# SPATIAL AND TEMPORAL VARIABILITY ANALYSIS OF SOIL HYDRAULIC PROPERTIES IN A SMALL GARDEN UNDER DRIP IRRIGATION

# ANALYSE DE LA VARIABILITE DANS L'ESPACE ET DANS LE TEMPS DES PROPRIETES HYDRAULIQUES DU SOL D'UN PETIT JARDIN SOUS L'IRRIGATION GOUTTE A GOUTTE

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## *ABSTRACT*

*Geological and pedologic factors affect the soil properties. Tillage, irrigation, planting, harvest, residue management, climatic conditions, etc., change the soil structure, which results in changes in the hydraulic conductivity. Several studies dealing with some soil hydraulic properties e.g. soil water content, soil matric potential and their spatio-temporal variability have shown that, although these properties change over time and according to their location in the field, the pattern of their spatial structure does not change over time when the observations are ranked or scaled against the mean value. The objective of this study was to identify the spatial and temporal variability of the hydraulic properties of a small kiwi garden soil under drip irrigation. The garden is located at the University of Guilan in Rasht in the North of Iran. This study was based on the use of the Beerkan infiltration method (Haverkamp et al., 1996) to provide soil hydraulic properties using a single ring infiltration test. After that, $K_s$ was calculated with Philips equation. The spatial structure of $K_s$ was identified by the semivariogram using the GS+ program. After identifying spatial variation, seven sets of infiltration measurements were taken for temporal variations assessment. The results demonstrated that hydraulic properties changed over time. This change related to the effects of wetting and drying cycles, soil biological activity and the effects of the root system. It can be recommended that in order to mitigate agro-environmental risk, the application of fertilizers should be done after the tilled soil has structurally stabilised.*

**Keywords:** *Temporal variation, spatial variation, Beerkan method, hydraulic conductivity.*

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# RESUME ET CONCLUSIONS

*Accroître le rendement des cultures en réduisant les coûts, améliorer la productivité de l'eau et aujourd'hui la réduction de la pollution de l'environnement sont les défis régulières dans l'agriculture pour les chercheurs, les agriculteurs, les conseillers et les décideurs dans ce domaine. Améliorer nos connaissances sur les sols nous aide à prendre des décisions pertinentes, par exemple en temps opportun et la dose appropriée de l'irrigation, les engrais et les agents chimiques. Des informations fiables sur les caractéristiques hydrauliques des sols et leur variabilité spatio-temporelle sont nécessaires dans l'agriculture de précision. Les facteurs géologiques et pédologiques influent sur les propriétés du sol. La rétention d'eau, h (θ), et la conductivité hydraulique du sol, étant les plus importantes propriétés hydrauliques du sol, peut être caractérisée par des modèles analytiques ou numériques. Il existe plusieurs méthodes de mesure pour estimer les propriétés hydrauliques du sol. Bien que les méthodes de laboratoire permettent de mesurer précisément, mais ils sont réalisés sur les échantillons de terrain et leur représentativité des conditions de terrain sont discutables. Les méthodes in situ sont plus difficiles à réaliser et à contrôler, mais il convient de noter que ces mesures sont plus représentatives. L'objectif de cette étude était d'évaluer les propriétés hydrauliques du sol et de leur variabilité spatiale et temporelle en utilisant la méthode Beerkan dans un jardin de kiwi sous irrigation goutte à goutte. Le jardin est situé à l'Université Guilan à Rasht dans le nord de l'Iran. Cette étude a été basée sur l'utilisation de la méthode d'infiltration Beerkan (Haverkamp et al., 1996) pour fournir des propriétés hydrauliques du sol à l'aide d'un test d'infiltration en utilisant un simple anneau. L'équation Philips a été utilisée pour l'ajustement des données d'infiltration. Six mesures de Beerkan ont été effectuées à 4,7 m d'intervalle dans chacune des neuf lignes espacées de 4,4 m, soit un total de 54 points de mesure. A chaque point, un test d'infiltration a été réalisée en utilisant un cylindre de 19.5 cm de diamètre enfoncés environ 1 cm dans le sol pour éviter les pertes latérale de l'eau de près de la surface.*

*Un échantillon de sol d'environ 200 cm$^3$ a été prélevé à chaque point avec un cylindre pour déterminer la densité apparente du sol sec (ρb) et sa teneur initiale en eau du sol. Un autre échantillon de sol a été recueilli pour l'analyse granulométrique. Le teneur en eau à saturation (θs) a été calculé comme étant la porosité totale du sol compte tenu de la densité des particules solides et de la densité apparente du sol à chaque point.*

*Variables estimées ont été analysées à l'aide de méthodes statistiques pour obtenir leur moyenne et le coefficient de variation des valeurs. La normalité de la fréquence de distribution de données a été testée en utilisant le test Kolmogotov-Smirnov. Analyse géostatistique a été utilisée pour quantifier la dépendance spatiale et la structure spatiale des paramètres $K_s$. La structure spatiale de $K_s$ a été identifiée par le variogramme en utilisant le programme GS+. En utilisant les valeurs interpolées par la méthode Kriging la carte de contour peut être établie pour $K_s$. Les résultats ont montré que les paramètres de forme de h(θ) et k(θ), soit n, m et η, a très peu varié à l'échelle jardin. Cette très faible variabilité est compatible avec l'hypothèse que ces paramètres sont principalement liés à la texture du sol. Le test de Kolmogorov-Smirnov effectuée sur les données brutes de $K_s$. Ce test a montré que les données ne sont pas tirées d'une population distribuée normalement.*

***Mots cles:** Variation dans le temps, variation dans l'espace, méthode Beerkan, conductivité hydraulique.*

*(Traduction française telle que fournie par les auteurs)*

# 1. INTRODUCTION

For farmers and land managers, increasing crop yields, cutting costs and improving agricultural water use efficiency while reducing environmental pollution is a constant challenge. To accomplish this goal, improved practical knowledge and techniques of farm management is necessary. Reliable information about soil hydraulic properties and their spatio-temporal variability is important in precision farming, irrigation scheduling and modeling of soil water flow and solute transport.

The water retention, h(θ), and the soil hydraulic conductivity, the two important soil hydraulic properties can be characterized by using analytical or numerical models. There are several measurement methods to estimate soil hydraulic properties. It should be noted that in-situ methods of measurements are more representative than the laboratory measured values.

Within a particular agricultural field, changes in soil structure and consequently in soil hydraulic properties- may occur due to different tillage, irrigation, planting and harvest/residues management (Mubarak et al., 2009). These changes may also occur during the cropping season and from year to year depending on climatic conditions (Strudley et al., 2008).

Several studies have recently focused on quantitative assessments and modeling of the spatial variability of hydraulic properties (Mubarak et al., 2009). But, the temporal dynamics of soil hydraulic characteristics is commonly not taken into account in models, primarily because its measurement is costly and time-consuming (Angulo-Jaramillo et al., 1997). For agricultural soils, tillage is a source of space-time variability of soil hydraulic properties (Messing and Jarvis., 1993). The mechanical action of tillage implements modifies soil structure, porosity, crop residue distribution and surface roughness. Generally, under tillage systems the saturated hydraulic conductivity ($K_s$) increases on after tillage and then decreases during the growing season due to the settling of the soil (Bormann and klaassen, 2008). Coquet et al. (2005) showed that tillage, especially plowing, creates macropores that temporarily increase saturated hydraulic conductivity. In no tillage system disturbance by tillage is minimized but the structure of the soil surface is affected by the presence of organic residues which can enhance infiltration rates (Findeling et al., 2003). Crop residue absorbs rainfall energy preventing soil surface from crusting or sealing (Blevins and Frye, 1993). The splash effect of rain is reduced and aggragates stability is generally improved. However, despite numerous references on the topic, the effects of tillage management systems on $K_s$ are still not clear (Strudley et al, 2008). The comparison of $K_s$ values under conventional and conservation tillage shows the results can be opposite if measurements are done at the beginning or at the end of the growing season. Part of these contradictory results may be explained by the high spatial variability of soil hydraulic properties which may overshadow the seasonal dynamics of those soil properties (Bormann and Klaassen, 2008). The aim of this study was to identify the spatio-temporal variability of the soil hydraulic properties of a small kiwi garden under drip irrigation.

# 2. MATERIALS AND METHODS

The experimental field is located at the University of Guilan in Rasht in the North of Iran. This study was based on the use of the Beerkan infiltration method (Haverkamp et al., 1996) to provide soil hydraulic properties using a single ring infiltration test. Six Beerkan measurements were done at 4.7m intervals in each of nine rows spaced 4.4m apart, giving a total of 54 measurement points. At each point an infiltration test was performed using a 97.5 mm-radius cylinder driven about 1 cm into the soil to prevent near surface lateral water losses. A soil sample of about 200 $cm^3$ was collected at each point with a core sampler to determine soil dry bulk density (ρb) and initial soil gravimetric water content. A fixed volume of water (100 ml) was poured into the cylinder at the time zero, and the time needed for the infiltration of the known water volume was recorded. When the first volume was completely infiltrated, a second known volume of water was added to the cylinder, and the time required for it to infiltrate was added to the previous time. The procedure was repeated until apparent steady state flow regime was reached, i.e., until three consecutive infiltration times were identical; and cumulative infiltration was recorded (Haverkamp et al., 1996; Lassabatere et al., 2006). After that, hydraulic conductivity was determined by Philips equation. These measurements have done for 7 period of time as temporal variability.

# 3. STATISTICAL AND GEOSTATISTICAL ANALYSIS

Estimated variables, namely saturated hydraulic conductivity, were analyzed using standard statistics to obtain their mean and coefficient of variation values. The normality of data frequency distribution was tested using both the Kolmogorov-Smirnov test and the values of the skewness ($g_1$) and kurtosis ($g_2$) coefficients. Following Vauclin et al. (1982), the latter coefficients are respectively expressed as:

$$g_1 = \frac{y}{(y-1)(y-2)} \frac{m_3}{(m_2)^{3/2}} \quad (1)$$

$$g_2 = \frac{y(y+1)}{(y-1)(y-2)(y-3)} \frac{m_4}{(m_2)^2} \quad (2)$$

where $m_2$, $m_3$ and $m_4$ are the 2nd, 3rd and 4th moments of the distributions, and y being the number of measurements. The student's t-variables associated with $g_1$ and $g_2$ were used to check the distribution. The data can be assumed drawn from a normally distributed population when $g_1 = 0$ and $g_2 = 3$ (vauclin et al., 1982).

The analysis of significance using the student's t-test at the 95% confidence interval was also used to compare the soil hydraulic parameter, $k_s$.

Geostatistics was used to quantify the spatial dependence and spatial structure of the $K_s$. The spatial structure of each variable was identified by the semivariogram using the GS+ package. The experimental semivariogram γ(l) was estimated as:

$$\gamma(l) = \frac{1}{2N(l)} \sum_{i=1}^{N(l)} [z(r_i) - z(r_i + l)]^2 \quad (3)$$

Where N(l) is the number of pairs separated by lag distance, l; $z(r_i)$ and $z(r_{i+l})$ are measured values at locations $r_i$ and $r_{i+l}$, respectively. If the semivariogram increases with distance and stabilizes at a priori variance value, it means that the variable under study is spatially correlated and all neighbors within the correlation range can be used to interpolate values where they were not measured. Experimental semivariograms were normalized by dividing each semivariance value by the experimental variance value (Vieira and Gonzalez, 2003).

# 4. RESULTS AND DISCUSSION

Table 1 summarizes the statistics of the soil hydraulic properties. They varied a lot. The mean value was estimated 0.2009 with a high value of CV (76%). Vauclin (1982) and Mulla and McBratney (2002) reported coefficients of variation of $k_s$ from 48 to 352%. Based on the Kolmogorov-Smirnov test and the values of the skewness, the linier distribution appeared to be acceptable for the $K_s$. The geometric mean value of $K_s$ was estimated at 0.087cmh$^{-1}$.

Table 1. Statistical parameters of the soil hydraulic conductivity (cmh-1) (paramètres statistiques de conductivité hydraulique)

| Coefficient of variation | kurtosis | skewness | Standard deviation | geometric mean | mean | min | max | Parameter |
|---|---|---|---|---|---|---|---|---|
| 0.76 | 12.1 | 3.53 | 0.39 | 0.087 | 0.2009 | 0.01 | 0.97 | $k_s$ |

Table 2. The indexes of fitting linear variogram (Les indices d'ajustement de variogramme linaire)

| RSS | $R^2$ | Effective range | Proportion $C/(C_o+C)$ | Sill $C_o+C$ | variable |
|---|---|---|---|---|---|
| 7.7E-3 | 0.96 | 15.16 | 0.5 | 1.51 | $K_S$ |

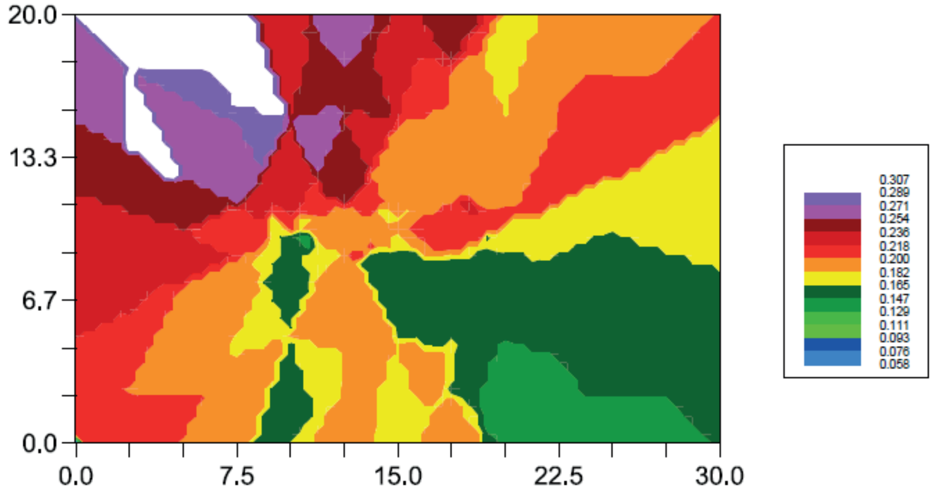


Fig. 1. The map of spatial distribution of $K_s$ (la carte de la distribution spatiale de $K_s$)

Fig. 1 shows the map of spatial distribution of $K_s$ which help to interpret the spatial distribution of the results within the field. For instance, they indicate lower values of $K_s$ in the southern part of the field than in the northern part.

Fig. 2 shows the values of $K_s$ obtained during the seasons as a function of time in three selected points of the garden. It has a sinus form being the results of drying and wetting cycles, soil biological activities, and the effect of the root system.

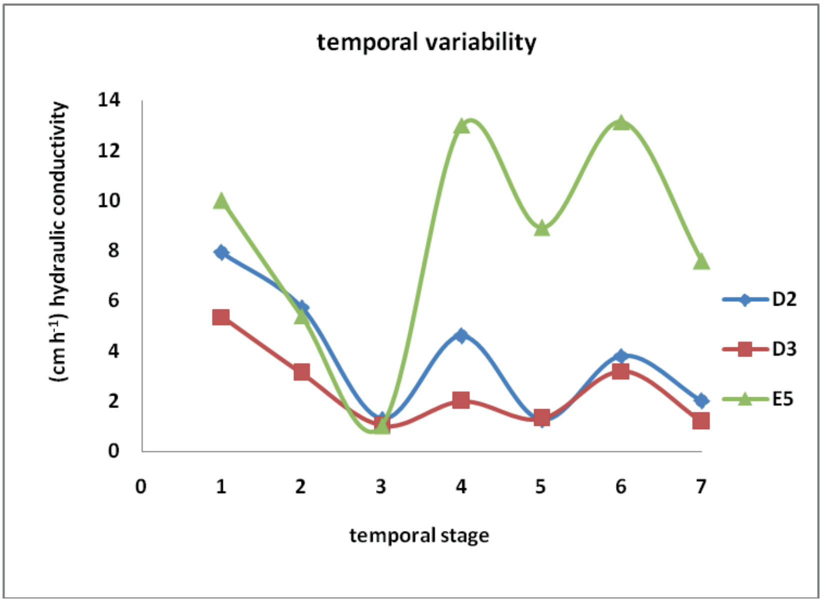


Fig. 2 Teporal variability of hydraulic conductivity

Our work raises questions about the usefulness of taking this phenomenon into account to improve the efficiency of both water and fertilizer applications. To answer this question, we should study the impact of temporal changes in soil hydraulic properties on the dimension of the wetting bulb using a modeling approach. As a practical result of this study, we recommend to apply fertilizers after the first irrigations in order to mitigate agro-environmental risks and to improve the efficiency of fertilizers and chemical agents. The temporal changes in soil hydraulic properties identified in our study should be taken into account in future studies when simulating soil water transfer under drip irrigation in order to improve irrigation scheduling practices.

# 5. CONCLUSIONS

The aim of this research was to assess the spatio-temporal variation of hydraulic conductivity in a small garden under drip irrigation. Beerkan infiltration method was used to provide soil hydraulic properties. The spatial structure of $K_s$ was identified by the semivariogram. The results show that hydraulic conductivity changes over time. According the results of this research, it can be recommended that in order to protect the environment, fertilizers and chemical agents should be applied after the restructuration of tilled soil.

# REFERENCES


Angulo-Jaramillo, R., Moreno, F., Clothier, B.E., Thony, J.I., Vachaud, G., Fernandez-Boy, E., Cayuela, J.A., 1997. Seasonal variation of hydraulic properties of soils measured using a tension disk infiltrometer. Soil Sci. Soc. Am. J. 61(1): 27-32.

Blevins, R.L., Frye, W.W., 1993. Conservation tillage; an ecological approach to soil management. Advances in Agronomy 51:33-78.

Borman, H., Klaassen, K., 2008. Seasonal and land use dependent variability of soil hydraulic and soil hydrological properties of two Northern German soils. Geoderma 145: 295-302.

Coquet, Y., Vachier, P., Labat, C., 2005. Vertical variation of near- saturated hydraulic conductivity in three soil profiles. Geoderma 126: 181-191.

Findeling, A., Ruy, S., Scopel, E., 2003. Modeling the effects of a partial rasidue mulch on runoff using a physically based appraoch. Journal of Hydrology 275:49-66.

Khaledian, M.R., Mailhol, J.C., Ruelle, P., Mubarak, I., Lahmar, R., Forest, F., Rollin, D., irzaii, M., Kradia, L., 2007. Impact of no-tillage and conventional tillage on some hydrauliccharacteristics of topsoil under the Mediterranean climate. 6p. 65th International conferenceon agricultural engineering, 09-10 October 2007, Hanover, Germany.

Lassabatere, L., Angulo-Jaramillo, R., Soria ugalde,JM., Cuenca,R., Braud, I., Havekap, R., 2006. Beerkan Estimation of soil Transfer Parameters through Infiltration Experiments BEST. Soil Sci. Soc. Am. J. 70: 521- 532.

. Messing, I., Jarvis, N.J., 1993. Temporal variation in the hydraulic conductivity of a tilled clay soil as measured by tension infiltrometers. J. Soil Sci. 44(1): 11-24.

Mubarak, I., Mailhol, J.C., Angulo-Jaramillo, R., Ruelle, P., Boivin, P., Khaledian, M.R., 2009. Temporal variability in soil hydraulic properties under drip irrigation. Geoderma 150: 158-165.

Mulla, D.J., McBratney, A.B., 2002. Soil spatial variability. In: Sumner, M.E. (Ed.), Handbook of soil Science. CRC pree, London, pp. A321-A352.

Strudley, M.W., Green, T.R., Ascough, J.C., 2008. Tillage effects on soil hydraulic properties in space and time. USDA-ARS, Agricultural Systems Research Unit, 2150-D Centre Avenue, Suite # 200, Fort Collins, Co 80526, USA.

Vauclin, M., 1982. Methods detude de la variabilite spatiale des propertietes dun sol. In : Variabilite spatiale des processus de transfert dans les sols. Avignon 24-25 juin 1982. Ed. INRA Publ., les Colloques de IINRA vol. 15.pp.9-43.

Vieira, S.R., Gonzalez, A.P., 2003. Analysis of the spatial variability of crop yield and soil properties in small agricultural plots. Bragantia Campinas 62(1),127-138.