Comparison of Fitting Quality and Changes Trend of Moisture Curve Parameters of
Mualem-Van Genuchten Model at Different compaction Treatments of Sandy Loam
and Clay Loam Soils

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ABSTRACT: Soil hydraulic properties including soil water characteristics curve and hydraulic conductivity are two important properties to determination of water movement in soil. The aim of this study was to evaluation of fitting quality of Mualem-Van Genuchten model on moisture curve and comparing in two soil texture classes (sandy loam and clay loam) and in different compaction treatments. Samples were collected from 0-10cm depth and Compaction created by proctor in six replication and four levels including C0 (control), C1, C2 and C3 by increasing in soil bulk density with the ratio of 5, 10 and 15%, respectively. Mualem-Van Genuchten model using RETC software were fitted on moisture-suction data obtained from pressure plate. Fitting quality of considered model achieved by R² and RMSE calculation. RMSE in sandy loam soil had no change compared to control. But clay loam soil had increasing trend in terms of RMSE. Due to little changes of model in sandy loam in all treatments compared to clay loam, the use of this model in light textured and field compaction status was recommended.

Keywords: moisture curve parameters, compacted soils, fitting quality, Mualem-Van Genuchten model

Introduction

Soil hydraulic properties including soil water characteristics curve and hydraulic conductivity are two important properties to determination of water movement in soil. Considering that using moisture curve equations, hydraulic conductivity functions and water flow in soil could be described, moisture curve is one the most important hydraulic property in soils. Moisture curve indicate the relationship between soil moisture and matric suction and is a basic characteristic in study of plant available water, infiltration phenomena, drainage, hydraulic conductivity, irrigation, plants water stress and solution movement in soil. Moisture curve have many applications in fields of agriculture (plant available water estimation) and environment (water flow modeling in unsaturated area).

As we know, compaction is the increasing in bulk density and soil bulk density (BD) is the mass of oven-dried undisturbed soil per volume unit (ISSS Working Group, 1998). This factor as basic physical properties was used as soil porosity and compaction index. Increasing in bulk density in agricultural soils was common
and occurred at different scales. Also it is possible that increasing in soil bulk density was resulted from artificial processes. Plowing might increase bulk density which affected hydraulic properties in soil profile (Or et al., 2000). Traffic management in the agricultural machinery reduced soil compaction (Van Dijck and Van Asck, 2002). Also, this management caused changes in soil hydraulic properties, which in turn affected changes in soil water, temperature and air (Stepniewski et al., 1994) and root growth (Lipiec and Hatano, 2003) and therefore production and environment quality (Hakansson et al., 1988).

Due to the high spatial variability of soil hydraulic properties, field and laboratory measuring of soil hydraulic properties such as moisture curve is time consuming and costly (Abbasi et al., 2011; Mohammadi and Vanclooster, 2011). Therefore, in addition to direct measuring methods of moisture curve, indirect methods of moisture curve estimation were proposed.

Mathematical express of moisture curve in a function form has many advantageous and disadvantageous. Coefficients state the soil moisture behavior during drying and applied in programming of water and mineral soft wares. Many mathematical models were proposed to soil moisture curve (Brooks and Corey, 1964; Tyler and Wheatcraft, 1992). Generally, models that estimate the sigmoid shape of moisture curve are more successful which of these models; we can point out Van-Genuchten model (1980).

In Iran, few investigations were conducted on quality of moisture curve models fitting. Specially, in compacted soil conditions no study was conducted in this respect. Therefore, aim of this study was to evaluation of fitting quality of Mualem-Van Genuchten model on moisture curve and comparing in two soil texture classes (sandy loam and clay loam) and in different compaction treatments.

**Method and Materials**

Studied samples randomly were collected from two different areas in Karaj; first Kordan due to light texture and low lime percent and second area from research farm of College of Agriculture and Natural Resources of Tehran University due to heavy texture. Samples were collected from 0-10cm depth. Soil samples analyzed for physical and chemical properties. Particle size distribution (PSD) was determined using hydrometer method (Gee and Bauder, 1986), bulk density by cylinder method and organic carbon measured by Walkley and Black method (1934).

Soil samples passed through 2mm sieve, and then were poured in standard steel cylinders (7.5 cm height and 7.5 cm diameter). Compaction created by proctor in six replication and four levels including C<sub>0</sub> (control), C<sub>1</sub>, C<sub>2</sub> and C<sub>3</sub> by increasing in soil bulk density with the ratio of 5, 10 and 15%, respectively. So, control treatment (C<sub>0</sub>) had the lowest impact and 15% treatment (C<sub>3</sub>) received the greatest impact to reach 6 cm height for condensing.

To determine the moisture curves after compaction treatments, initially soil samples were saturated from below for different compaction treatments. Then, treatments moisture contents after reaching equilibrium by pressure plate were determined at 0, 0.33, 0.5, 1, 5, 10 and 15 bar suctions. Mualem- Van Genuchten moisture curve model is as equation (1):

\[
\theta = \theta_s + \left( \theta_o - \theta_s \right) \left[ 1 + (\alpha h)^n \right]^{-m} = 1 - L^{-n} \quad n>1
\]

Where \( \alpha \), \( n \) and \( m \) are shape parameters, \( \theta_o \) residual moisture (L<sup>-3</sup>), \( \theta_s \) is saturation moisture which all of them are model coefficients. \( \alpha \), \( n \) and are constant empirical coefficients that affected moisture curve shape. In Mualem VanGenuchten model \( \alpha \) parameter are related to converse suction in air entry point to soil. Suction amounts of air entry point obtained from equation (2):

\[ h_d = 1/\alpha \]

Coefficient of \( n \) controls the moisture curve slope. Shape parameters more affected moisture curve shape and hydraulic conductivity. These parameters often caused displacement of moisture characteristics in vertical direction (up and down), While, \( \theta_o \), and \( \theta_s \) caused horizontal displacement (left and right).

In the present study, Mualem-Van Genuchten model (1980) were fitted to experimental data, and in order to evaluation of fitting quality of this model, R<sup>2</sup> and RMSE criterions by using RETC software were used. R<sup>2</sup> described as determination coefficient in models and RMSE as root mean squares errors. In order to evaluation of the best fitting quality model, these parameters were used. Low amounts of RMSE indicated the little deviation of estimated results from observed results. RMSE amounts estimated according to measured moisture contents and calculated as equation (3):
\[ RMSE = \sqrt{\frac{1}{N} \sum_{i=1}^{N} \left[ \theta_i - \theta_{i(p)} \right]^2} \]  

[3]

Where, \( N \) is number of moisture curve points, \( \theta_i \) measured moisture content at relevant i suction and \( \theta_{i(p)} \) is estimated moisture at relevant suction i.

Result and Discussion

Soil physical properties in different compaction treatments were presented in Table 1. Particle density of soils was assumed as 2.65 g.cm\(^{-3}\).

<table>
<thead>
<tr>
<th>Site</th>
<th>Depth(cm)</th>
<th>Sand(%)</th>
<th>Silt(%)</th>
<th>Clay(%)</th>
<th>OM(%)</th>
<th>Compaction Level</th>
<th>( \rho_b )(gcm(^{-3}))</th>
</tr>
</thead>
<tbody>
<tr>
<td>Kordan</td>
<td>0-10</td>
<td>65</td>
<td>16</td>
<td>19</td>
<td>0.28</td>
<td>control</td>
<td>1.61</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td>5%</td>
<td>1.69</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td>10%</td>
<td>1.77</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td>15%</td>
<td>1.85</td>
</tr>
<tr>
<td>Farm of Faculty</td>
<td>0-10</td>
<td>33</td>
<td>33</td>
<td>34</td>
<td>1.38</td>
<td>control</td>
<td>1.52</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td>5%</td>
<td>1.59</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td>10%</td>
<td>1.67</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td>15%</td>
<td>1.75</td>
</tr>
</tbody>
</table>

Based on soil texture triangle (USDA), Kordan region soil texture and farm of University College were sandy loam and clay loam, respectively. These soils were significantly different in physical properties. Bulk density range in sandy loam was between 1.61 and 1.85 and for clay loam was 1.52 to 1.75 g.cm\(^{-3}\).

Moisture curve model parameters (\( \theta_s \), \( \theta_r \), \( \alpha \), \( n \) and \( m \)) as well as air entry point suction (\( h_d \)) for sandy loam and clay loam soils in compaction treatments was presented in Table 2.

<table>
<thead>
<tr>
<th>Texture</th>
<th>Treatment</th>
<th>( \theta_s )</th>
<th>( \theta_r )</th>
<th>( \alpha )</th>
<th>( n )</th>
<th>( m )</th>
<th>( h_d )</th>
</tr>
</thead>
<tbody>
<tr>
<td>Clay</td>
<td>control</td>
<td>0.437037</td>
<td>0.1753</td>
<td>0.00468</td>
<td>1.50126</td>
<td>0.333893</td>
<td>213.675</td>
</tr>
<tr>
<td></td>
<td>5%</td>
<td>0.411111</td>
<td>0.1753</td>
<td>0.00289</td>
<td>1.58243</td>
<td>0.368061</td>
<td>346.021</td>
</tr>
<tr>
<td></td>
<td>10%</td>
<td>0.381481</td>
<td>0.1753</td>
<td>0.00141</td>
<td>1.83959</td>
<td>0.456401</td>
<td>709.22</td>
</tr>
<tr>
<td></td>
<td>15%</td>
<td>0.351852</td>
<td>0.1753</td>
<td>0.0007</td>
<td>2.59665</td>
<td>0.614888</td>
<td>1428.57</td>
</tr>
<tr>
<td>Sandy</td>
<td>control</td>
<td>0.403704</td>
<td>0.1169</td>
<td>0.0265</td>
<td>1.41283</td>
<td>0.292201</td>
<td>37.7358</td>
</tr>
<tr>
<td></td>
<td>5%</td>
<td>0.374074</td>
<td>0.1169</td>
<td>0.0154</td>
<td>0.43167</td>
<td>0.301515</td>
<td>64.9351</td>
</tr>
<tr>
<td></td>
<td>10%</td>
<td>0.344444</td>
<td>0.1169</td>
<td>0.00733</td>
<td>1.522</td>
<td>0.301515</td>
<td>136.426</td>
</tr>
<tr>
<td></td>
<td>15%</td>
<td>0.314815</td>
<td>0.1169</td>
<td>0.00426</td>
<td>1.50442</td>
<td>0.335292</td>
<td>234.742</td>
</tr>
</tbody>
</table>

As could be seen in Table 2, saturation volumetric moisture percent (\( \theta_s \)) reduced by increasing in compaction and residual moisture amount (\( \theta_r \)) depended on soil texture and would not change over compaction treatments. The amount of \( \alpha \) in both textures reduced with increasing compaction levels. Amount of this parameter in control treatment of clay loam was 0.00468 and in 15% compaction equal to 0.0007. Also its amounts in sandy loam texture in control and 15% compaction treatments were 0.0265 and 0.00426, respectively. The amount of \( \alpha \) inversely related to suction in air entry point (\( h_d \)) and decreased with increasing air entry point.
suction. This parameter caused vertical displacement in moisture curve; it means that compaction reduced $\alpha$ amount and moisture curve shifted downward with increasing compaction. These results were in agreement with Zhang et al. (2006) results. These authors stated that compaction decreased $\alpha$ in all soil textures, also $n$ amount increased with increased compaction. In line with these researches, Porebska (2006) studied the changes of these parameters ($\alpha$, $n$, $\theta_c$, $\theta_r$) in three layers of soil with different bulk densities in Mualem- Van Genuchten model. Change rate of $\alpha$ parameter or gleysol soil was in 0.012 to 0.6557 ranges and for phaozem soil were 0.004 to 0.1336. For $n$ parameter, Porebska (2006) obtained the amounts of 1.089 to 1.6381 for phaozem and 1.17 to 3.41 for gleysol.

Considering the above mentioned equation (3), suction in air entry point ($h_d$) in both soils, increased with increasing compaction levels. The range of these changes in clay loam soil was 213.67 to 1428.57, and for sandy loam was 37.73 to 234.74. The range of changes in clay loam soil was high due to having high porosity and, especially fine porosity. Slope of S-shaped moisture curve controlled by $n$ parameter. Considering Table 2, $m$ and $n$ increased with increasing in compaction levels. It means that compaction increased moisture curve slope. Also, unlike $\alpha$, these parameters caused the upward vertical displacement of moisture curve.

Among the moisture curve models, some like Brooks and Corey model (1964) and Mualem- Van Genuchten model (1980) are most widely used (Mermoud 2006). Generally, models that estimate the sigmoid shape of moisture curve are more successful which of these models; we can point out Mualem-VanGenouchten model (1980). This model was not able to calculate the suction amount at air entry point to soil but had a turning point that makes it a better performance than the Brooks and Corey model, especially in regions close to saturation and the Campbell model is in many soils.

Fitting quality of Mualem-Van Genuchten model to laboratory data in compaction treatments for both sandy loam and clay loam soils were shown on Table 3.

### Table 3- Fitting quality of Mualem-Van Genuchten model to laboratory data in compaction treatments

<table>
<thead>
<tr>
<th>Texture</th>
<th>Treatment</th>
<th>$R^2$</th>
<th>SSE</th>
<th>RMSE</th>
</tr>
</thead>
<tbody>
<tr>
<td>Clay Loam</td>
<td>control</td>
<td>0.998</td>
<td>0.0001</td>
<td>0.00378</td>
</tr>
<tr>
<td></td>
<td>5%</td>
<td>0.998</td>
<td>0.00012</td>
<td>0.00414</td>
</tr>
<tr>
<td></td>
<td>10%</td>
<td>0.993</td>
<td>0.00023</td>
<td>0.005732</td>
</tr>
<tr>
<td></td>
<td>15%</td>
<td>0.962</td>
<td>0.00115</td>
<td>0.012817</td>
</tr>
<tr>
<td>Sandy Loam</td>
<td>control</td>
<td>0.999</td>
<td>0.00001</td>
<td>0.001195</td>
</tr>
<tr>
<td></td>
<td>5%</td>
<td>0.999</td>
<td>0.00001</td>
<td>0.001195</td>
</tr>
<tr>
<td></td>
<td>10%</td>
<td>0.999</td>
<td>0.00001</td>
<td>0.001195</td>
</tr>
<tr>
<td></td>
<td>15%</td>
<td>0.999</td>
<td>0.00001</td>
<td>0.001195</td>
</tr>
</tbody>
</table>

Table 3 resulted from Mualem- Van Genuchten model fitting on laboratory data. In this table, determination coefficient ($R^2$) and RMSE amounts were estimated. As mentioned earlier, $R^2$ and RMSE statistical indices are very important factors in determination of moisture curve model fitting capacity on compacted treatments. In order to determination of moisture curve model efficiency using of $R^2$ and RMSE was more appropriate (Nimmo, 1991).

$R^2$ amounts of clay loam soil in control, 5% and 10% treatments were very close as well as RMSE in first three compaction treatments, while in 15% compaction in clay loam $R^2$ lowered and RMSE increased.

In sandy loam soils, amounts of both $R^2$ and RMSE in all treatments remained constant. It means that in all compaction treatments at sandy loam soil, Mualem- Van Genuchten model well able to estimate the moisture curve and RMSE error amount in all treatments was equal to 0.0011 cm$^3$cm$^{-3}$, but in clay loam RMSE amount in control and 5% treatments was low and increased with increasing in compaction. Results are in consistent with Nabizadeh and Beygi (2011) results. They founded that Mualem- Van Genuchten model had lowest
RMSE (from 0.001 to 0.021 cm$^3$cm$^{-3}$) in moisture curve model fitting on soils. These authors studied the moisture prediction changes in different moisture curve models and texture classes and concluded that changes in sandy loam class much lower than silty clay, silty loam and silty clay loam. This means that performance of moisture curve models in this texture class was better. Also, Mualem- Van Genuchten model performance especially was better in area near to saturation. These finding are in consistent with Assouline et al. (1998) and Manyame et al. (2007) results.

As could be seen in Table 3, actually no changes could be observed in RMSE amounts of sandy loam texture in compacted treatments, but these change existed in all compaction treatments of clay loam texture and these changes in 15% compaction were strong.

Kashkooli and Zeynalzadeh (2001) compared the fit ability of two empirical models including Saxton et al. (1986) and Hutson and Cass (1987) (which estimated using easy access information such as soil texture) with Mualem-Van Genuchten model (1980) and concluded that Mualem- Van Genuchten, Saxton et al. and Hutson and Cass models, had best fitting, respectively. Also, they founded that Mualem-Van Genuchten model among other models had lowest RMSE amount in moisture curve fitting. Increasing RMSE resulted in reduction of models accuracy in soils moisture estimation.

**Conclusion**

In the present study, fitting quality of Mualem-Van Genuchten model on compacted soil moisture curves was evaluated. At all compacted treatments $R^2$ amounts in sandy loam were higher than clay loam and in clay loam soil amounts or $R^2$ at 15% compaction were lower than other treatments. RMSE in sandy loam at compaction treatments was constant but RMSE in clay loam soil increased with increasing in compaction and model error in clay loam at 15% compaction reached on 0.0128. By fitting this model on light and heavy textured soils concluded that Mualem-Van Genuchten model in compacted sandy loam soil has better results than compacted clay loam and the use of this model was recommended in compacted light textured soils in field conditions.

**References**


