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Spatial Analysis of Infiltration Experiment

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Abstract: Developing correlations between various soil parameters are considered the major challenge to diminish time and cost associated with field measurements. Soil hydraulic and physical properties were extensively characterized using tension disc infiltrometer and soil sampling in a silty clay agricultural field in Kalaat El-Andalous, Tunisia. Tension disc infiltrometer experiments were conducted at 109 plots with two supply water potentials (-30,-60 mm) at each plot to determine the hydraulic conductivity, sorptivity, capillary length, and matric flux potential. In addition, soil samples were analyzed to determine the soil bulk density, and water content. From the statistical and spatial analysis for the different parameters, it was found that the soil hydraulic parameters had larger variability than bulk density. Sorptivity, capillary length, matric flux potential, and bulk density had lager variance with the distance between the plots. No correlation was found between bulk density and the soil hydraulic parameters, nor could the soil hydraulic parameters be correlated to each other.

Key words: Tension disc infiltrometer; soil hydraulic parameters; Minitab; Geoeas; Tunisia.

1. INTRODUCTION

One option for coping with the inaccurate estimation of crop requirements and the potential for groundwater contamination from numerical simulation is the deterministic estimation of soil hydraulic properties. Water retention and hydraulic conductivity curves are vital input data in any numerical simulation for water flow and solute transport. In addition, the accurate determination of soil hydraulic parameters had a great effect on the susceptibility of the computed water balances (Jhorar *et al*., 2004).

The non-availability of hydraulic properties for most soils is the hindrance to be overcome for general application of the numerical models (Messing and Jarvis,1993; Simunek *et al*.,1998). Laboratory experiments are rooted in the adequate measurement of flow processes, but they are generally carried out on small soil samples that lead to many questions about their validity in representation the field conditions. One reason for the uncertainty of laboratory method results is the difficulty to capture the existence of stones, cracks, fissures, natural soil pipes, root holes, and fractures in unsaturated soil profiles in small-scale laboratory samples. On the other hand, inverse modeling had provided an alternative method for determining the hydraulic properties instead of direct measurements but future improvement could still be needed (Abbaspour *et al*., 2001; Nemes *et al*., 2003; Ungaro *et al*., 2005).

Another different approaches for predicting soil hydraulic properties has been developed during the last decade like artificial neural networks (Minasny and McBratney, 2002; Schaap *et al*., 2001), vector machines (Lamorski *et al*., 2008), and non-parametric pattern recognition tools (Nemes *et al*., 2006c). Baroni *et al*. (2010) employed five direct and indirect methods to determine soil hydraulic parameters, two methods were based on laboratory and field measurements, remaining three methods were based on the application of widely used Pedo-Transfer Functions Rawls and Brakensiek, HYPRES, and ROSETTA. They demonstrated that a great difference of soil hydraulic parameter values generated with the direct and indirect methods, especially for the saturated hydraulic conductivity and the shape parameter of the van Genuchten curve.

According to the aforementioned methods, although the difficulty of managing and controlling the field methods, the in situ experiments are still the most confidence and robust method for determining the parameters that describe the soil hydraulic properties. Tension disc infiltrometer is a commonly method for steady state field measurement of the unsaturated soil hydraulic conductivity at potential head close to saturation (Perroux and White, 1988; Ankeny *et al*., 1991; Reynolds and Elrick, 1991; Logsdon and Jaynes, 1993; Angulo-Jaramillo *et al*., 2000). Moreover, it used for quantifying the effects of macropores and

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preferential flow paths on infiltration. Measurements of the contribution of macropores to the overall infiltration can be obtained by comparing infiltration rates during ponded conditions (Villholth *et al*., 1998).

Tension disc infiltrometer is a device used in both laboratory and field to illustrate water entry into the soil under different negative water potential; the water flow through very small pores at large negative pressure head. In Laboratory, Clothier *et al*. (1992) estimated the mobile and immobile water fractions depending on knowledge of the steady state water and solute distributions. Also Quardi *et al*. (1994) validated their finite difference model for axisymmeteric water flow and solute transport using the same experimental set up.

Tension infiltrometer was used in field to determine the near saturated hydraulic conductivity by Messing *et al*. (1995) in six tilled soils of contrasting texture ranging from loamy sand to silty clay under supply pressure heads ranged from negative100 mm up to zero. They concluded that the near saturated hydraulic conductivity increased by three to four orders of magnitude in the finer textured soils and by about two orders of magnitude in two sandy soils. Angulo-Jaramillo *et al*. (1997) used the tension disc infiltrometer to estimate the unsaturated hydraulic conductivity in two different soils under conventional tillage and different irrigation practices. They noted that the sandy soil under furrow irrigation showed a significant decrease in its hydraulic properties with an increase in the bulk density. In addition, strong nonlinearity in the hydraulic conductivity was found for the stony soil. Finally, they concluded that a good understanding of the porous network could be obtained from tension infiltrometers.

IRNASs and IAV (2000) participated in a joint experiment in the experimental site Saboun, Morocco. The hydraulic conductivity and sorptivity were measured in the range near saturation by a tension disc infiltrometer. The water potentials applied in the experiments were -120, -80, -30, and –5 mm. Four transects were investigated resulting in 15 measuring points. High variability was found for both hydraulic conductivity and sorptivity. For hydraulic conductivity at water potential equal -5 mm, the mean was 0.043 and standard deviation was 0.028. For sorptivity at same pressure, the mean was 0.339 and standard deviation was 0.114.

On the other hand, Bagarello *et al*. (2005) used the tension infiltrometer in sandy loam to evaluate the influence of pressure head sequence (ascending or descending) on the hydraulic conductivity (K_0) value. They concluded that the applied pressure head sequence did not affect significantly the relative variability of the K_0.

Determining general correlations between various soil hydraulic parameters by mean of tension disc infiltrometer dose not appear to have caught researcher's attention so far. Therefore, Comprehensive analysis of the soil hydraulic parameters using tension disc infiltrometer was conducted so that an attempt to reduce the field data required for numerical modeling could be done by establishing correlations between different soil hydraulic parameters. The aim of this work was to 1) Analyze the spatial variability of soil hydraulic parameters in an agricultural field soil in order to describe water flow properties and 2) Establish correlations between different soil parameters.

2. MATERIALS AND METHODS

2.1 Theoretical Background:

Zhang (1998) proposed several procedures for estimating soil hydraulic conductivity from the data of tension disc infiltrometer. The combination of Wooding's (1968) analytical solution for steady infiltration from a circular source and the unsaturated hydraulic conductivity function given by Gardner's (1958) exponential model, is the most commonly applied approach used to determine the soil hydraulic conductivity from the tension infiltrometer data.

The relation between unsaturated-saturated hydraulic conductivity given by Gardner as follows

$$K(\psi) = K_{sat} \exp (\alpha\psi) \tag{1}$$

Wooding's analytical solution for infiltration from a circular source with a constant pressure head at the soil surface and with the unsaturated hydraulic conductivity is given by

$$Q(\psi) = \pi r^2 K(\psi) \{ 1 + (4/ \pi r\alpha) \} \tag{2}$$

By combining equation 1,2 one can get the following equation

$$Q(\psi) = \pi r^2 K_{sat} \exp (\alpha \psi) \{ 1 + (4/ \pi r\alpha) \} \tag{3}$$

Either multiple disc radii (Hussen and Warrick, 1993) or multiple potentials (Ankeny *et al*., 1991; Messing and Jarvis, 1995) are required to analyze the tension disc infiltrometer data based on the previous equation. By using two different potentials ψ_1, ψ_2 equation (3) will be in the form of

$$Q(\psi_1) = \pi r^2 K_{sat} \exp(\alpha \psi_1) \{ 1 + (4/ \pi r\alpha)\} \tag{4}$$

$$Q(\psi_2) = \pi r^2 K_{sat} \exp(\alpha \psi_2) \{ 1 + (4/ \pi r\alpha)\} \tag{5}$$

From equations 4,5 (α) can be described as follows

$$\alpha = \frac{\ln[Q(\psi_2)/Q(\psi_1)]}{\psi_2 - \psi_1} \tag{6}$$

Sorptivity (S) is a parameter that describes how well the soil absorbs water. There are many ways for determining sorptivity. The simplest method is by using Philip (1957) one-dimensional horizontal infiltration equation:

$$S = I / \sqrt{t} \tag{7}$$

Eq. 7 is a simplified form of: $I = S\, t^{½} + At + Bt^{1.5}$ (8)

The first term of eq. 8 on the right hand side dominates the flow for a brief time after initiation of infiltration (about 120 s) and thus sorptivity can be calculated using eq. 7 (Klute, 1986). White and Sully (1987) and Vandervaere *et al*. (2000) have described calculations for sorptivity and the relationship with hydraulic conductivity in more details.

Water in soil is subjected to capillary forces due to surface tension of the air-water interface and the contact angle with the solid particles (Hillel, 1971). Large soil capillary length increases the available water for the plant roots. The macroscopic capillary length can be calculated according to White and Sully (1987) as follows

$$\lambda_c = \{ K(\psi_0) - K(\psi_n)\} * \int_{\lambda_n}^{0} K(\psi) d\psi \tag{9}$$

According to Wooding the capillary length equation can be simplified to:

$$\lambda_c = \alpha^{-1} \tag{10}$$

Another parameter controlling the availability of water to the plant is the matrix flux potential ($Ø_m$); It describes how well the soil particles attract water. Large matric flux potential will cause the water to stay in the top layer of the soil where it is possible for the plants to reach it. Then, matric flux potential can be used when estimating how much irrigation water is needed and is expressed as follows:

$$Ø_m = K(\psi) / \alpha \tag{11}$$

2.2 Area Description:

The infiltration experiments were carried out during the period 27/2/2002 to 16/3/2002 at an agricultural field in Kalaat El-Andalous. The experimental site is situated in lower Medjerdah Valley, which is located approximately 40 km NW of Tunis, Tunisia. The Soil is classified as silty clay and the water table is located at about 1.5 m depth. The field was planted during most of the year and irrigated from the Medjerdah River located close to the field. Since the field had been in use for several years, the top soil layer was well mixed. The climate at the field site is Mediterranean, characterized by mild rainy winters and dry summers. During the period of experiments, there were some short nightly rainfalls, each lasting for a few hours. The temperature varied from 11 to 15 C^o with strong sun during the day.

2.3 Field Experiments:

Tension disc infiltrometer experiments were conducted in 109 plots within Kalaat El-Andalous agricultural area (Fig. 1). At each plot, two different potential -30,-60 mm were used. Although, a certain degree of packing was observed due to the compaction by tractor wheel traffic. No plots were located directly in a tractor track. Before experiments, the soil surface was leveled without disturbing the soil structure. Local irrigation water was used for the experiments.

The infiltrometer disc had a diameter of 8 cm and covered with special filter membrane. In addition, a thin layer of fine sand was placed on the soil surface underneath the infiltrometer to assure good contact between the infiltrometer disc and the soil. Perroux and White (1988) recommended applying a high-permeability material to the undisturbed soil surface to establish a complete hydraulic bond between the disk and the infiltration surface. Other studies (Close *et al.* ,1998; Bagarello *et al.*, 2001) have shown that the use of the contact material affects the infiltration.

During the experiments, a transducer, connected to the top of the infiltrometer water reservoir to convert the negative potential in the water reservoir to voltage. The measured voltage was recorded every five seconds by mean of data logger connected to the transducer. This procedure was done to observe if the negative potential in the air pocket at the top of the water reservoir could be linearly related to the height of the water in the reservoir. If so, it would be possible to monitor the infiltration using shorter time interval.

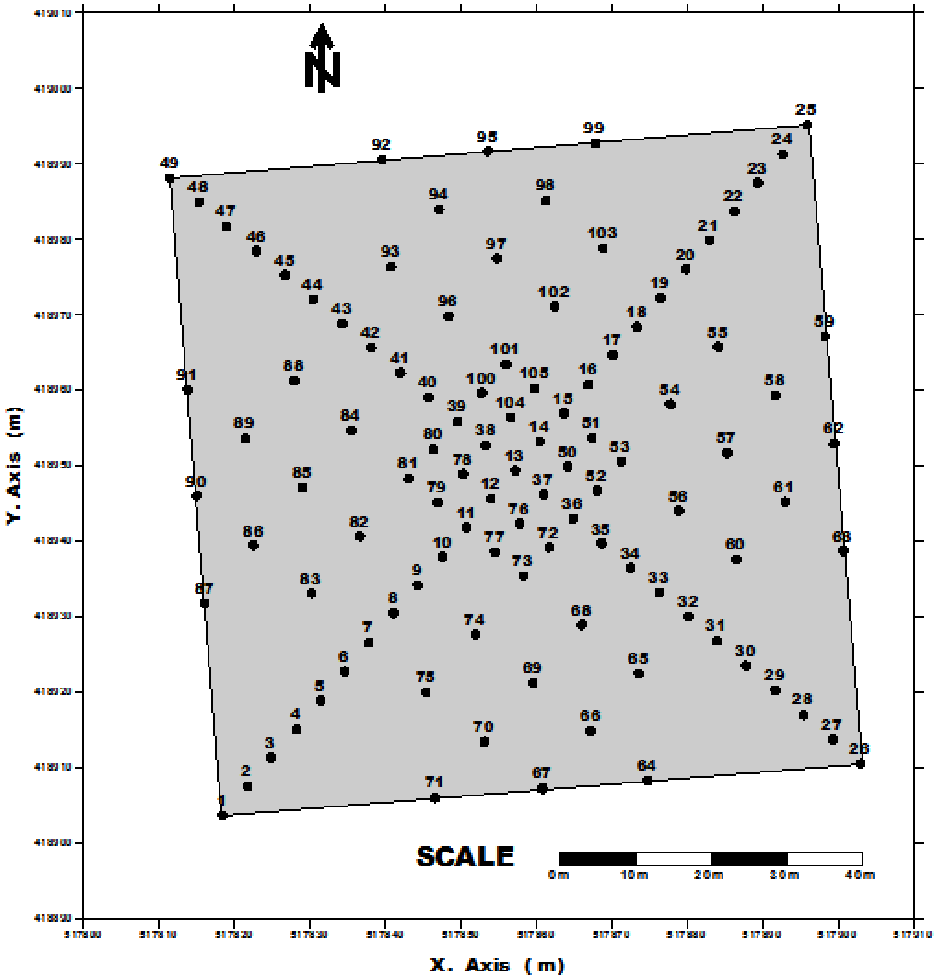


Fig. 1: The experimental area.

Each experiment was carried out until reaching steady state condition, which means that the infiltration of water was constant. In each plot, two soil samples at depth (0-10 cm, and 10- 20 cm) were taken in the infiltration area to analyze the water content in the wetted soil. In addition, samples for measuring the bulk density were taken adjacent to the plot at the same depths.

2.4 Statistical Properties:

Statistical analyses using a statistical software program Minitab version 7.2 were conducted on hydraulic conductivity, sorptivity, capillary length, matric flux potential, bulk density and water content. Minitab calculated the mean value (x*), the trimmed mean (tr x*) (the mean value of data after ignoring the smallest and largest five percent of the reading), standard deviation (σ), and the standard error of the mean (se x*). The standard error of the mean was calculated to note if the mean value is reprehensive for a series of data. If the calculated error is small compared to the mean value, it is possible to use the mean as a representative number for a whole series of data.

The last parameter calculated by Minitab was the first and third quartile, Q_1 and Q_3. Where the first quartile is the number, at which 25% of all values are lower than that number. Similarly, the third quartile is the number when 75% of all values are lower than that number.

3. RESULTS AND DISCUSSION

3.1 Hydraulic Properties:

The data collected during the experiments were infiltration rate, which was manually observed from the infiltrometer, and soil potential measurements from the data logger. An attempt was conducted to identify a relation between the data logger values and the manual reading. By mean of twelve plots (7,8,9,38,39,40,41,42,43,47,48, and 49).A regression equation with the following form was conducted to calculate infiltration from the data logger readings.

$$Y = 934.38X + 883.12 \qquad (12)$$

Where, X is the mean voltage (mV) and Y is the manually observed infiltration depth (mm).

Comparing the measured infiltration values with the calculated values from the regression equation. It was noted that there was a large variability between the measured and calculated values. The variability was probably due to a too sensitive transducer that picked up the pressure change when a bubble reached the surface in the water tower. Therefore, the regression equation cannot be used.

After a constant infiltration rate was reached, using Wooding's method, the saturated hydraulic conductivity and near saturated hydraulic conductivity were calculated. Sorptivity, capillary length, and matric flux potential were calculated according to the aforementioned equations in the previous section.

3.2 Statistical Analysis:

Statistical results obtained from Mintab are shown in table 1. The higher values of sorptivity were observed in plots 15 and 17 under both water potentials -30, -60 mm. This was probably due to an early ceasing of the experiments which didn't allowed to reach the steady state and made the infiltration to be high. These higher sorptivity values were replaced with the mean sorptivity value to minimize its influence on the statistical analysis.

From the statistical analysis, it was observed that the standard error of the mean was small in comparison to the mean value, which indicates a dense concentration of values around the mean value. An exception was seen for the sorptivity. This was due to plots 15 and 17 had values up to 20 times larger than the mean values (as mentioned before). The influence of those plots could be seen when comparing the sorptivity and the modified sorptivity values. Large variability was observed in each hydraulic parameter between the plots. The extreme values of each series of numbers indicate a wide range of values for each parameter. Only plot 86 represented three maximum values included two maximum values for hydraulic conductivity. It was evident that there was neither plot nor area that showed extreme results for all of the parameters.

Table 2 shows the percent spread for each of the parameters. It was observed that for some of the parameters the mean value was not a good approximation due to the wide range of values. The soil hydraulic parameters had large spread than the bulk density. It is probably due to preferential pathways in the soil and variability of the lateral flow in each plot. Bulk density had low standard deviation and could be simplified by using the mean value as a representative value for the whole field.

3.3 Spatial Analysis:

3.3.1 Hydraulic Conductivity:

The hydraulic conductivity was calculated for three different potentials, -30 mm, -60 mm, and at saturation.

Table 1: Results of statistical analysis with Minitab

Soil parameters	n	x*	tr x*	σ	se x*	m	(plot)	M	(plot)	Q_1	Q_3
K_{sat} (mh^{-1})	109	0.060	0.058	0.026	0.0025	0.0095	(15)	0.14	(79)	0.042	0.079
K_{-30} (mh^{-1})	109	0.031	0.031	0.010	0.0010	0.008	(15)	0.063	(86)	0.024	0.037
K_{-60} (mh^{-1})	109	0.016	0.016	0.0042	0.0004	0.0066	(15)	0.031	(86)	0.014	0.019
S_{-30} ($mh^{-0.5}$)	109	0.0038	0.0028	0.0085	0.0008	0.0015	(48,49,50)	0.081	(15)	0.0023	0.0033
S_{-30} modified ($mh^{-0.5}$)	109	0.0028	0.0027	0.0007	0.00007	0.0015	(48,49,50)	0.0050	(16)	0.0023	0.0032
S_{-60} ($mh^{-0.5}$)	109	0.0067	0.0050	0.014	0.0014	0.0008	(7)	0.14	(17)	0.0035	0.0064
S_{-60} modified ($mh^{-0.5}$)	109	0.0050	0.0049	0.002	0.0002	0.0008	(7)	0.011	(60)	0.0035	0.0063
λc (m)	109	0.053	0.052	0.019	0.0019	0.03	(5)	0.17	(15)	0.042	0.0058
$Øm_{-30}$ (m^2h^{-1})	109	0.0015	0.0015	0.0004	0.00003	0.00084	(55)	0.0027	(86)	0.0013	0.0017
$Øm_{-60}$ (m^2h^{-1})	109	0.0008	.0008	0.0002	0.00002	0.00041	(7)	0.0016	(26)	0.0007	0.01
ρ, depth 0-10 cm (gcm^{-3})	109	1.36	1.36	0.099	0.0094	1.11	(82)	1.6	(63)	1.29	1.43
ρ, depth 10-20 cm (gcm^{-3})	109	1.29	1.29	0.092	0.0088	1.07	(96)	1.56	(10)	1.23	1.34
Θ depth 0-10 cm (%)	109	17.9	17.8	3.6	0.35	9.4	(40)	33.8	(4)	15.8	20.1
Θ depth 10-20 cm (%)	109	14.9	14.9	2.2	0.21	9.4	(7)	21.6	(9)	13.5	16.2

Table 2: The percent spread for each parameter.

Soil parameters	K_{sat} (mh^{-1})	K_{-30} (mh^{-1})	K_{-60} (mh^{-1})	S_{-30} ($mh^{-0.5}$)	S_{-30} modified ($mh^{-0.5}$)	S_{-60} ($mh^{-0.5}$)	S_{-60} modified ($mh^{-0.5}$)
(σ/ x*) x 100 (%)	43	32	26	224	25	209	40
Soil parameters	λc (m)	$Øm_{-30}$ (m^2h^{-1})	$Øm_{-60}$ (m^2h^{-1})	ρ, depth 0-10cm (gcm^{-3})	ρ, depth 10-20cm (gcm^{-3})	Θ depth 0-10cm (%)	Θ depth 10-20cm (%)
(σ/ x*) x 100 (%)	36	27	25	7	7	20	15

The maximum value for K_{sat} was reached in plot 79 and in plot 86 for K_{-30} and K_{-60}. The minimum value was in plot 15 for all different potentials. The distribution of hydraulic conductivity values is shown in figure 2. Figures 3a-3c show the variation of the hydraulic conductivity over the field.

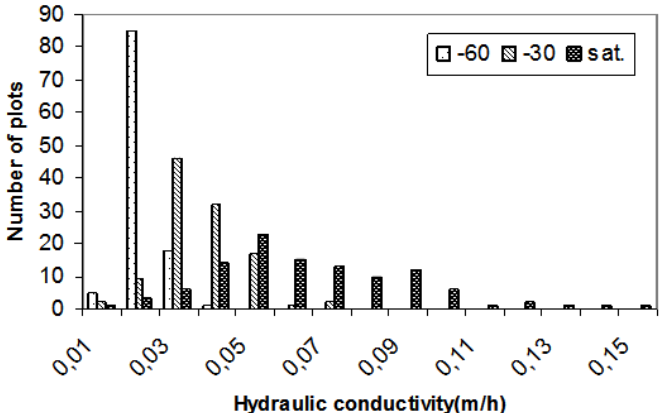
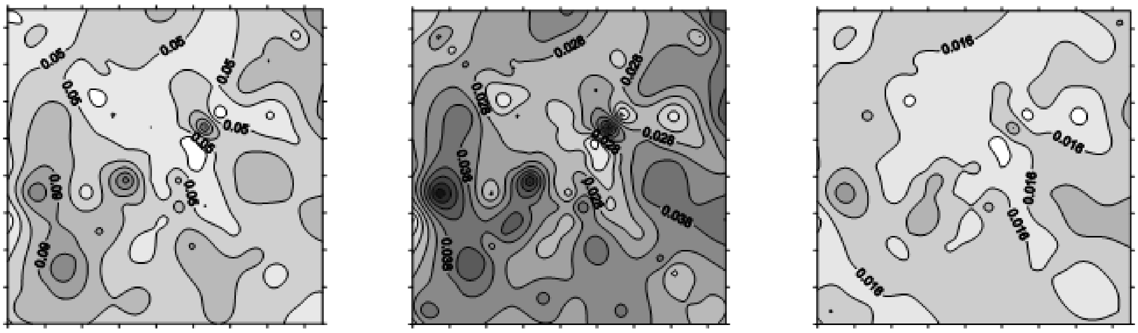


Fig. 2: Hydraulic conductivity distribution.

3.3.2 Sorptivity:

The sorptivity values were found to have larger spread at a potential of -60 mm than-30 mm for the modified values. The maximum value was in plot 60 and plot 16 for potentials -60 mm and -30 mm respectively. The minimum value was in plot 7 for potential -60 mm and in plots 48, 49, and 55 for potential -30 mm. Figures 4, 5a, and 5b show the distribution of the modified sorptivity and the variation of the modified sorptivity over the field.



(a) saturation (b) potential = -30 mm (c) potential = -60 mm.

Fig. 3: Variation of the hydraulic conductivity (mh^{-1}).

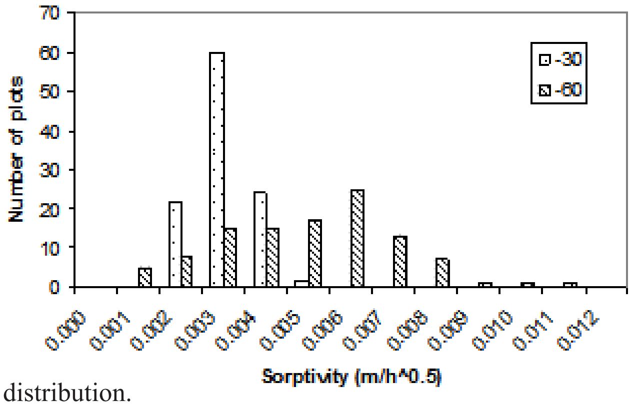
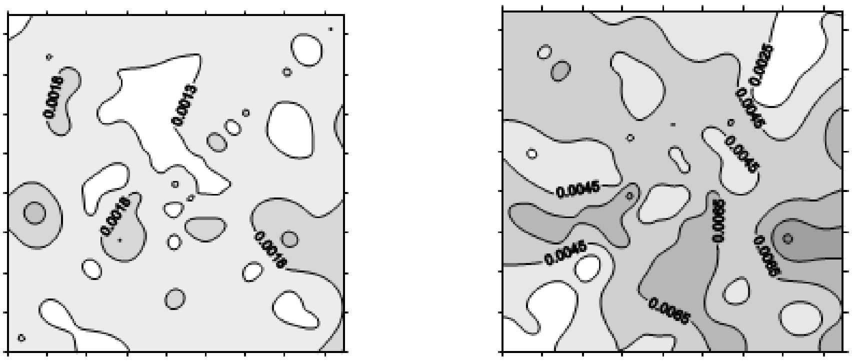


Fig. 4: Modified sorptivity distribution.



(a) potential = -30 mm. (b) potential = -60 mm.

Fig. 5: Variation of the modified sorptivity ($mh^{-0.5}$).

3.3.3 Capillary Length:

The distribution for the capillary length is lognormal, thus it was impossible to use one value to categorise the whole field. The distribution of the capillary length is shown in figures. The spatial variation of the capillary length (Fig. 7) confirms that the peaks are not concentrated to any part of the field and the variation seems to be random. The maximum value was in plot 15 and the minimum in plot 5.

3.3.4 Matric Flux:

The spread of the matric flux was normally distributed for both potential -60 mm and -30 mm (fig.8). The matric flux becomes smaller with decreasing potential (Figs. 9a and 9b). The most negative potential indicates small values for matric flux potentials. Maximum values for matric flux were found in plot 26 for potential -60 mm and in plot 86 for potential -30 mm. Minimum values were in plot 7 and in plot 55 for potentials -60 mm and -30 mm respectively.

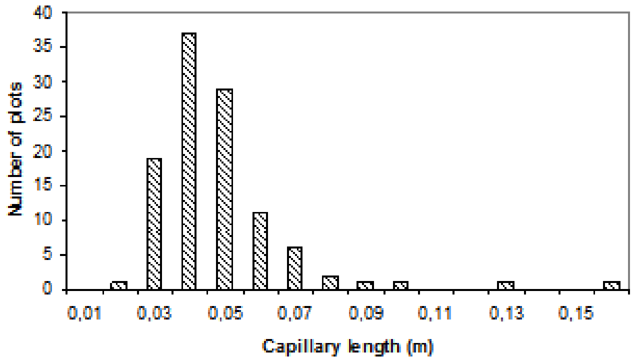


Fig. 6: Capillary length distribution.

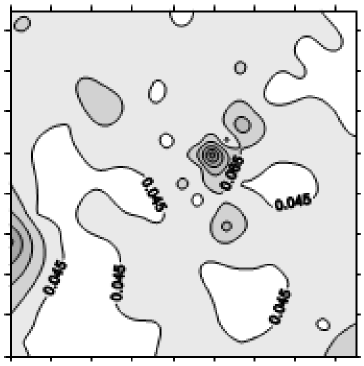


Fig. 7: Variation of Capillary length (m).

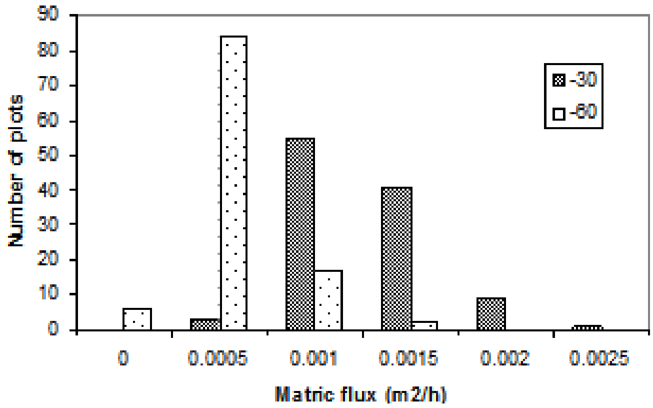
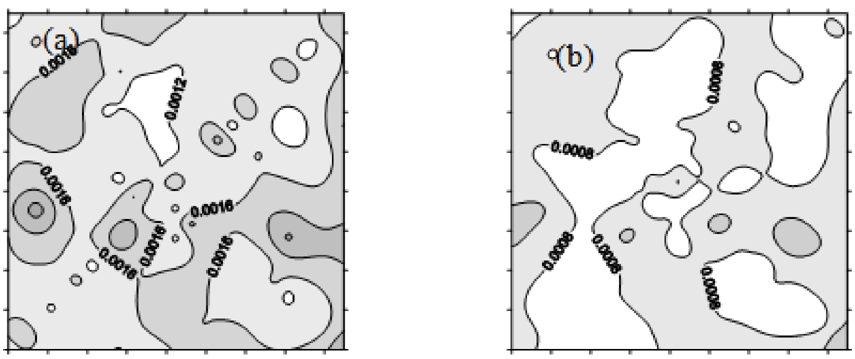


Fig. 8: Matric flux potential distribution.



(a) potential = -30 mm. (b) potential = -60 mm.

Fig. 9: Variation of the matric flux potential (m^2h^{-1}).

3.3.5 Bulk Density:

The statistical analysis showed that the mean value of bulk density was almost the same. The soil had been ploughed directly before experiments, so it was reasonable to assume that the top soil layer was well mixed and less compacted. For both depths the bulk density had a normal distribution. Figures 10,11a, and 11b show the distribution and the variation of the bulk density over the field.

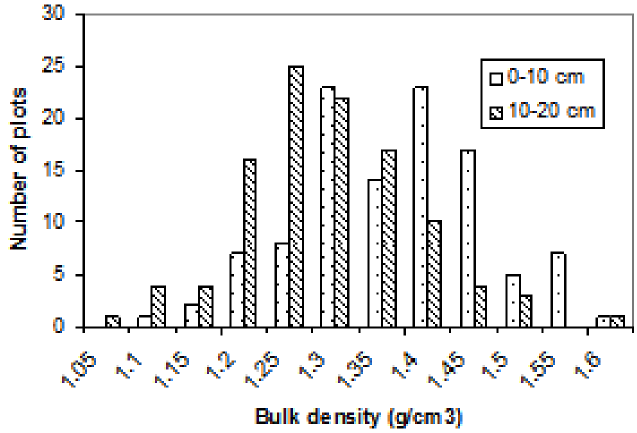
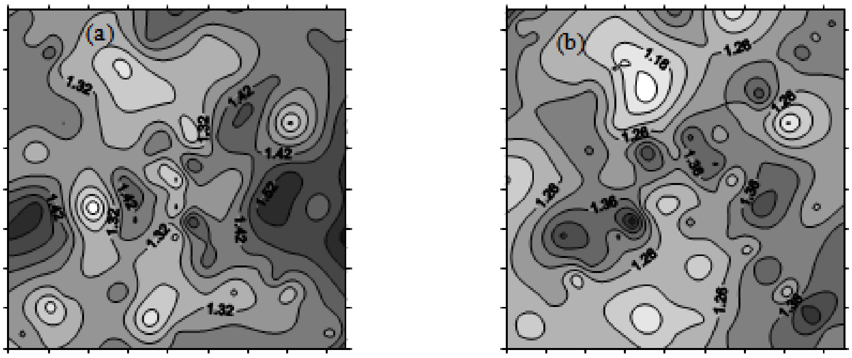


Fig. 10: Bulk density distribution.



(a) depth -10 cm. (b) depth 10-20 cm.

Fig. 11: Variation of the bulk density (gcm^{-3}).

3.3.6 Water Content:

Water content had a normal variation and naturally the upper most layers had the highest water content (Fig. 12). For depth 0-10 cm the maximum value was in plot 4 while the minimum value was in plot 40. For depth 10- 20 cm the maximum value was in plot 9 while the minimum value in plot 7 (Figs. 13a, and 13b).

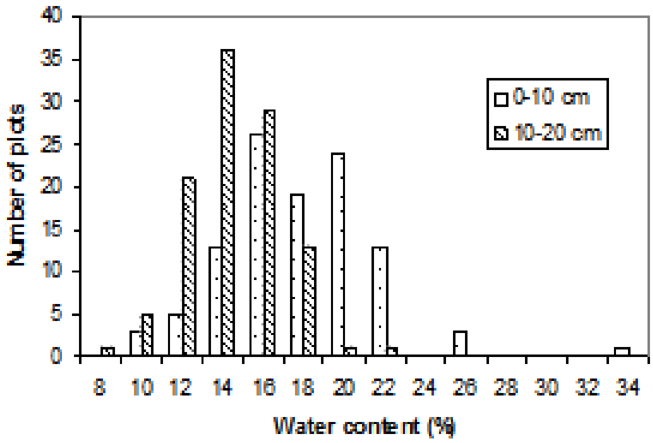
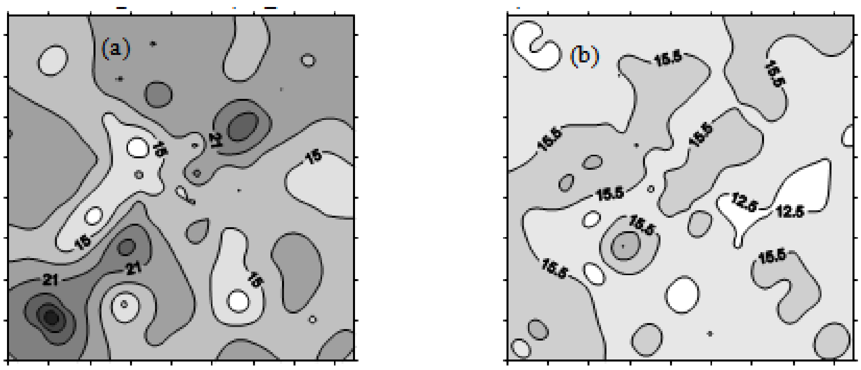


Fig. 12: Water content distribution.



(a) depth 0-10 cm. (b) at depth 10-20 cm.

Fig. 13: Variation of the water content (%).

3.4 Variograms:

Comparison analysis was made to analyze how the parameters variance depended on the distance in between the plots. This was made in a geostatistical program called Geoeas (U.S. EPA Enviromental Monitoring Systems Laboratory, Version 1.2.1). The results were plotted in variograms (Figs. 14a-14n) to visualize where a relation was found. From these plots, it was noted that the variance in hydraulic conductivity was not related to the distance between plots. On the other hand, the variances of the modified sorptivity at both potentials increase with the distance in between the plots. Contrary the capillary length did not vary with the distance between the plots. Matric flux shows a small variation with the distance in between the plots and bulk density showed that the variance was related to the distance in between plots. Similarly, the water content in depth 0-10 cm, but no relation with distance was found for the lower soil layer.

Mintab was used to decide which parameter correlated to the other, correlation graph was drawn between the parameters. A regression equation was added to the graph to calculate the relationship between the parameters (figures 15a-15h). From these figures, it can concluded that a correlation was found between saturated hydraulic conductivity and hydraulic conductivity at potential -30 mm as well as between the hydraulic conductivity at both potentials -30 mm (K_{-30}) and -60 mm (K_{-60}). Although the dense concentration of values around the trend line for the relation between the capillary length and both K_{sat} and K_{-30}. No correlation was found. This may be due to the small pore diameter infiltrated at less negative potential. Smaller pores have larger capillary rise. On the other hand, although there was a correlation between the $Ø_m$ and K_{-60}, no correlation was found between $Ø_m$ and K_{-30}. So it looks like no relation between the matric flux potential and the unsaturated hydraulic conductivity. No correlation was found between the bulk density and other hydraulic parameters as well as water content.

4. Summary and Conclusions:

Soil hydraulic and physical properties were extensively characterized using tension disc infiltrometer and soil sampling in a silty clay agricultural field in Kalaat El-Andalous, Tunisia. Tension disc infiltrometer experiments were conducted at 109 plots with two supply water potentials (-30,-60 mm) at each plot to determine the hydraulic conductivity, sorptivity, capillary length, and matric flux potential. In addition, soil samples were analyzed to determine the soil bulk density, and water content. Statistical analyses using a statistical software program Minitab version 7.2 were conducted on hydraulic conductivity, sorptivity, capillary length, matric flux potential, bulk density and water content. In addition, comparison analysis was made using geostatistical program called Geoeas to analyze how the parameters variance depended on the distance in between the plots. From Minitab results, it was found that the soil hydraulic parameters had a large spread than the bulk density and the bulk density did not correlate with the soil hydraulic parameters. In addition, low correlations were found between the parameter and mutual correlation was found for hydraulic conductivity and matric flux potentials. The Spatial analysis demonstrated also that, there was neither plot nor area that showed extreme values for all parameters. Meanwhile, the hydraulic conductivity and the sorptivity showed a trend towards larger values in NE quadrant of the study area. This indicated that the infiltration is larger in that part of the field but the large sorptivity values shows that the soil is good at holding back the water from infiltrating rapidly. Therefore, more irrigation water should be needed on that part of the field.

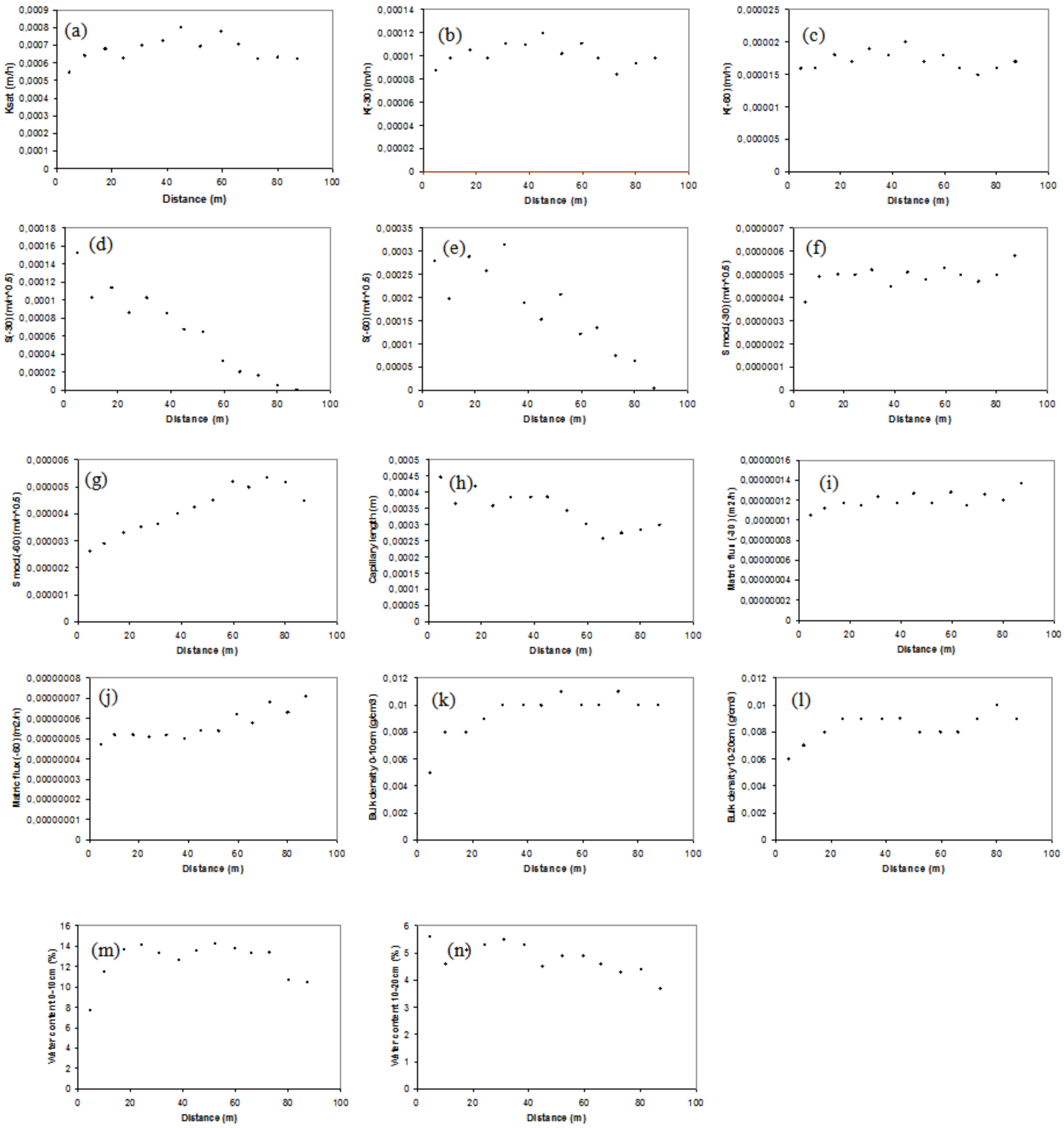


Fig. 14: Variance of the hydraulic and physical parameters against distance: (a) saturated hydraulic conductivity, (b) hydraulic conductivity at potential = -30 mm, (c) hydraulic conductivity at potential = -60 mm, (d) sorptivity at potential = -30 mm, (e) sorptivity at potential = -60 mm, (f) modified sorptivity at potential = -30 mm, (g) modified sorptivity at potential = -60 mm, (h) Capillary length, (I) matric flux at potential = -30 mm, (j) matric flux at potential = -60 mm, (k) bulk density at depth 0-10 cm, (l) bulk density at depth 10-20 cm, (m) water content at depth 0-10 cm, (n) water content at depth 10-20 cm.

The geostatistical analysis showed that the variance of hydraulic conductivity and water content not related to the distance. In addition, Capillary length, matric flux potential, and bulk density had larger variance with the distance in between the plots while the variances of the modified sorptivity at both potentials increase with the distance in between the plots.

Overall, no correlation was found between bulk density and the soil hydraulic parameters, nor could the soil hydraulic parameters be correlated to each other.

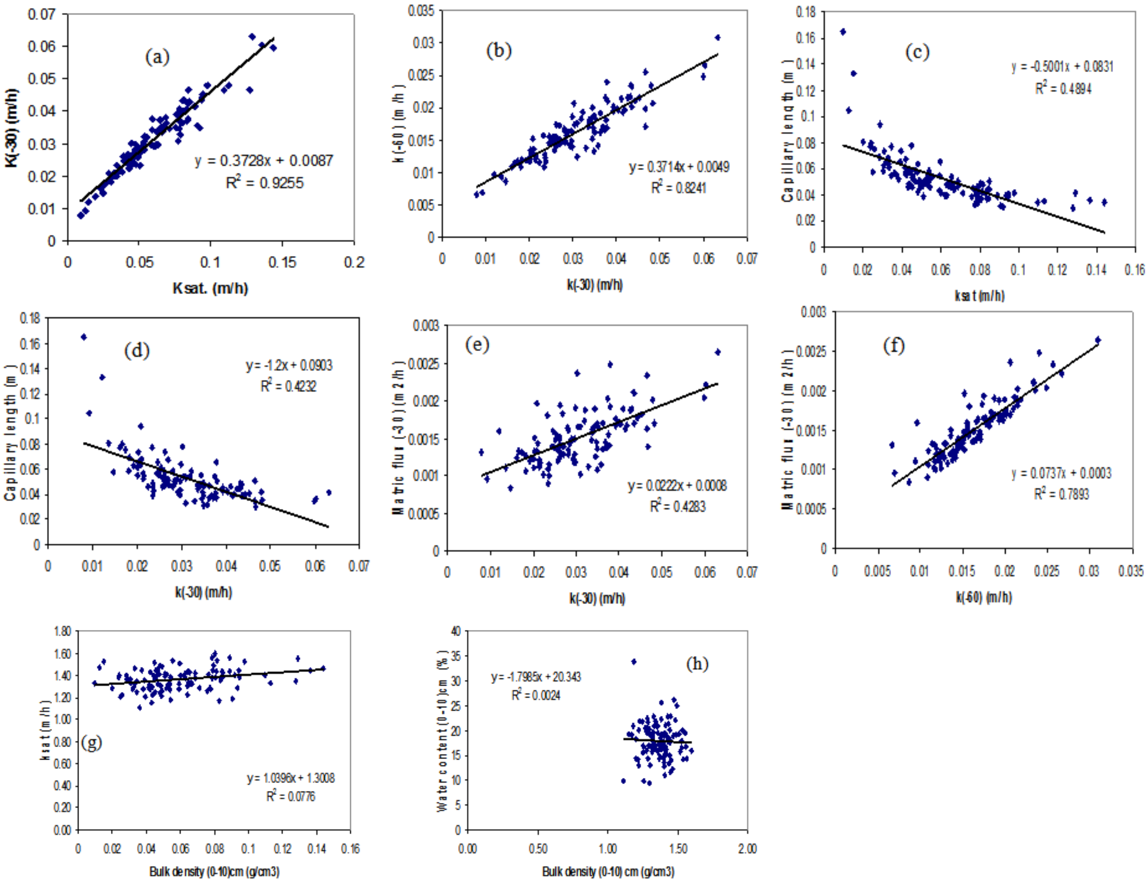


Fig. 15: Correlation between various parameters.

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List of Notation:

K_{sat}	Saturated hydraulic conductivity, (LT^{-1}).
r	Radius of circular source, (L).
K_0	Soil hydraulic conductivity corresponding to a given pressure head, (LT^{-1}).
S	Sorptivity, $(LT^{-0.5})$.
$K(\psi)$	Soil hydraulic conductivity at potential ψ, (LT^{-1}).
I	Cumulative infiltration, (L).
$K(\psi_1)$	Soil hydraulic conductivity at potential ψ_1, (LT^{-1}).
t	Cumulative time, (T).
$K(\psi_2)$	Soil hydraulic conductivity at potential ψ_2, (LT^{-1}).
λ_c	Capillary length, (L).
ψ, ψ_1, ψ_2	Potentials applied to the infiltrometer (L).
$Ø_m$	Matric flux potential, (L).
α	Contact angle (exponential slope), (L^{-1}).