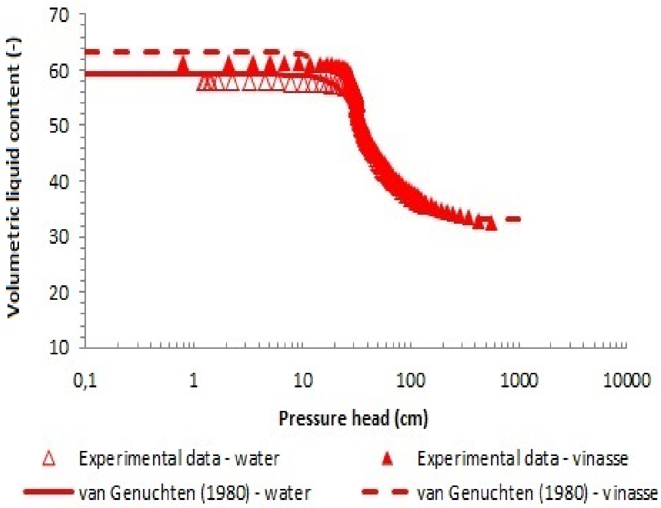

Figure 3. Capillary pressure curves of Soil 2 saturated with water and with vinasse.

As can be observed, in both soils, water already occupied approximately one-fifth of the total volume of pores. Since the water / vinasse mixtures are predominantly vinasse, the surface tension observed is close that of pure vinasse (Table 2). It is assumed that the similarity of the vinasse retention curves to those of water is due to the known water-soil molecular attraction, even when the moisture content of the soil before the addition of vinasse is low. The water remains the main wetter after the vinasse is added, with no apparent changes in pressure head.

3.2 *Hydraulic conductivity functions*

Figures 4 and 5 show the hydraulic conductivity curves as a function of pressure head for Soils 1 and 2, respectively.

Figures 4 and 5 suggest that for Soil 2, unsaturated hydraulic conductivity was lower for vinasse than for water for any given pressure head value (between zero and 100 cm). This lower hydraulic conductivity of the vinasse could initially be attributed to its greater resistance to flow because its viscosity is nearly double that of water (2.24 cP, Table 2).

However, it is presumed that the finer particles are dispersed after interacting with the vinasse, since the phenomenon is observed only in the clayey soil. Additional particle-size analyses of soils were thus made to study the dispersive effect of the vinasse on the soil. The conventional procedure for deflocculation (NBR- 7181 of the ABNT similar to ASTM D422-63) recommends the use of sodium hexametaphosphate as the standard. However, for the additional tests, the samples were treated with vinasse as the deflocculation agent for comparison with other samples not submitted to deflocculation. The results for Soil 1 and 2 are shown in Figures 5 and 6, respectively.

As seen in Figures 6 and 7, the curves for the distribution of particle size when vinasse was used as a deflocculation agent revealed an intermediate level of dispersion, something between that of the samples treated with sodium hexametaphosphate and non-deflocculation test for a range of particle size. This behaviour is increasing from particle sizes between 0.01 and 0.02mm, i.e. slightly smaller than those of silt (0.06 mm). Although dispersion was greater in the clayey texture of Soil 2, the smaller pores were more prone to clogging than were those of Soil 1.

4 CONCLUSIONS

Although further studies are recommended, these results show that for the samples tested the retention

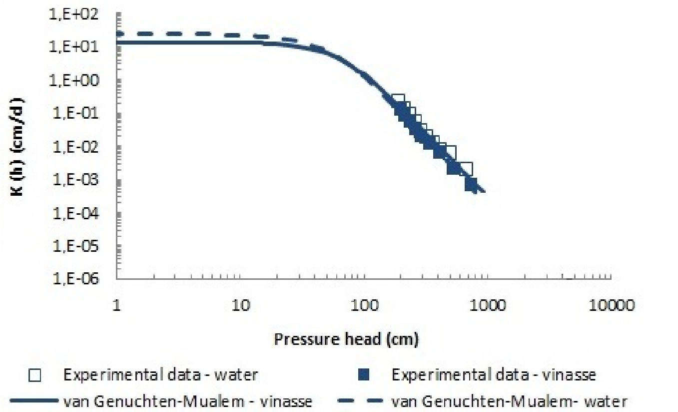

Figure 4. Hydraulic conductivity as a function of pressure head for Soil 1 saturated with water and vinasse.

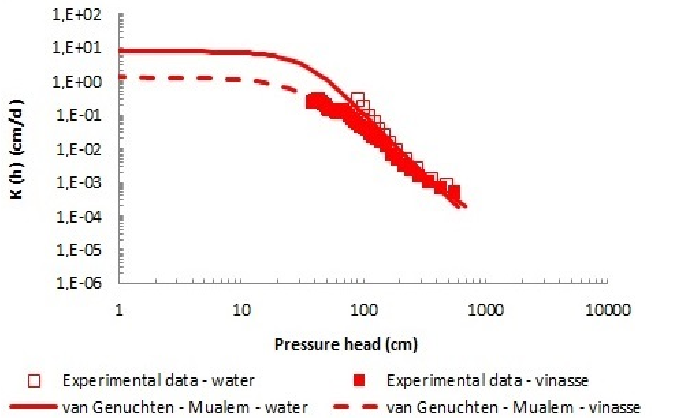

Figure 5. Hydraulic conductivity as a function of pressure head for Soil 2 saturated with water and vinasse.

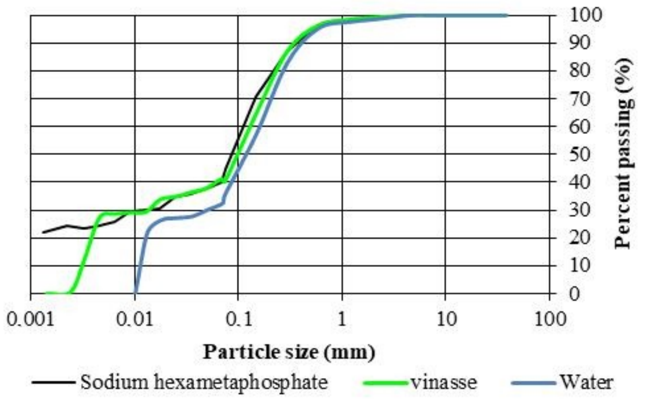

Figure 6. Particle size distribution for Soil 1 after the addition of hexametaphosphate and vinasse, as well as samples with no defloculating agent.

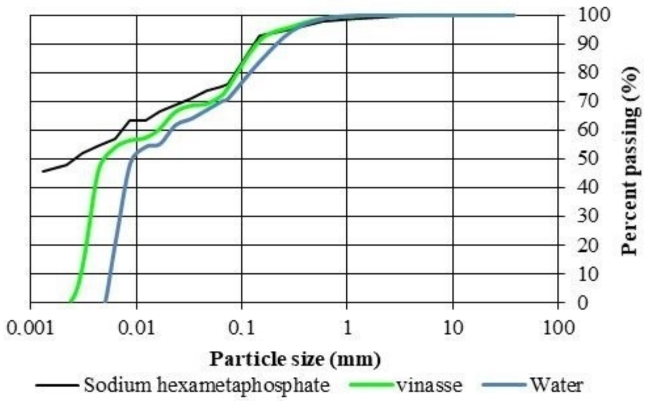

Figure 7. Particle size distribution for Soil 2 after the addition of hexametaphosphate and vinasse, as well as samples with no defloculating agent.

and hydraulic characteristics of soils containing vinasse differ little from those without vinasse. However, discrepancies were found in the hydraulic conductivity of the soil with a greater clay content led to the following remarks:

The tendency for a reduced unsaturated hydraulic conductivity can be related to the dispersion of smaller particles in soils with sufficient availability in the clay fraction, due to the high concentration of potassium with positive electric charge in the vinasse. In these cases, the use of indirect methods to obtain the hydraulic conductivity from the retention curve (such as those used in solute transport analysis) could be inadequate.

Reduction in hydraulic conductivity observed in unsaturated soils could be less evident when the evaporation method is used. The tests reported in the literature, however, have used continuous infiltration in saturated soil, a procedure which may have facilitated the dispersion of the finer particles.

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