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Estimation of the van Genuchten Soil Water Retention Properties for Sugar mill's Wastewater Affected Soil at NBSM

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ABSTRACT

A laboratory experiment was designed and conducted In order to estimate the performance of van Genuchten model of the retention curve equation for sugar mill's wastewater affected soil. Wastewater-affected and wastewater-unaffected soil samples both for disturbed and undisturbed conditions from two locations at North Bengal Sugar Mill's (NBSM) were collected: one location was West Baiddanathpur village and the other was East Baiddanathpur village. Textural classes of those soils were determined and the soil-water retention curves were drawn. Wastewater caused an increase water holding capacity of the soil, but it was more pronounced at small suctions than at larger suctions. van Genuchten model can describe soil-water retention curves of wastewater-unaffected as well as wastewater-affected soil for both disturbed and undisturbed condition. The fitting between the measured and estimated (by van Genuchten equation/model) soil-water retention curves was better for wastewater-unaffected soil than that of wastewater-affected soil. The fitting was also better for disturbed condition than for undisturbed condition of soil. Wastewater caused a change in the values of van Genuchten's parameters (m, n and α) of soil-water retention curves. Due to the effect of wastewater, the parameter m and n decreased for three cases among four cases. The parameter m and n increased only for disturbed soil of West Baiddanathpur. Due to the effect of wastewater, α also decreased for three cases among four cases and that increased for disturbed soil of East Baiddanathpur.

Key words: van Genuchten model, retention curve, sugar mill's wastewater, soil.

INTRODUCTION

At present there are 15 sugar mills in Bangladesh, mostly established in rural areas that produce sugar as well as large amount of effluent water (hereafter called wastewater) from their establishments. The wastewater comes mainly from the cooling system and floor washing. Leakage in valves and glands of the pipelines adds sugarcane juice, syrup and molasses in the effluent water. An important time match for the sugar mill's wastewater is that: November to April is the time for sugar production on one hand, and it is also the time for irrigation of sugarcane and most rabi crops on the other hand. Thus, the use of sugar mill's wastewater can be highly beneficial for the cultivation of sugarcane and rabi crops. Wastewater can be a valuable resource if it is not harmful for the environment and health. It is, therefore, important to manage the effluent water properly to minimize its undesirable effects. More importantly, managing this water for using in irrigation in a sustainable way can be a good venture. In general, sugar mill's wastewater contains acidic and alkaline compounds, a significant concentration of suspended solids, and a high BOD, COD, and sugar concentration. The, minimally treated wastewater can also be used to irrigate the neighboring sugarcane fields thus making the sugar production process a close-loop-system that utilizes its own wastes as inputs. There are possibilities of accumulation of sludge in the irrigated fields (UN ESCAP, 1982). However, there are some negative impacts of wastewater irrigation on environment and health as well as on soil physicochemical properties. So, when wastewater irrigation is planned, the factors related to soil properties must be taken into consideration.

The water retention curve is an important hydrophysical property of soil which is necessary in many disciplines of science from agriculture to ecology, can be measured experimentally and/or estimated using mathematical or statistical models.

Specification of the water retention curve is necessary for studying water availability for plants, plant water stress, infiltration, drainage, melioration as well as water and solutes movement in the soil (Kern, 1995). Water retention is one of the most important soil features. It governs the conditions of plant growth, development and yield as well as the availability and uptake of nutrients and toxic substances by plant root systems (Reinhard, 2001; Walczak *et al.*, 2000; Walczak *et al.*, 2001).

Methods for the estimation of the soil water characteristics have recently been intensively developed as determination of soil water characteristics is time- and labour-consuming and requires the use of expensive and specific equipment. Many semi-empirical and statistical equations (pedotransfer functions) describing the water retention curve have been proposed in the literature (Kutilek and Nielsen, 1994). These equations contain parameters which, generally, have no direct physical sense and are mainly used as fitting parameters to match function to experimental points. However, Guber *et al.* (2004) postulated that the physical correlate of van Genuchten's parameter n is the impact content of small aggregates in soil and that the parameter α relates to the content of large aggregates.

One of the most popular is van Genuchten's model/equation (van Genuchten, 1980):

$$S_e = \left[1 + (-\alpha h)^n\right]^{-m} \text{ ------------- (1)}$$

Where, S_e is the effective saturation and is defined by

$$S_e = \frac{\theta - \theta r}{\theta s - \theta r}$$

θ = volumetric soil-water content (decimal)
θ_r = residual water content (decimal)
θ_s = saturated water content (decimal)
α = a parameter (>0) used to scale the matric head
m & n = dimensionless parameter (n>1)
h = suction head/metric potential (cm of water)

Most of the researchers tried to find equations describing the water retention curve using the simplest set of measurable parameters of soil solid phase such as particle size distribution, bulk density, or organic matter content.

In the 1990s, Wösten and Lilly (2004) created the European soil data base, HYPRES (HYdraulic PRoperties of European Soils), containing van Genuchten's parameters for soils in European Union countries, classified according to texture classes. The next step was correlation of these parameters with selected physical parameters of soil solid phase. In 2004, similar investigations were performed by Rajkai *et al.* (2004) for Hungarian soils. The researchers correlated van Genuchten parameters α, n, θ_s, θ_r (Eq. (1)) with soil bulk density and contents of organic matter and sand, silt, and clay fractions. The aim of this work was to estimate the van Genuchten's parameters of the retention curve equation for sugar mill's wastewater affected soil.

MATERIALS AND METHODS

Sugar mill's wastewater unaffected and affected soil samples were collected from two locations at NBSM: where one location was West Baiddanathpur,Lalpur, Natore and the other one was East Baiddanathpur, Lalpur, Natore. West Baiddanathpur was closer to head end of the wastewater disposal canal than East Baiddanathpur. These samples were transferred to the laboratory, dried in air and sieved through a 2-mm square mesh sieve. The samples stored in plastic buckets for analysis. Three undisturbed soil samples were also collected from the same locations in core samplers (5 cm diameter and 5 cm height) both for Sugar mill's wastewater unaffected and affected soil.

The texture of the soils, collected for analysis, was determined by Hydrometer Method. Then by plotting the percentage values of sand, silt and clay on the Marshall's Triangular co-ordinate, the textural classes of the soils were found and listed in Table 1.

Table 1. Percentage of sand, silt and clay content along with the texture of 2 wastewater-unaffected and 2 wastewater-affected soils.

Location of sample	Pollution status	%Sand	%Silt	%clay	Soil texture
West Baiddanathpur	Unaffected	12.96	51.84	35.2	Silty clay loam
East Baiddanathpur	Unaffected	16.96	59.84	23.2	Silt loam
West Baiddanathpur	Affected	22.96	56.84	20.2	Silt loam
East Baiddanathpur	Affected	8.96	65.84	25.2	Silt loam

Soil-water retention in the experimental soils were determined in the laboratory of Department of irrigation and water management, BAU, Mymensingh by using a Sand Box (Eijkelkamp, Agrisearch Equipment, The Netherlands) for low suction (<0.1kPa) and a pressure plate apparatus (Soil Moisture Equipment Corp., Santa Barbara, Ca., USA.) for high suctions above 0.1 kPa to 10,000 kPa hence plotting these water contents against the corresponding soil-water suctions, the soil-water retention curves were drawn for different samples. Van Genuchten's equation was fitted to the experimental water retention curves using a computer program (Microsoft Excel) estimating the parameters of the equation (called the van Genuchten's parameters) by least square methods.

RESULTS AND DISCUSSION

Soil-water retention

Figures 1–4 illustrate the soil-water retention curves of the disturbed and undisturbed soils to compare the effects of wastewater on the soil in terms of water holding capacity at different suctions. Due to the effect of sugar mill's wastewater, water holding capacity of the soil increased both for the disturbed and undisturbed conditions at the two sites. The difference in water content between the wastewater-affected and wastewater-unaffected soil was more pronounced at small suctions than at large suctions. Wastewater contained a number of organic and inorganic substances, which improved soil structure, and consequently, increased porosity as well as water holding capacity of the wastewater-affected soils. Besides this, wastewater contained solutes and fine particles, which deposited in the soil micro pores with a consequent relatively reduced water holding capacity of wastewater-affected soils at higher suctions. Increase in soil-water content due to the effects of wastewater was also reported by Dawes and Goonetilleke (2004) and Tarenitzky *et al.* (1999).

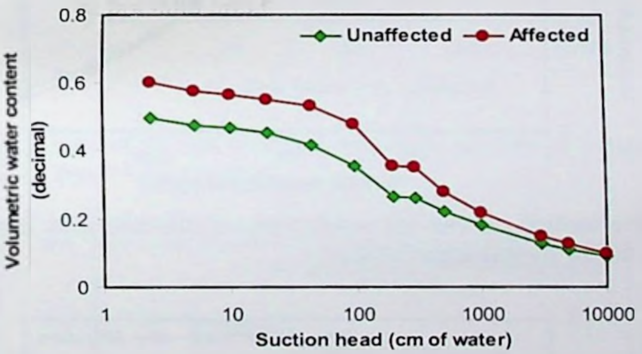

Fig. 1 Soil-water retention curves for wastewater-unaffected and wastewater-affected disturbed soil of West Baiddanathpur.

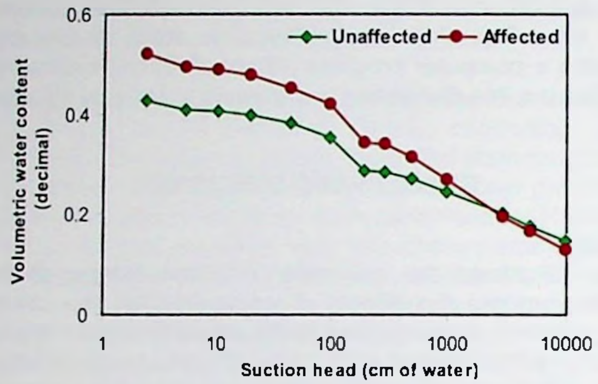

Fig. 2 Soil-water retention curves for wastewater-unaffected and wastewater-affected undisturbed soil of West Baiddanathpur.

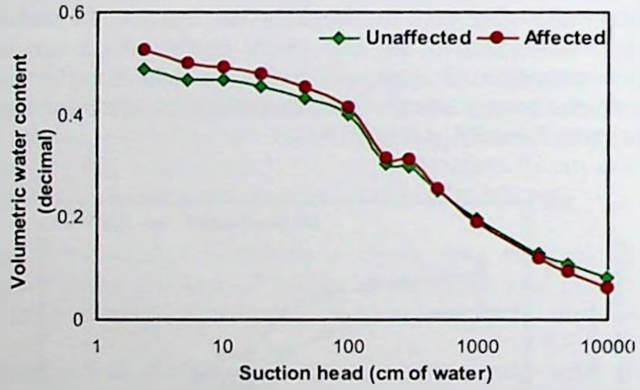

Fig. 3 Soil-water retention curves for wastewater-unaffected and wastewater-affected disturbed soil of East Baiddanathpur.

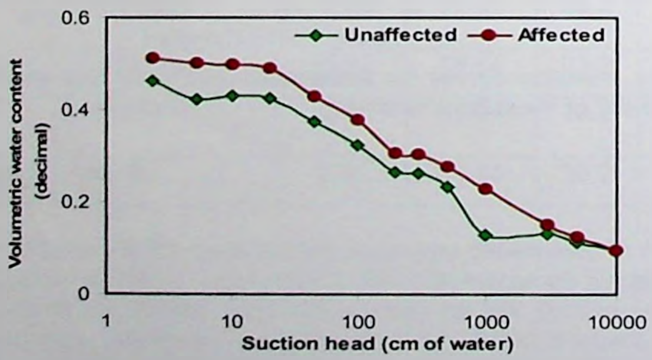

Fig.4 Soil-water retention curves for wastewater-unaffected and wastewater-affected undisturbed soil of East Baiddanathpur.

Comparison of measured and estimated soil-water retention curves

Figures 5–12 compare the measured and estimated (by van Genuchten equation, Eq.1) soil-water retention curves for wastewater-unaffected as well as wastewater-affected soils at West Baiddanathpur and East Baiddanathpur both under disturbed and undisturbed conditions. Although fitting between the measured and estimated soil-water retention curves was fair for all soils, the best fitting was for wastewater-unaffected disturbed soil of West Baiddanathpur. The fitting was relatively weak for wastewater-affected disturbed soil of East Baiddanathpur. The fitting between the measured and estimated soil-water retention curves was better for disturbed condition than for undisturbed condition of soil except for wastewater-affected soil of East Baiddanathpur. The fitting was also better for wastewater-unaffected soil than for wastewater-affected soil except for the undisturbed soil of East Baiddanathpur.

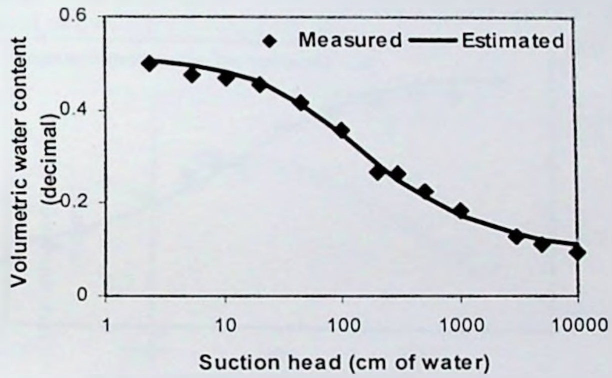

Fig.5 Measured and estimated soil-moisture retention curves of wastewater-unaffected disturbed soil of West Baiddanathpur.

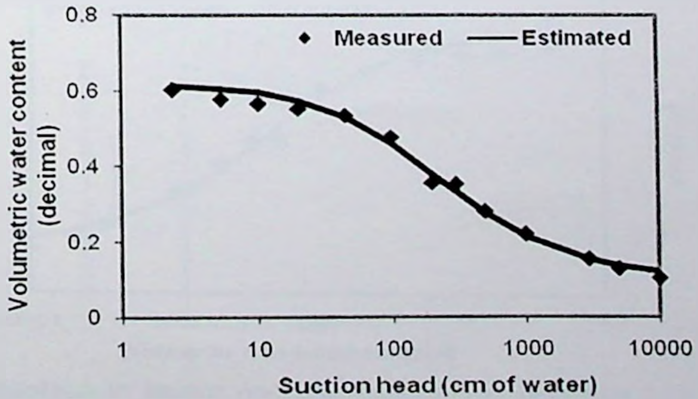

Fig.6 Measured and estimated soil-moisture retention curves of wastewater-affected disturbed soil of West Baiddanathpur.

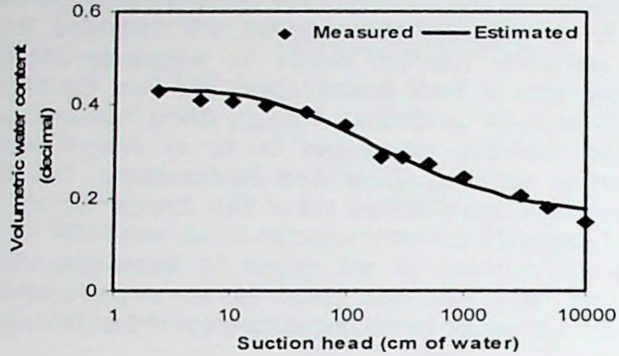

Fig.7 Measured and estimated soil-moisture retention curves of wastewater-unaffected undisturbed soil of West Baiddanathpur.

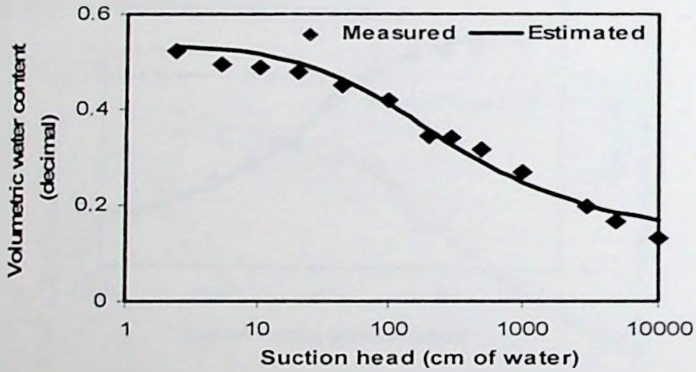

Fig.8 Measured and estimated soil-moisture retention curves of wastewater-affected undisturbed soil of West Baiddanathpur.

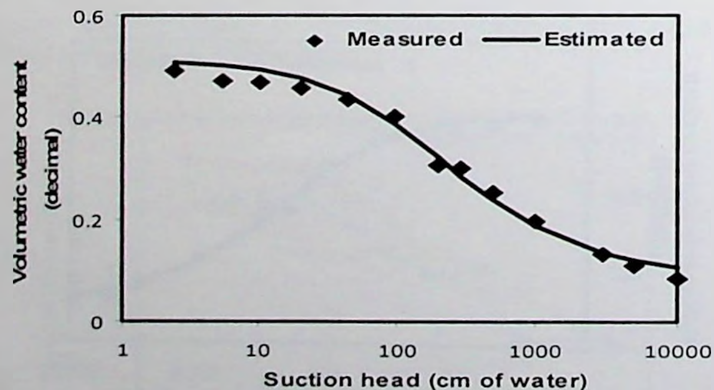

Fig.9 Measured and estimated soil-moisture retention curves of wastewater-unaffected disturbed soil of East Baiddanathpur.

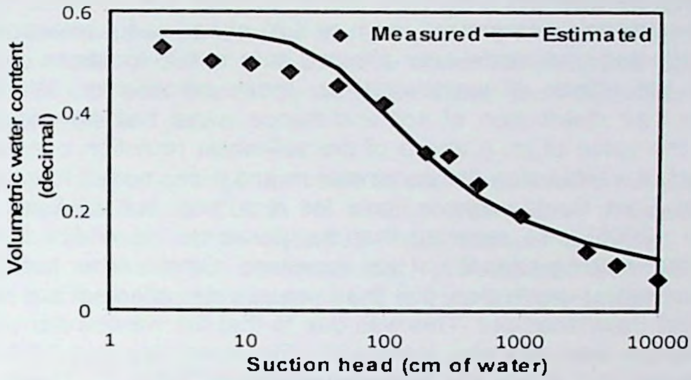

Fig.10 Measured and estimated soil-moisture retention curves of wastewater-affected disturbed soil of East Baiddanathpur.

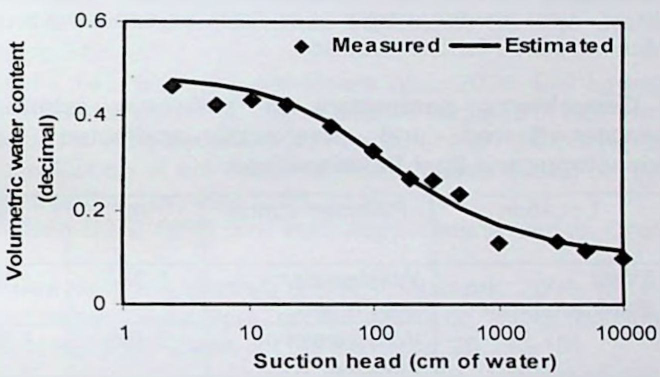

Fig.11 Measured and estimated soil-moisture retention curves of wastewater-unaffected undisturbed soil of East Baiddanathpur.

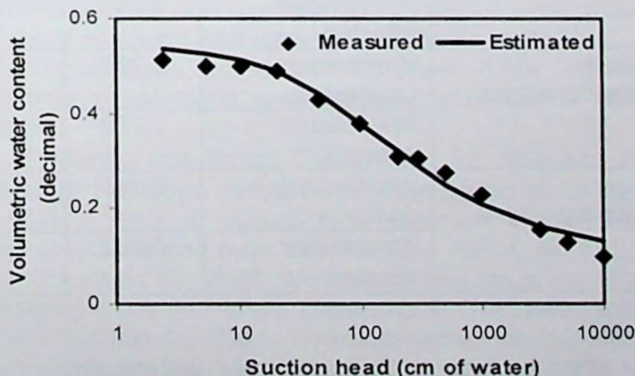

Fig.12 Measured and estimated soil-moisture retention curves of wastewater-affected undisturbed soil of East Baiddanathpur.

van Genuchten's parameters

van Genuchten's parameters (m, n and α) of soil-water retention curves for the wastewater-unaffected and wastewater-affected soils at two locations are given in Table 2. to compare the effects of wastewater on these parameters. Wastewater caused change in pore size distribution of soil and hence water holding capacity of the soil. Consequently, the value of m, n and α of the soil-water retention curves also changed. Due to the effect of wastewater, the parameter m and n decreased for undisturbed soil of both West and East Baiddanathpur, and for disturbed soil of East Baiddanathpur. Porebska *et al.* (2006) also reported that the parameter m and n decreased as the porosity and water holding capacity of soil increased. On the other hand, m and n were smaller for wastewater-unaffected soil than wastewater-affected soil under disturbed condition at West Baiddanathpur. This was due to that the wastewater-unaffected soil at West Baiddanathpur was silty clay loam with 15% more clay and 10% less sand than wastewater-affected soil at this site that was silty loam (Table 1). These results were in agreement with that of Porebska *et al.* (2006) who found that the parameter n increased considerably with increasing sand content and decreased with increasing silt and clay contents. Due to the effect of wastewater, α decreased both for disturbed and undisturbed soils of West Baiddanathpur. For East Baiddanathpur, α decreased for undisturbed soil but increased for disturbed soil.

Table 2. Van Genuchten's parameters of soil-water retention curves for wastewater-affected and wastewater-unaffected soils of West Baiddanathpur and East Baiddanathpur.

Soil structure	Location	Pollution status	m	n	α
Disturbed	West Baiddanathpur	Wastewater unaffected	0.333	1.500	0.0248
		Wastewater affected	0.359	1.559	0.0144
	East Baiddanathpur	Wastewater unaffected	0.336	1.505	0.0153
		Wastewater affected	0.313	1.456	0.0200
Undisturbed	West Baiddanathpur	Wastewater unaffected	0.283	1.394	0.0242
		Wastewater affected	0.282	1.393	0.0222
	East Baiddanathpur	Wastewater unaffected	0.316	1.461	0.0315
		Wastewater affected	0.288	1.405	0.0286

Conclusion

Due to the effect of sugar mill's wastewater, water holding capacity of the soil increased though the difference in water content between the wastewater-affected and wastewater-unaffected soil was more pronounced at small suctions than at large suctions. Fitting between the measured and estimated (by van Genuchten equation, Eq.1) soil-water retention curves was fair for all soils. The fittings between the measured and estimated soil-water retention curves were better for disturbed condition than for undisturbed condition of soil. The fitting was also better for wastewater-unaffected soil than for wastewater-affected soil.

Wastewater caused change the value of van Genuchten's parameters (m, n and α) of soil-water retention curves. Due to the effect of wastewater, the parameter m and n decreased for undisturbed and disturbed soil except disturbed soil of West Baiddanathpur. Due to the effect of wastewater, α decreased both for disturbed and undisturbed soils but increased for disturbed soil of East Baiddanathpur.

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