Methodology for determining the soil water content based on fractal dimension

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Abstract

One of the difficulties in the studies of the processes that occur in the soil porosity space, as the retention and water movement, is the definition of water content accurately variation. The experiment was developed in Guarapuava-PR to evaluate the use of soil fractal dimension to establish methodology for the determination of soil water content for irrigation management. It was verified that the soil fractal dimension obtained through the Spadotto equation and structured soil sample makes possible obtaining soil water content determination. The proposed methodology, starting from the results of this work, can be considered a field tool for irrigation management.

Key words: soil water content, fractal, irrigation management

Introduction

The fractal geometry is a new mathematics theory that can describe objects with complex geometric shapes and that have high degree of self-similarity, that is, presenting the same appearance at different scales. According to Backes and Bruno (2006) currently the Fractal Geometry, and in particular the Fractal Dimension, has been used in many areas, such as the study of systems and patterns of objects characterization; analysis and pattern recognition in images; analysis of textures and length measurement of curves and quantifications.

As for the direct applications of fractals studies Azevedo et al. (2006) stress that the fractal dimension is used to characterize irregular natural phenomena, with more precision then the conventional assessments, allowing an analysis with minor distortions of reality.

The properties of water retention in the soil, is to be expected that there is viability in the proposition of models based on the fractal organization of soil structure. This is possible because the structure mentioned has characteristics of fractal geometry as a hierarchy that is manifested, for example, in the organization of aggregates sizes (macro to micro scale) and self-similarity, seeming identical regardless of scale they are presented. For Bacchi and Reichardt (1993) one of the difficulties in studies processes that occur in soil porosity space, such as water retention and movement, is to establish geometric models capable of simulating reasonably well the structure of the soil, allowing the characterization of some fundamental relations between particles and pore space that govern such proceedings.

In the variations case of water content in soil, the use of fractal mathematics can represent a simplified method of determining, because through its results it is possible to interpret not only the water aspect, but also several other characteristics associated with changes dimensions of the association of relations between the particles of soil, air and water. Fuentes et al. (2005) describe results of research which the concept of fractal geometry is used to justify empirical correction in the classic models of hydraulic conductivity, and the models developed enable precise quantitative interpretations related to the porosity of the soil. In this case, it appears that the application of fractal dimension in the study of soil porosity may enable new knowledge regarding quantification of water content of the soil.

The expressive relation of fractal geometry with the dimensions of soil solution were also studied by Webster et al. (1985) which found that the spatial variability of soil fragmentation has been well established through the use of fractal dimension, allowing the definition of homogeneous areas and specific definition the spatial correlation of soil. What expresses the relation of space and volume, leading the possibility of interpreting the volume of water in the soil.

The aim of the study was to evaluate the accuracy of different methods for determining the content of water in the soil, aiming to use a fractal dimension method as a new practical alternative to the irrigation management, and check the results of the use of these methodologies in the irrigation management of corn crop.

Materials and methods

The study was developed in the Department of Agronomy / CEDETEG campus of State University of West Center - UNICENTRO, Guarapuava-PR, 25.1 S and 51.6 ° W and average altitude of 1050m. It was used data of fractal dimension to estimate the content of water in the soil. The direct evaluations of moisture and fractal dimension of soil were held in the laboratory of agricultural water. The activities of the field application of the methods were performed in the experimental area with the corn crop.

For laboratory tests the samples of soil with different moisture conditions were collected in the experimental area where later was conducted with corn crop, and partly used for fractal dimension determining and partly dry in the oven at 105 º C to determination of the gravimetric moisture.

The fractal dimension of the soil was determined by the Spadotto equation (eq. 1), as present by Spadotto and Seraphim (1998):

$$D = \frac{\log V}{\log \sqrt[3]{M}} \qquad \text{(eq.1)}$$

D = fractal dimension V = volume of the sample, M = mass of the sample

The methodology consisted of a) the use of the cubeta method, originally presented by the author's formula in which he employed a cubeta that consists of acrylic material with a capacity of 10 cm^3.For determination the cubeta was filled with soil in conditions of current moisture, lightly pressed to completely fill the container (disturbed sample), which was weighted in a balance of precision after being filled. With the values of volume and weight of the sample added to the formula, it was determined the fractal dimension of the soil. B) the use of volumetric ring of 74.92 cm^3 of volume (6,0cm in diameter and 2.6 cm in height) through which the soil sample was collected in the field (structured sample), weighted, and the data used to calculate the fractal dimension, and the sample also used for determining the gravimetric moisture.

The data were used to correlate the values of fractal dimension obtained through the use of the volumetric ring and the *cubeta* with the gravimetric soil moisture. Thus, it was possible to apply a regression analysis to estimate the soil moisture through its fractal dimension.

After the completion of these evaluations, the accuracy of the methodology was assessed through the conduction of a field experiment with corn crop, and three treatments consisted of irrigation management based on **1)** determining soil moisture through gravimetric method and estimated with **2)** fractal dimension performed using the *cubeta* method and **3)** the volumetric ring.

The cultivar of hybrid corn P-3071 was sown in tillage system on 18 October 2006 in plots of 2x3 m. It was used a population of 60,000 plants ha-1 with the base fertilization of 250 kg ha-1 of NPK fertilizer 5-20-20. The climate data for the period were obtained from the UNICENTRO agrometeorological station, located approximately 100 meters from the experimental area.

The experimental design was completely randomized with six repetitions, totaling 18 units trial. The irrigation have been implemented using graduated sprinklers, which were used because the difficulty of installing a sprinkler system, considering the small area of experimental units.

The water balance of culture was carried out considering the rainfall and the irrigation were applied when the water depletion in the soil accumulated 25 mm at 30 cm deep. The soil sampling for moisture determination was made in the depths of 10cm and 25cm, the first representing the layer of 0 to 20cm and the second layer of 20 to 30 cm. The depletion of water in the soil was determined daily based on the sum of the values of humidity obtained for both layers.

The statistical analysis related to soil moisture consisted of analysis of variance and comparison of the daily average through the test of Tukey, using as control the results obtained by gravimetric method, and the regression analysis. The assessment of the culture production was made by Tukey comparison.

Results and discussion

According to the physical and chemical characteristics of the site, the soil is classified as Latossolo Bruno Distroférrico típico, very clayed, as the methodology established by EMBRAPA (1999). The main physical and chemical characteristics are presented in table 1.

Through assessments conducted in the laboratory it was found that the use of *cubeta* as a delimiter of volume to determine the fractal dimension of soil caused results of lower accuracy when compared to the use of the volumetric ring for the same purpose. This is presented by figure 1, where it presents the distribution of ordered pairs and the coefficient of determination of the regression curves determined from the correlation between the gravimetric moisture and fractal dimension of the soil.

The highest coefficient of determination and the lowest dispersal of the points caused by the use of the volumetric ring enable to verify greater accuracy of the fractal dimension estimate of the soil. As for the practical management of irrigation this result is important, therefore, when it is employed the method of fractal dimension to estimate the gravimetric moisture, is being developed different methods to quantify the water content of soil, with the possibility of the calibration for direct use in the field.

To assess this result should be taken into account the process of soil accommodation at the moment of filling in the *cubeta,* because of using disturbed sample of soil is necessary equalize and pressing the soil into the container, for a suitable filling. Meanwhile, the completion of this process represents a technical problem, because there was great difficulty in repeating it with homogeneity, which does not occur when using the volumetric ring since the samples were structured sampled.

It should also be involved the high quantity of sample evaluated when using the volumetric ring. It is necessary to emphasized that it would not be consistent to interpret the results considering the *cubeta* as an inadequate equipment for studies of soil using the fractal dimension, but for the specific case of moisture determinations, which was more appropriate with the use of structured soil samples, as this is an heterogeneous system as to this material, so the sampling method should consider the presence of materials such as small aggregates, organic material and even rock fragments which due to its irregular format difficult the standardization of the *cubeta* method

Another consideration should be made about the effect of different conditions of soil moisture in the differential behavior of this to the issue of *cubeta*, resulting in practical difficulty for precise application of the method. Arya et al. (1999) demonstrated that variations in the particles size as characteristics that influence significantly the accuracy of soil shown content measurements. Silva et al. (2000) stress that the quality of sample preparation is essential point for method comparison to determine soil characteristics.

After the completion of these direct evaluations in laboratory were conducted experimental works in the field to assess the methodologies through its application to irrigation management of the corn crop. However, due to difficulties in verification of the sampling of structured soil samples using the volumetric ring, especially in depth of 25cm, it was decided to evaluate the possibility of developing an equipment that could facilitate the completion of the sampling while search field.

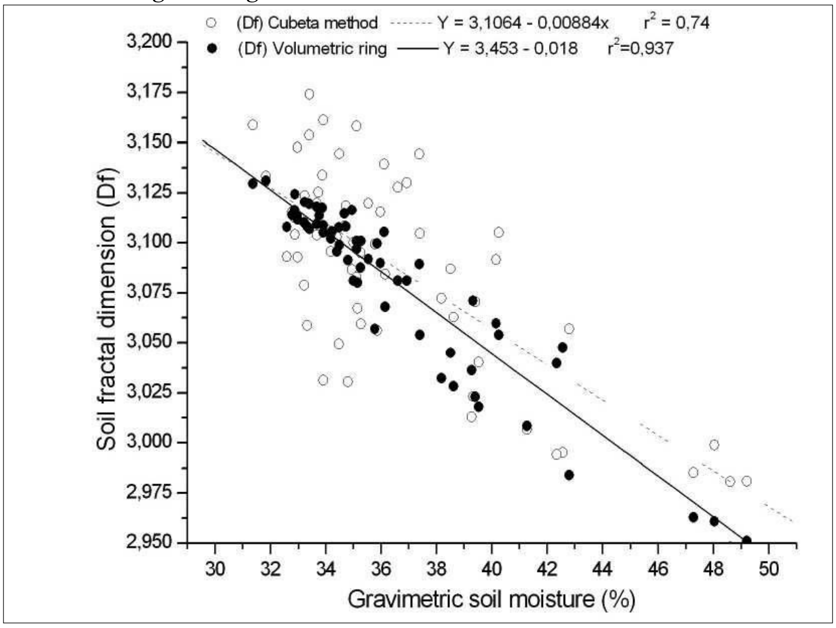
After the relevant tests, it was possible to establish a sampler model design scheme as shown in figure 2. The equipment is made of stainless

Table 1. Physical and chemical characteristics of the soil of the experimental area.

P	**C**	**pH**	------------------	**dm $^{-3}$**	------------------					**--------%-------**		**Dens.**
mg dm $^{-3}$	Mg dm $^{-3}$	$CaCl_2$ 0,01M	Al^{3+}	$H^+ + Al^{3+}$	Ca^{2+}	Mg^{2+}	K^+	Sb	CTC	V	M	g cm $^{-3}$
0.65	22.5	6.4	0.1	4.28	7.0	5.7	0.18	12.8	18.1	74.98	0.80	1.287

P and K: extrator Mehlich $^{-1}$

Figure 1. Distribution of correlation and regression analysis between the fractal dimension determined through different methodologies and gravimetric soil moisture.



steel, presenting a device called the cartridge of penetration in the soil, which fits a cylinder that supports a volumetric ring, which is composed of two parts that enables its opening for the insertion and removal of the volumetric ring. When is pressed by a holder, the cartridge, which has the lower end, penetrates the soil loading the volumetric ring and cylinder. The opening of these elements on both ends, allows the passage of the soil through these until the desired depth is reached to the collection of the sample.

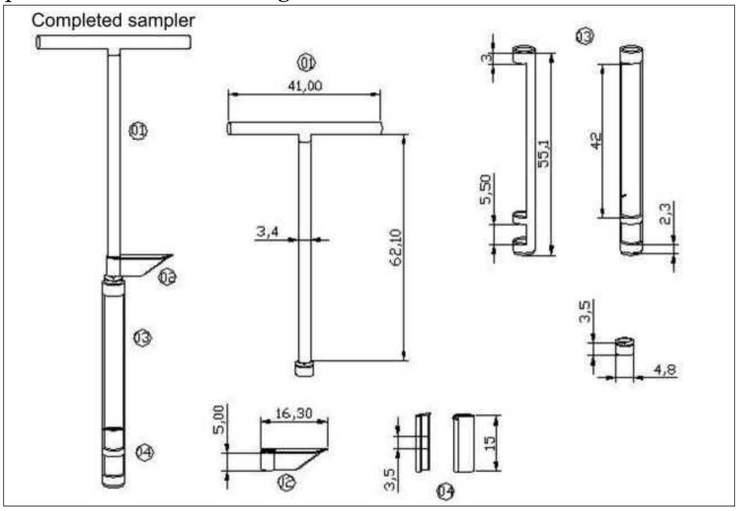
After the removal of equipment from the ground, the cylinder is obtained from the cartridge of penetration, and the volumetric ring can be accessed. The dimensions of the cylinder exactly equal in diameter and more elongated in length compared with the ring, allows it to be completed in a homogeneous and that the excess of soil is removed, resulting in the appropriate completing of the ring with volumetric structured soil sample. This equipment was called the *sampler Jadoski model, version 1.0* having been requested patent with the competent organ in the state of Paraná.

The technical efficiency of this equipment can be seen clearly, because it allowed the removal of samples adequately making the work faster and more efficient. However, studies with new adjustments should continue, resulting in more enhanced versions, as were some difficulties associated with the effort required for their introduction into the soil, as it uses the physical strength of the operator, which in the case of more compressed land may represent a limitation to their use. figure 3 is presented photo without a scale of the components of the borer Jadoski.

The greater accuracy of the results using the volumetric ring as a way to estimate the gravimetric soil moisture can also be found during the conduction of the field experiment with corn crop. In this experiment the methodologies were applied daily during the period of 128 days. The results of the variation in the water depletion accumulated in the soil (mm) and fractal dimension of soil for the period are presented in figure 4 (a). The statistical evaluation of the results presented no significant difference between the use of the volumetric ring and gravimetric method to assess the soil moisture. Due to the data values being very close, the variation curve for these methods were unified

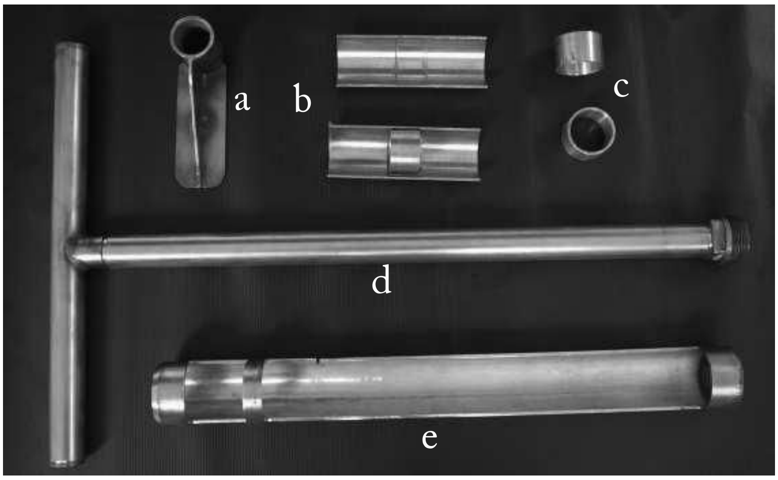
The *cubeta* method presented to be less efficient to assess changes of water content in soil in relation to the other. Through figure 4 (a) and (b)

Figure 2. Scheme with dimensions of the sampler Jadoski model, version 01, developed for the sampling of structured soil samples with a volumetric ring.



Which: 01 - cable; 02 - stem of force application; 03 - cartridge to penetrate the soil with cylinder support, 04 - drum support of the volumetric ring; 05 - volumetric ring.

Figure 3. Photograph of the components of the sampler Jadoski model, version 1.0 developed for the sampling of structured soil samples with a volumetric ring.

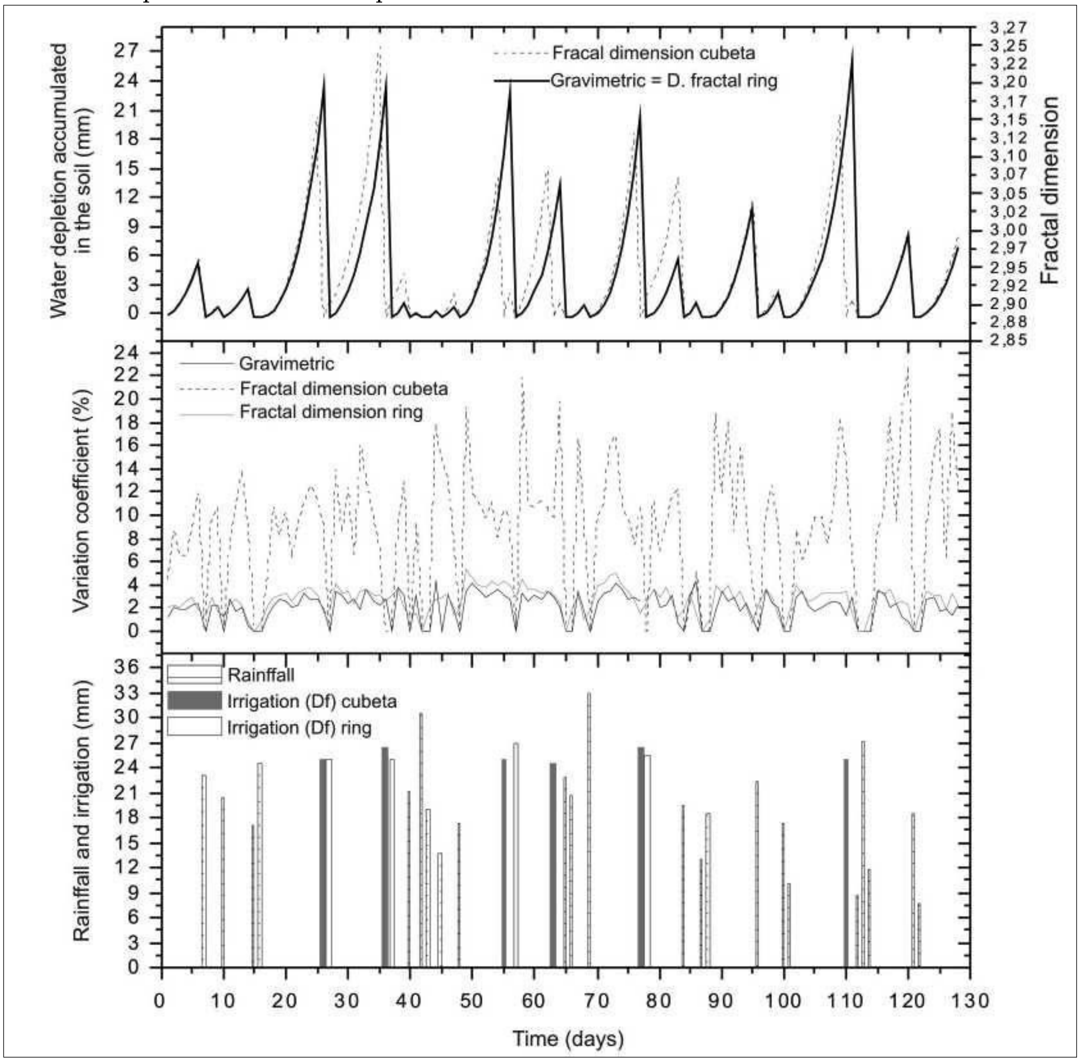


Which: a - stem of force application; b - drum support of the volumetric ring; c - volumetric ring d – cable; e - cartridge of penetration in the soil with support of the cylinder

it is observed that the accuracy of results has been reduced, occurring a distance in relation to the curve verified using the gravimetric method, considered worldwide as a standard, which in this case did not differ from volumetric ring. Statistical differences were verified through a test for the comparison of averages, however, they are best displayed when presented in the form of coefficient of variation (Figure 1 (b)).

These results present that the use of the fractal method using the volumetric ring generates precise measurements of water content in soil, which does not occur with the same accuracy when it employed the *cubeta* method. This finding should be linked to the

Figure 4. Representation of the variations of the water depletion in the soil and fractal dimension (a), coefficients of variation for different layers of irrigation methods (b) and rainfall (c)occurred during the course of development of the corn crop.



fact of having had difficulties for the standardization of filling in the *cubeta* in different repetitions, due to the use of deformed soil sample, which does not occur with the volumetric ring where the sample is structured. Siqueira et al. (2008) present results of the soil attributes evaluation with different methods checking the efficiency of the volumetric ring.

102 mm of water were applied through the determinations using the gravimetric and volumetric ring methods and 153mm through the *cubeta* method. However, due to the rainfall distribution, the culture production did not present significant statistical differences. The average production of grains was 10.050,3 kg ha^{-1} and the dried mass of the air part was the average of 147.3 g $plant^{-1}$.

Conclusions

The use of fractal dimension determined by the equation of Spadotto enables precise determination of water content in soil.

The use of the volumetric ring to determine the fractal dimension and content of water in the soil gives precision gravimetric method similar to the standard and thus can be used as a tool for irrigation management.

In sampler Jadoski model is an efficient tool for the sampling of structured soil samples using the volumetric ring as an accessory.

References

ARYA, L.M.; LEIJ, F.J.; VAN GENUCHTEN, M.T.; SHOUSE, P.J. Scaling parameter to predict the soil water characteristic from particle-size distribution data. **Soil Science Society American Journal**, Madison, v.63, p.1063-1070, 1999.

AZEVEDO, R.B. de; SPADOTTO, J.A.; CARVALHO. W.A. Aplicação da análise fractal em bacia hidrográfica de terceira ordem de ramificação representativa de argissolos. **Revista Núcleo de Pesquisa Interdisciplinar**, v.2, n.1. 2006.

BACCHI, O. O. S; REICHARDT, K. Geometria fractal em física do solo. **Scientia Agrícola**. v.50, n.2, p.321-325, 1993.

BACKES, A.R.; BRUNO, O.M. Técnicas de Estimativa da Dimensão Fractal: Um Estudo Comparativo. **Journal of Computer Science**, v.4, n.3, p.122-136, 2005.

EMPRESA BRASILEIRA DE PESQUISA AGROPECUÁRIA - EMBRAPA. Centro Nacional de Pesquisa de Solos**. Sistema Brasileiro de Classificação de Solos**. Brasília, 1999. 412p.

FUENTES, C.; DANTAS NETTO, A.C.; MACIEL, A.; LIRA, C.A.B.de O.; JOAQUIM, J. Desenvolvimento de um modelo fractal para a estimativa da condutividade hidráulica de solos não saturados. **Revista Brasileira de Ciência do Solo**, v.29, p.51-60, 2005.

SILVA, R.S.; REINERT, D.J.; REICHERT, J.M. Comparação entre os métodos do cilindro e do torrão na determinação da porosidade e da densidade do solo. **Ciência Rural**, v.30, n.6, p.1065-1068, 2000.

SIQUEIRA, G.M; VIEIRA, S.R.; CEDDIA, M.B. Variabilidade de atributos físicos do solo determinados por métodos diversos. **Bragantia,** v.67 n.1, p.38-46, 2008.

SPADOTTO, A.J.; SERAPHIM, O.J. Determinação da dimensão fractal pela fórmula Spadotto e pelo MC-D. **Revista Energia na Agricultura***,* v.12, p.24-31, 1998.

WEBSTER, R. Quantitative spatial analysis of soil in the field**. Advances in Soil Science**, p.51-70, 1985.