Reprint ISSN 1994-1978 (Web Version)

Journal of Soil and Nature (JSN)

(*J. Soil Nature*)

Volume: 8	Issue: 2	July 2015

J. Soil Nature 8(2): 24-29 (July 2015)

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ISSN-1994-1978 (Online)
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THE RELATIONSHIP BETWEEN FRACTAL DIMENSION OF PARTICLE SIZE DISTRIBUTION AND SOME SOIL PHYSICAL PROPERTIES IN THE NORTH OF IRAN

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Accepted for publication on 13 June 2015

ABSTRACT

Doaei S, Pazira E, Mahmoudi S, Torkashvand AM (2015) The relationship between fractal dimension of particle size distribution and some soil physical properties in the north of Iran. *J. Soil Nature* 8(2), 24-29.

Fractal geometry and geostatistics have become effective tools for quantifying spatial variability of soil physical. In this research, fractal dimension (D_m) of Particle Size Distribution (PSD) was used to explain relationships between D_m and some physical properties of soils. Samples from 51 soil series with varying properties were collected from north of Iran. Sand fraction was determined by sieving and silt and clay fractions by the hydrometer methods. Fractal dimension of PSD was computed by Tyler & Wheatcraft model. Statistical analysis showed significant and positive correlations between D_m and clay (0.93) and silt (0.80) particles; and the correlation between D_m and sand (0.73) were significantly negative. Therefore, D_m had significant relations with soil textural fractions and textural classes, and might be used as an integrating index in modeling studies. Results also showed that greater D_m was associated with greater self-similarity in pore size distribution.

Key words: *fractal dimension, north of Iran, physical properties of soils, soil particle size distribution*

INTRODUCTION

Soil Structure, texture and distribution of soil particles size, are an index of soil characteristics and productivity. Soil texture is an important factor in moisture retention and determination of nutrient concentration in the soil solution. Soil structure, porosity and aeration depend on soil texture (Martin *et al.* 2005).

Study of soil physics has been started from its mechanical analysis, which consists of separation of soil particles into three groups: sand, silt and clay. Soil particle size is assessed by two common criteria, particle size distribution and soil texture. Distribution of soil particles is the result of geological and geophysical processes and it is applied in classification of various soils and determination of hydraulic properties (Alizadeh 2009).

Nowadays the application of fractal geometry and fractal dimension of shapes is common in recognition of the heterogeneity in natural environments (Kutlu *et al.* 2008). Fractal dimension (D_m) of distribution of soil particles, is introduced as a useful tool for estimating the related characteristics of soil texture. Various fractal dimensions can be used to define the geometry and characteristics of porous environments (e.g. soil) and to modeling and formulation of different processes (such as transport processes in soil). Fractal parameters prove the dependence of soil characteristics to measurement scale and it may be manifested by relationship between mass and diameter or number and diameter of aggregates particles (Ahmadi *et al.* 2011).

Recent attempts were done for application of fractal concepts in hydraulic phenomena in soil, seeking to identify structural characteristics such as size distribution-solid particle number, size distribution-number of aggregates, distribution of size-soil pores, the relationship between size and density of aggregates, porosity or pore interface with solids (Perrier *et al.* 1996). NabiZadeh and Beigi (2011), found that the accuracy of the fitting of fractal model increased by increasing size of sand and it was done in order to select the most appropriate model of soil particle size distribution, and more accurate estimation of hydraulic characteristics, likewise an inverse relationship was observed between fractal model and the amount of silt in soil samples.

Liu *et al.* (2009), using fractal dimension analysis of soil size distribution and porosity of surface soil of Yimeng mountain of China with different management and vegetation, found that there is a significant and direct relationship between fractal dimension and clay. Likewise, there is a significant linear correlation between the amount of D_m and soil porosity. The authors found that the plant management, with influence on water holding capacity in the soil, plays an important role in small-scale soil aggregation.

Salako (2006) measured fractal dimension of soil profile in different heights of Savana by using data of distribution of particles size and concluded that the amount of D_m increased by depth of soil. Likewise, fractal scale was an indicator of difference between distributions of particles size along toposequense. Prosperini and Perugini (2008) found that distribution of soil particles size shows fractal behavior. Also, two ranges of fractal scale (for identifying different ranges of particles size) were identified by the past authors.

Variety of vegetation including paddy and tea fields, forests and rangelands are seen from plain to heights and in heights most of the fields are bare lands. These fields, considering high variety of plant cultivation in Guilan, have significant differences physically and chemically. Different Texture and structure have various effects on hydraulic characteristics and quality of water retention and nutrients of soils in different heights of Guilan (Mohammadi and Torkashvand, 2010). Therefore the necessity of quantification of these changes, in order to implement soil administrative planning, is inevitable.

There has been no study on comparison between physical characteristics of these soils by fractal dimension, physiographic units in Guilan province in land uses of rangelands, forest, agriculture and horticulture. Presenting a model for evaluating soil structure and distribution of particles size can be useful step in leading administrative aims of natural resources of the province.

This research has been conducted to quantify the amount of self-similarity of soil structure and distribution of particles size in various physiographic units of by using fractal models, as well as investigation of relationship between D_m of particles size distribution and distribution of aggregates size soil physical and chemical characteristics such as texture components (sand, silt, and clay), porosity, organic carbon and pH.

MATERIALS AND METHODS

Guilan province, having 14711 km^2 extents, is counted as the homiest area of Iran, because of being besieged by Caspian Lake and Alborz mountains. And it has more than 2000 mm rainfall annually. Vast part of the province is plain and the rest of it is surrounded by mountainous. In this study, 51 soil samples were taken from surface of soils 4 types of land uses, including paddy field, tea, forest and bare lands in the road of Deilaman to the Caspian Lake in the spring 2014.

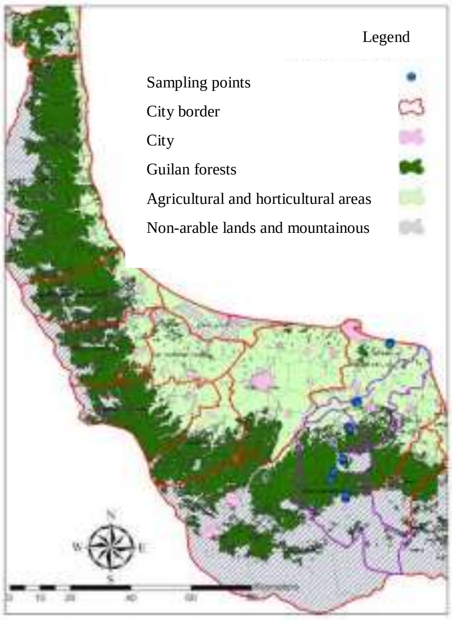

Fig. 1. Distribution of samples taken from Deilaman to the Caspian Lake

After air drying, the samples were crushed and passed through a 2 mm sieve to analyze the physical and chemical properties on them. Particles size distribution of clay and silt fractions were determined by hydrometer method and particles size distribution of sand was determined by sieving method (Gee and Or, 2002). The percentage of organic carbon by Walkey & Black method (Goos 1995) and soil pH was measured by potentiometric method (Richards 1954). The samples suspension with distilled water at a ratio of 1: 2.5 soil to water was prepared and then was shaked for half an hour and pH was measured by pH meter Orion model. Electrical conductivity (EC) was measured in soil saturation extract by extract.

Bulk density of soil was measured by clod and paraffin method and Particle density of soil was measured by picnometer. Soil porosity was obtained by using Bulk and Particle density and the following equation.

$$n = 1 - \frac{\rho_b}{\rho_s}$$

N is soil porosity; and P_b and P_s are bulk density and particle density, respectively. First proportional ratio of particles in different ranges was determined by soil particles size distribution curve for calculating fractal dimension and then fractal dimension of soil particles was measured from distribution of particles size and by using the following model:

$$\frac{M(r < R_i)}{M_T} = (\frac{R_i}{R_l})^{3-D_Y}$$

Which in it $\frac{M(r<R_i)}{M_T}$ aggregated mass of soil particles with diameter less than R_i, R_i is the mean of particles diameter myriad i class equal size of mean diameter if higher and lower limit in i class i_m mm, R_i average diameter of particles in the largest class size.

M_r is total mass of sample soil (g), Dr is the fractal dimension of soil particles size distribution and it is calculated by drawing curve $\frac{M(r<R_i)}{M_T}$ is calculated against Log R_i/R_l. If K is equal to the slope of the regression line, D_Y is calculated from the following equation:

$D_Y = 3\text{-}K$

Statistical analysis, data process and graphical diagrams were conducted by Excel 2007 and SPSS16 software.

RESULTS AND DISCUSSION

Table1. Maximum, minimum, mean, standard deviation (SD), coefficient of variation (CV), determined characteristics of soils

Characteristics of soil	**Unit**	**Minimum**	**Maximum**	**Mean**	**SD**	**CV**
Clay	(%)	0.00	55.00	27.98	11.61	41.52
Silt	(%)	0.50	59.00	41.29	13.04	31.48
Sand	(%)	0.00	99.00	30.72	22.10	72.25
pH	-	4.26	8.06	6.12	0.91	14.91
EC	dS/m	0.22	2.56	0.69	0.48	70.40
Organic carbon	(%)	0.40	7.80	2.79	1.70	61.10
Bulk density	gr/cm^3	1.03	1.81	1.45	0.16	10.85
Particle density	gr/cm^3	2.25	2.62	2.50	0.07	2.91
Porosity	(%)	30.50	60.17	41.82	6.03	14.43
Weight mean of particles	gr	0.03	2.53	1.19	0.52	43.7
Fractal dimension of soil particles	-	2.16	2.87	2.74	0.10	3.91

The results indicate the high dispersion of measured characteristics in the tested soils. The highest coefficient of variation (CV) is related to the (43/7%) which indicates high generalization ability of the results to other soils.

Also, this coefficient is a criterion of proportional variability of clay, sand, electric conductivity and organic carbon more than 35% which is classified based on Welding and Dars in groups with high maximum coefficient. The coefficient variation of silt was mean and pH, Bulk density and Particle density, porosity and fractal dimension of soil particles were in variable groups by low variation. Table 2, also, shows statistical characteristics of measured fractal dimension for distribution of studied soil particles size.

The relationship between distribution of particles size and fractal dimension

The calculated values of D_m varied from 2.16 till 2.87. Tyler and Wheatcraft (1990), Millan *et al.* (2003), Gubber *et al.* (2005), Huang and Zhang (2002), Prosperini and Perugini (2008), Wang *et al.* (2010) also concluded that mass fractal dimension is less than 3. Figure 2 depicts the relationship between fractal dimension and clay percentage of soil. There is a significant difference between D_m and clay percentage of soil. In other words, the amount of D_m increases significantly by increasing clay percentage of soil. As the soils with heavy texture have wider distribution of particles size rather than the soils with lighter texture, they enjoy more fractal dimension. It can be said that fractal models have high potential in simulating clay percentage, considering this coefficient.

Ahmadi *et al.* (2011) reported positive power relationship between these two parameters. As it can be observed in figure 3, the existence of linear relationship with lower correlation coefficient is reportable. Sue *et al.* (2004) and Kutlu *et al.* (2008) also reported significant and positive linear relationship between these two parameters.

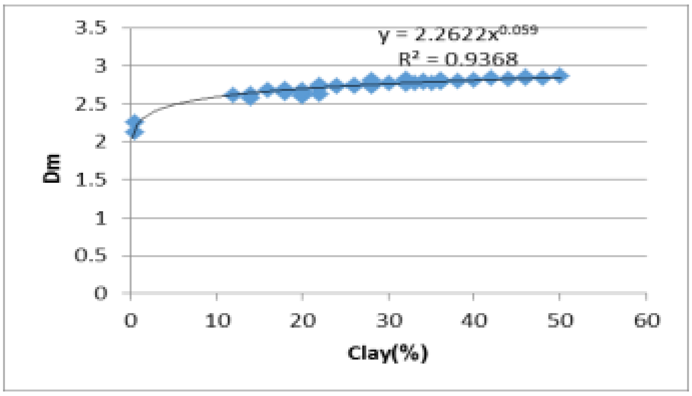

Fig. 2. The relationship between mass fractal dimension of soil particles size (D_m) and soil percentage (power)

D_m has significant and positive relationship with the amount of and it has significant and negative relationship with sand percentage of soil (Figures 4 and 5). This result can justify D_m diminish with being more sandy of soil texture. The results are in accordance with the Sue *et al.* (2004), and Ahmadi *et al.* (2011) findings. It is concluded that D_m can be applicable in simulating the amount of silt and sand of soil.

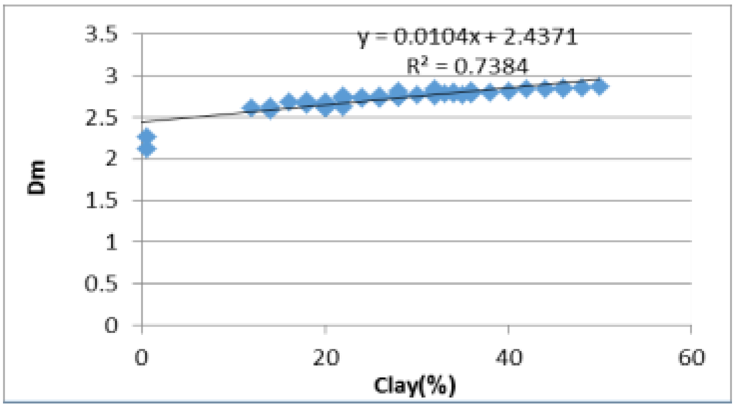

Fig. 3. The relationship between mass fractal dimension of soil particles size (D_m) and soil clay percentage (linear)

Stronger relationship between D_m and clay in comparison with sand and silt, is probably due to the greater frequency of the number of sand of soil particles rather than sand and silt section, by considering this strong relationship it is concluded that other parameter can be calculated by reasonable accuracy, having either of D_m variables or the amount of sand of soil.

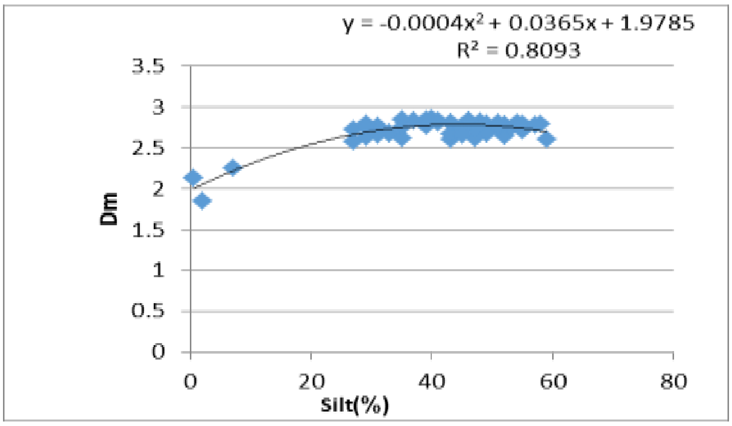

Fig. 4. The relationship between mass fractal dimension of distribution of size of soil particles (D_m) and percentage of soil silt

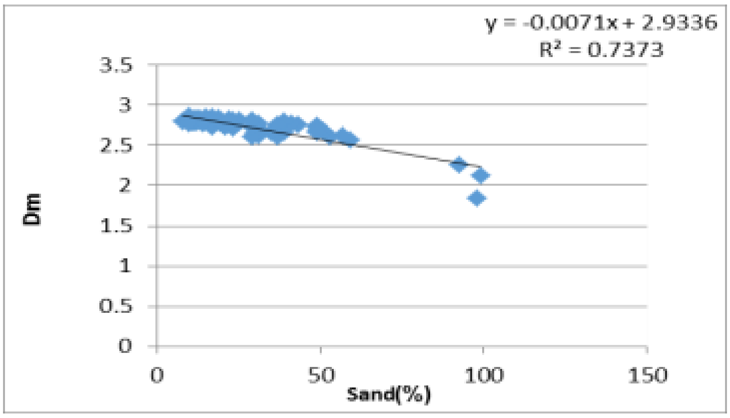

Fig. 5. The relationship between mass fractal dimension of distribution of size of soil particles (D_m) and percentage of sand of the soil

Figure 6 shows second and reversed grade relationship between two parameters of D_m and acidity of soil, namely D_m has diminished by increasing pH. Also, the relationship between D_m and soil bulk density was not that much strong but positive (figure 7). The relationship between D_m and porosity of soil had not significant difference.

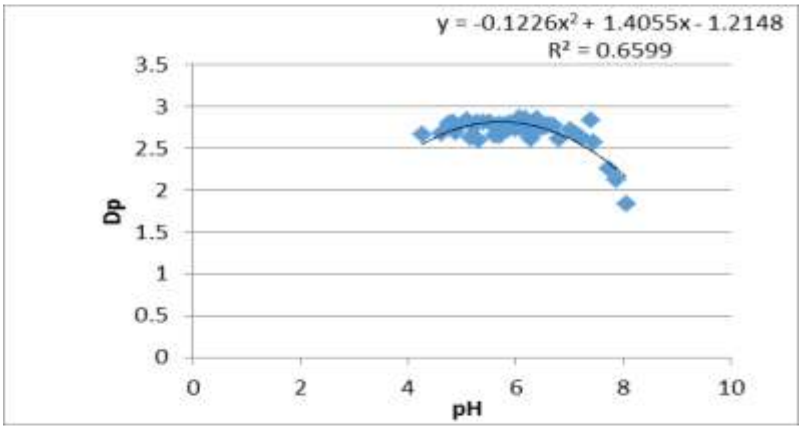

Fig. 6. The relationship between mass fractal dimension (D_m) and Soil pH

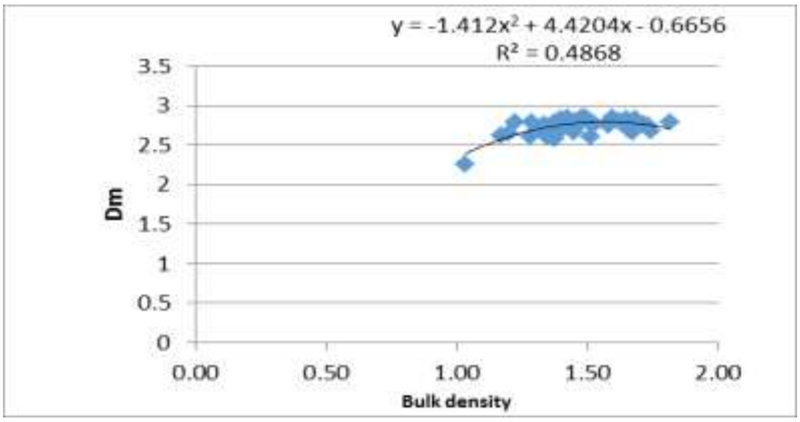

Fig. 7. The relationship between mass fractal dimension of (D_m) and Bulk density

Table 2 describes different values of D_m in different textures of the tested soils. As it can be observed the maximum values of D_m are related to clay soils and these amount have drastic difference with other soils. Wang *et al.* (2006), Kutlu *et al.* (2008), Ahmadi *et al.* (2011) also reported that sandy and clay soils had the minimum and the maximum amount of D_m, respectively. So it can be expressed that D_m parameter has the ability of soil differentiation from the aspect of the class of the texture of the soil.

Table 2. Mean of fractal dimension and texture classes of tested soils

Textural class	**Number of soil samples**	**D_m**
Clay	3	2.85
Silty clay	4	2.84
Silty clay loom	14	2.79
Clay loom	10	2.79
Silty clay loom	1	2.73
Silty loom	6	2.69
Loom	10	2.69
Sand	3	2.08

CONCLUSSION

Fractal dimension of distribution of the size of soil particles had significant and positive correlation with the amounts of clay, silt and bulk density of soil and it had negative and significant correlation with percentage of sand and acidity of the soil. Large values of D_m belonged to micro texture soils and small values are belonged to macro texture soils. As a result, D_m can be applicable in simulating of components of texture and the class of soil texture.

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