Analysis of some parameters related to the hydraulic infiltration of a silty-loam soil subjected to organic and mineral fertilizer systems in Southern Italy

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Abstract

This experiment was carried out to detect the most linear process to calculate the hydraulic conductivity, with the aim to classify the soil of experimental station of the Unit for Research in Cultivations Alternative to Tobacco (CAT), locate in South Italy (Scafati, Province of Salerno), subject to different types of manure: compost and mineral fertilizer. The field tests were made by a system measuring infiltration by double, inner and outer ring, inserted into the ground. Each ring was supplied with a constant level of water from external bottle (3 cm), and hydraulic conductivity is determined when the water flow rate in the inner ring is constant. Four areas, two fertilized by mineral fertilizer (areas I and III) and two amended with compost (areas II and IV) at two depths, 5 and 10 cm (H_1-H_2), were analysed. The parameters were recorded at the following dates: on 18th and 19th September 2009, respectively, at 5 and 10 cm of depth (H1-H2) in area I; on 7th and 8th October 2009 in area II; on 13th and 14th October 2009 in area III; on 16th and 17th October 2009 in area IV. The effect of compost, used one time only, is present in all parameters, even if with a low statistical significance (P<0.01-0.05). This biomass stores a better water reserve [g (100 g)$^{-1}$)-$\Delta\theta$] and causes a lower avidity for water (bibacity) and a better speed of percolation (Ks) of exceeding water. The organic matter decreased the variability of soil along field. The studied soil showed to be almost permeable and not having any serious problem concerning rain intensity.

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Introduction

The hydraulic conductivity is one of the most important parameters of the cultivated soil, since it explains the type of water movement into the soil itself. The saturated flow of the water is defined as the flow present in a soil, where either the larger or the smallest pores are filled with water. The unsaturated flow of the water is defined as the flow present in a soil, where the larger pores are filled with air and the smallest with water. Total porosity (Sartori *et al.*, 1985; Pagliai, 1987), gradient of water, temperature (Grent, 2004), manure amendments (Fares *et al.*, 2008), past and present tillage (Leeds Harrison and Yongs, 1997; Franzluebbers, 2002; Matula, 2003) of soil have influence on this parameter. Significant correlations between macroporosity and satured hydraulic conductivity were found in some previous studies on the effect on soil qualities following the agricultural machineries traffic (Marsili *et al.*, 1998; Servadio *et al.*, 2001, 2005; Pagliai *et al.*, 2003). The study of hydraulic conductivity is essential to define the intensity rain in the sprinkler irrigation, the interval time (D) of irrigation and the estimation of wetting bulb in the drip irrigation. The definition of intensity rain in the sprinkler irrigation is important to avoid run off, differentiated distribution of the water and superficial erosion of the soil (Megale, 2009; Fileccia, 2002-2009; Various Authors, 2005-2006).

Hydraulic conductivity defines the interval time of irrigation, which is the ratio between the total volume of water (V) and the hydraulic conductivity (Ks) (D=V/Ks). In a drip irrigation system, the estimation of wetting bulb of emitter is important to design the drip system and the wet bulb; the latter is determinant to predict the lateral and vertical movements of water and to reduce the loss of water and fertilizers due to deep percolation (Mubarak *et al.*, 2009). The present experiment was carried out to compare the mathematical processes to calculate the hydraulic conductivity and determine the most linear one, with the aim to classify the soil of experimental station of the Unit for Research in Cultivations Alternative to Tobacco (CRA-CAT), located in South Italy (Scafati, SA), subjected to different kinds of manure: compost and mineral fertilizer. Hydraulic conductivity is determined by hydraulics experiments using the Darcy's law and it can be calculated in three different ways. The first way follows the formula of Guelf infiltrometer, where the final field saturated hydraulic conductivity value (Kfs) is considered: the formula of Darcy is taken into account, but Kfs is corrected for the same parameter of wetting area. The second way is following the Darcy formula, where the mean value of hydraulic conductivity is taken in account [K(Vmean)]. The third way is the same formula where the final value of hydraulic conductivity is considered [K(R)]; the last two ways have been calculated without corrections for wetting area.

Materials and Methods

Soil and treatments

The instrument used in measuring the ability of a porous medium to transmit water was a system at double ring, one inner and one outer, inserted into the soil at two depths (5 and 10 cm). Each ring is supplied with a constant head of water from external bottle, hydraulic conductivity is determined when the water flow rate in the inner ring is constant (Figure 1). Water level in the rings was at 3 cm from surface of soil. The inner ring had a diameter of 30 cm while the outer ring had a 53 cm diameter.

A gauze and a plastic plate were put inside the inner ring to avoid flow from external bottles lifting up the soil (Nigrella, 1994). This method mimics the condition of flooding irrigation. To calculate the water flow in the inner ring from reservoir a coefficient of infiltrometer was used, calculated with the following formula: (cm of external bottle x diameter of external bottle)/diameter of inner ring); the value obtained was 14.4. Both rings were put 5 cm under surface of soil (H_1) and second observation was made at 10 cm under soil surface (H_2). The H_2 was made on saturated soil on the same location of H_1 the day after (Soilmoisture Equipment, 2008). The studied soil belongs to the Experimental Station of the Unit for Research in Cultivations Alternative to Tobacco, Agricultural Research Council (CRA-CAT) of Scafati (Salerno Province of Salerno), presenting the physical and chemical parameters indicated in Table 1. The soil is a silty-loam soil, lightly alkaline, with high content of organic matter, normally equipped in nitrogen and particularly abounding in phosphorus (Table 1). Soil is classified as *vitric andosol calcaric*, according with the *World Reference Base* (for soil resource, WBR) described by Basile and Terribile (2006), and with FAO (1998).

Four areas, two fertilized by mineral fertilizer (areas I and III) and two amended with compost (areas II and IV) were analysed; in each area two depths (H_1=0-5 cm; H_2=0-10 cm) were analysed, for a total of eight treatments (Table 2).

The compost used (Progeva-Evafruit), in quantity of 20 t/ha, was distributed five months prior to the experiment in basal dressing on other cultivation that had been ploughed in soil: the *Torzella* (ancient *cauliflower-Brassica-Cruciferae*). The mineral fertilizer used ammonium nitrate in quantity of 100 kg/ha has been distributed partially in basal dressing and partially in top dressing by fertirrigation.

The parameters were recorded in the following dates:

On 18th and 19th September 2009, respectively, at 5 and 10 cm of depth (H_1-H_2) on area I;

On 7th and 8th October 2009, respectively, at 5 and 10 cm of depth (H_1-H_2) on area II;

On 13th and 14th October 2009, respectively, at 5 and 10 cm of depth (H_1-H_2) on area III

On16th and 17+ October 2009, respectively, at 5 and 10 cm of depth (H_1-H_2) on area IV.

The values determined were the following: i) cumulated hydraulic conductivity (Ic); ii) mean of hydraulic conductivity (V1-V2); iii) instantaneous hydraulic conductivity (Ki); iv) steady state rate of fall of water during running at 5 and 10 cm of depth (R_1-R_2); v) saturated hydraulic conductivity or permeability coefficient Ks: (Kfs), [K(Vmean)], [K(R)]; vi) matric flux potential (ϕ); vii) Water content [g (100 g)$^{-1}$)-$\Delta\theta$]; viii) rate of flow (Q): Q(Kfs), Q[K(Vmean)], Q[K(R)]; ix) Bibacity or sorptivity (B or S).

Cumulated hydraulic conductivity

The cumulated hydraulic conductivity resulting from adding all the water volumes dropped from the external bottles was recorded in mm.

The values of hydraulic infiltration have been interpolated with a curve, which function was expressed by the exponential equation of Kostianoff

$$y = at^b \qquad \text{(Eq.1) (Cavazza and Torri, 1997)}$$

where

y is cumulated infiltration;

t is time in minutes;

a and b are constants.

Figure 1. Double ring in field.

Table 1. Chemical and physical characteristics of the soil tested in 2005 at the CRA-CAT laboratory.

Parameters	Unit	Values	Classifications
Sand content	g(1000)$^{-1}$	350.5	
Slimy content	g(1000)$^{-1}$	575	
Clay content	g(1000)$^{-1}$	75	Silty-loam soil
Field capacity	g(100 g)$^{-1}$	26	
Wilting point	g(100 g)$^{-1}$	9	
Bulk density	t m^{-3}	1.33	
pH	-	8.05	Under alkaline
$CaCO_3$ total	g Kg^{-1}	46	Average (SISS)
$CaCO_3$ active	g Kg^{-1}	32	Low (SISS)
Electrical conductivity	dS^{-1}	0.23	Very low (SISS)
Cation exchange capacity	Cmoli Kg^{-1}	23.8	High (SISS)
Phosphorus	mg Kg^{-1}	35.5	Very high (SISS)
Total nitrogen (N)	g Kg^{-1}	1.2	Normal (SISS)
Organic matter (C)	g(100 g)$^{-1}$	2.15	High (SISS)
C/N	-	10.5	Normal (SISS)

SISS, Italian Society of Soil Science.

Table 2. Description of treatments.

Treatment	Area	Depths	Type of fertilizer
MI-H_1	I	H_1	Mineral
MI-H_2	I	H_2	Mineral
CII- H_1	II	H_1	Compost
CII- H_2	II	H_2	Compost
MIII-H_1	III	H_1	Mineral
MIII-H_2	III	H_2	Mineral
CIV- H_1	IV	H_1	Compost
CIV- H_2	IV	H_2	Compost

Mean of hydraulic conductivity

The mean of hydraulic conductivity (V mean) was calculated as ratio between the total volume of infiltrated water in mm, and the total time in minutes multiplied by the infiltrometer coefficient of the double ring system.

The survey was organised as follows: three measures were taken at a 5 min interval, 7 measures at a 10 min interval, and the remaining measurements each 20 min, until constant speed. The hydraulic infiltration is the speed with which the water pierces the soil and depends on the water load on the ground; this value decreases in damp ground and is minimum in the saturated ones.

This parameter is very important to regulate the intensity of sprinkler irrigation, the intervals of time for irrigation and estimation of wetting bulbs in the drop irrigation. The intensity of the rain (Ip) in sprinkler irrigation must be lower than the saturated hydraulic conductivity (ks) to avoid run off, differentiated water distribution and superficial soil erosion (Ip<Ks) (Megale, 2009).

Interval time (D) of irrigation is influenced by hydraulic speed because it is the ratio between volume of single irrigation (V) and saturated hydraulic conductivity (D=V/Ks). In conclusion, the saturated hydraulic conductivity measures the extent to which water moves laterally and vertically from an emitter in drip irrigation, so that the estimation of wetting bulb can be made.

Instantaneous hydraulic conductivity

The instantaneous hydraulic conductivity was measured by the first derivative of the equation of Kostianoff

$$y' = abt^{b-1} \qquad \text{(Eq. 2)}$$

where
y' is first derivative of y from function of Eq. 1.

Final rate of water level change

The final change of water level change (R_1-R_2) to 5-10 cm of depth has been calculated as the ratio between final constant infiltration and corresponding final time interval expressed in minutes and it was multiplied by infiltrometer coefficient to correct difference existing between diameters of reservoir and inner ring.

Field saturated conductivity

The Field saturated conductivity expressed in cm sec^{-1} $*10^{-4}$ has been calculated by the following equation (Soilmoisture Equipment, 2008):

$$Kfs = \frac{CAR}{\left[2\pi H^2 + C\pi a^2 + \left(\frac{2\pi H}{\alpha *}\right)\right]} \qquad \text{(Eq. 3)}$$

where
A is a section of cylinder in cm^2 (706.2 cm^2);
R is a steady state rate of fall corresponding to H_1 and H_2 (deep 5 and 10 cm) of water in the inner reservoir when the head of water is established. They were final speeds in cm sec^{-1} (R_1-R_2);
C is a factor shape dependent on value H/a, calculated by the graphic of Reynolds (1993). In this work, H/a resulted to be 0.33 and 0.66 with corresponding values of C of 0.25 and 0.45 respectively, in the Reynolds' graph (Figure 2);
H is a depth of sampling, in cm (H_1=5 cm, H_2=10 cm);
A is a radius of the well (internal cylinder=15 cm);
α^* is a related to texture of the soil, usually 0.12 cm^{-1} from the table of Reynold (1993) and Erlick *et al.* (1989) (Table 3).
π is the constant 3.14.

Matric flux potential (ϕ)

The matric flux potential (ϕ) expressed in cm^2 sec–1×10^{-3} is the quantity of water that, if available on the plant surface, would be removed from the ground and is calculated as follows:

$$\phi = \frac{CAR}{\left[\left(2\pi H^2 + C\pi a^2\right)\alpha^* + 2\pi H\right]} \qquad \text{(Eq. 4)}$$

Water content

The humidity is often referred as water content and is obtained drying the sample at 105 °C in an oven for 48 h; the mass of water lost is expressed as change of percentage of the height [g(100 g)$^{-1}$] and as change of volume ($\Delta\theta$).

$\Delta\theta$ is the difference between the water content in volume of saturated soil and the water content of soil before the infiltration trial, expressed in cm^3/cm^3.

Hydraulic flow in porous medium or soil permeability

The hydraulic flow in porous medium or soil permeability has been calculated by Darcy's formula (Fileccia, 2002-2009; Various Authors, 2005-2006).

Henry Darcy in 1956 related the water flow in Lh^{-1} (Q), with the area soil sample in mm^2 (A), and the hydraulic gradient in mm (H). The equation reveals that hydraulic flow (Q) and the piezometric head to be directly proportional variables, and flow (Q) and length (L) of the sample to be inversely proportional variables:

$$Q = \frac{KsAH}{L} \qquad \text{(Eq. 5)}$$

where
Ks is the satured hydraulic conductivity;
A is the section of cylinder in cm^2 (706.2 cm^2);
H is the sum of H' and L (*H'*=3 cm, is the water height into the cylinder, from soil surface);

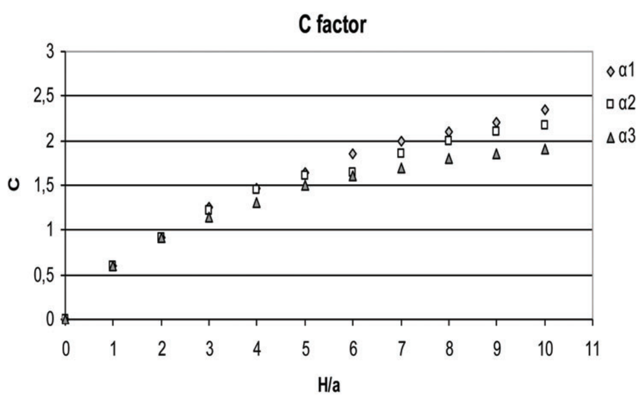

Figure 2. Reynolds' Graph.

Table 3. Table of Reynolds (1993) and Elrick *et al.* (1989).

Soil texture /Structure category	α* (cm^{-1})
Compacted, unstructured, clayey materials such as landfill caps and liners, lacustrine or marine sediments, etc.	0.01
Soils both fine textured (clays) and unstructured	0.04
Most structured soils from clays through loams; including unstructured medium to fine sands (first choice for most soils)	0.12
Coarse and gravely sands; may include some highly structured soils with large cracks (vertisoils) and macropores	0.36

L is the inserting depth on soil (3-10 cm).

Rings are inserted into the soil at two depths (5 and 10 cm); satured hydraulic conductivity or coefficient of permeability in constant running (mm min^{-1}) has been calculated by soilmoisture formula Kfs, as well as with Ks (mean V) and with Ks (R). The last two were calculated by multiplying mean V and final R for the ratio H/L (Megale, 2009), where H=(H'+L). H' is head of water of inner ring (3 cm is the piezometric head, corresponding to the height of water on the soil surface) and L is the length of the porous matrix, namely the length of cylinder inserted into the ground at the two depths (Bianchi, 2003). The mathematic law on water distribution for horizontal and vertical Ks variability is logarithmic (Fileccia, 2002-2009; Various Authors, 2005-2006).

Bibacity or sorptivity

The bibacity (B) or sorptivity (S) is the ability of the soil to adsorb water at starting of the infiltration trial:

$$S = \sqrt[2]{2\Delta\Theta\Phi} \qquad \text{(Eq. 6)}$$

where

$\Delta\theta$ is the variation of water content.

The statistical analysis was performed by the Post Hoc Test, data analysis software system Statistica v. 7.1 (www.statsoft.com).

Results

Water content

The calculated water content revealed a decreasing trend from area I to area IV, among the selected areas. The most evident gradient was observed in samples almost saturated, probably for the differences in texture or in porosity, maybe caused by deep tilling. The values of water content before the experiment are lower at 5 cm than at 10 cm, as shown in Figure 3. The soil treated by compost showed a higher value of water content at the beginning (31.42; 29.08) and lower at the end of the experience (44.66; 49.12), compared with the values recorded from mineral fertilized soil (Figures 4 and 5). The variability of water content in the soil treated with compost is smaller than the one recorded for the areas with nitrogenous fertilizer, at 5 and 10 cm of depth, maybe due to the fact that the organic matter retains water. The variability of water content, expressed as $\Delta\theta$ of volume (cm^3/cm^3), is lower in areas amended with compost (0.20-0.064) than in those treated with mineral fertilizer (0.30-0.10) (Figure 6). The lowest water content change in soil amended with compost makes the environmental conditions more favourable for the plants. The statistical analyses showed that the change of water content in volume, the type of fertilizations (mineral and organic) and the depth are proportional dimensions (Table 4).

Mean of hydraulic conductivity (V mean)

The mean of infiltration coefficients (or permeability coefficients) resulted higher in the areas amended with compost, whether analyzing separately V_1 and V_2 (4.33-1.51 mm min^{-1} *vs* 3.19-1.47) or the mean values without considering the different depths (2.92 *vs* 2.33) (Figures 7 and 8). The differences among the logarithmic data of mean hydraulic conductivity (V mean) are significant (0.046%), showing higher values in areas treated with compost than in mineral fertilized areas, confirming the good porosity of the soil amended with compost (Pagliai *et al.*, 1987). The natural differences in texture and tilling of field probably cause changes in the elaborated values between areas fertilized in the same way; however, this event is more evident in soil treated with mineral fertilizer, since compost reduces discontinuity of soil texture and porosity.

Final rate of water level change

The differences in the final values of infiltration (R_1-R_2) among the theses decrease using R as absolute value and become significant (0.038%) when R values are transformed in logarithmic values (Figure 9 and 10). The compost, in conclusion, reduces changes of water content and makes the soil porosity or the texture uniform; this is clearly stated in Figures 7 and 9, seeing separately mineral and compost theses. The final speed of infiltration in constant running is obtained in shorter time in organic fertilized areas than in the mineral fertilized ones from area II and IV, 193-195.00 min at 5 cm of depth and 205-91.00 min at 10 cm of depth; from area I and III, 196-205.00 min at 5 cm and 215-227.00 min at 10 cm (Table 5). The curves resulting from analyses

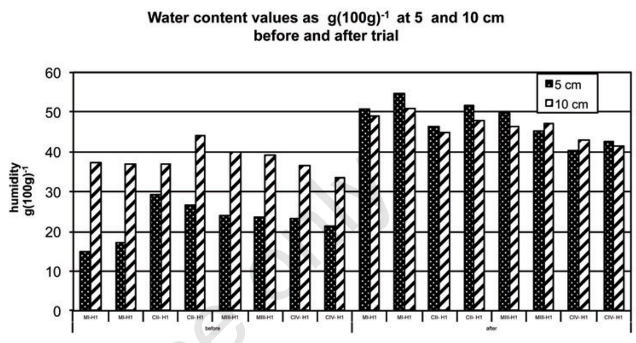

Figure 3. Values of water content.

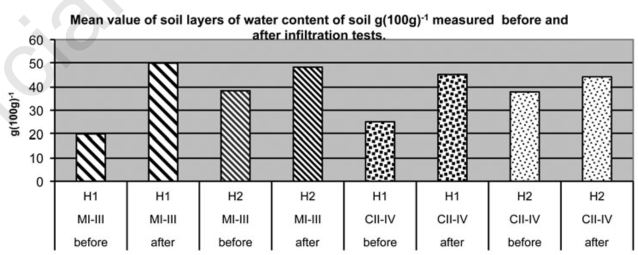

Figure 4. Water content in organic and mineral areas.

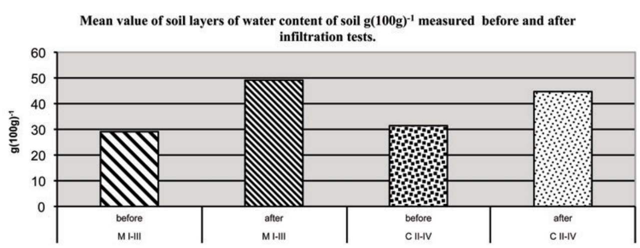

Figure 5. Mean of water content in organic and mineral areas.

Table 4. Unvaried test for change of water volume ($\Delta\Theta$).

Treatment	MI-III-H_1 0.30	CII-IV-H_1 0.20	MI-III-H_2 0.10	CII-IV-H_2 0.064
MI-III-H_1				
CII-IV-H_1	0.000103			
MI-III-H_2	0.000059	0.00103		
CII-IV-H_2	0.000045	0.000059	0.0002	

of the values of cumulated speed and instantaneous speed of water, or the equations obtained with data collected from areas I and II (treatments MI-H_1 and CII-H_1) are showed in Figures 11 and 12.

The soil can be classified as sandy, for the mean of hydraulic conductivity (V_1-V_2 mean) recorded at 0-5 cm of depth, with mean values ranging between 19.16-25.69 cm h^{-1} respectively, recorded from mineral and organic fertilized soils.

The soil can be classified as loamy-sand, for the water mean conductivity recorded at 10 cm of depth, with mean values ranging between 8.85-9.04 cm h^{-1} or, finally, as sandy considering the mean of all recorded values (14-17.51 cm h h^{-1}), according to table of O'Neal reported by Falciai (1993) (Table 6).

Comparing the recorded values of water conductibility with those elaborated from Ooserbaan and Nijland (Nigrella, 1994) (Table 7), the soil can be classified as medium sand considering the mean speeds (V_1-V_2) of the water at 5 and 10 cm of depth and as at medium texture-fine-sand considering the final values of R_1-R_2. The conductivity is middle high or high.

Table 5. Synthesis of different parameters of field in CRA-CAT 2009 (Scafati, Province of Salerno).

Treatment	Cumulated time in minutes	Velocity mean (V1-V2) in cm h^{-1}	Final velocity (R1-R2) cmh^{-1}	Instantaneous velocity (Ki) in cm h^{-1}	Cumulated velocity (Ic) in mm
MI-H_1	196	24.62	15.1	10.70	804.24
CII-H_1	193	35.48	11.4	11.713	1141.2
MIII-H_1	205	13.70	8.6	4.52	468.00
CIV-H_1	195	16.50	13.0	5.45	536.4
MI-H_2	215	13.98	14.3	7.77	501.12
CII-H_2	205	12.85	11.9	10.146	439.2
MIII-H_2	227	3.71	2.4	1.99	140.4
CIV-H_2	91	5.22	4.3	2.86	79.2

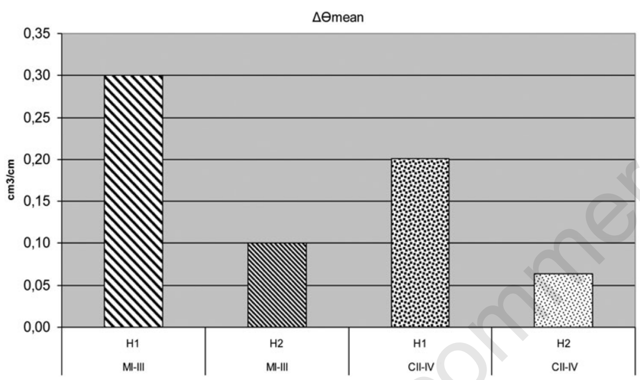

Figure 6. Variation of water content expressed as volume.

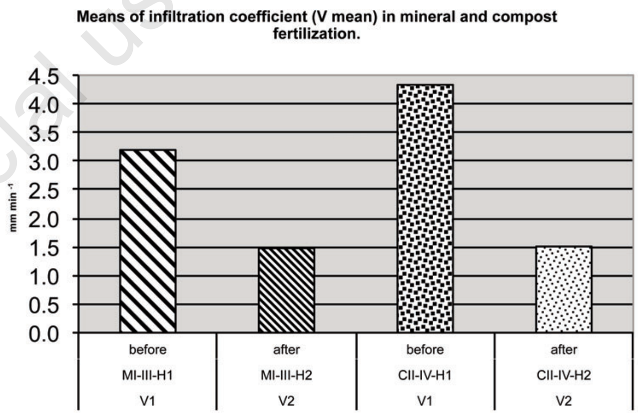

Figure 8. Mean of infiltration coefficients in two different theses.

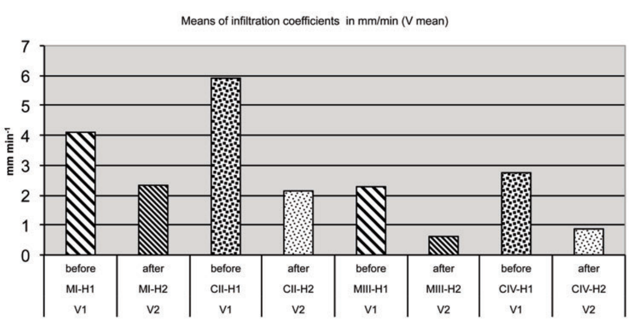

Figure 7. Mean velocity (V mean) of infiltration.

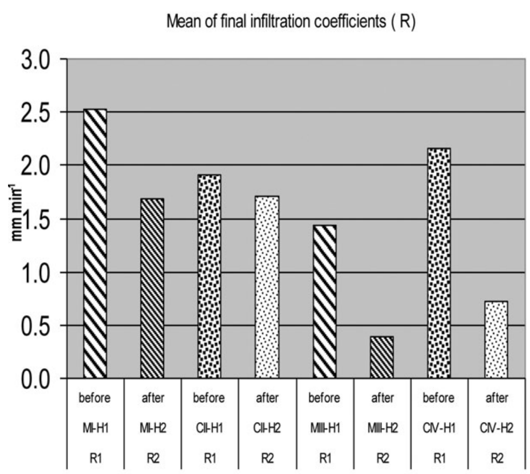

Figure 9. Final hydrology coefficients (R_1-R_2) mm min^{-1}.

Field saturated conductivity

The studied soil of Scafati, considering the values of conductivity of water at the *saturation point or permeability* (kfs), can be considered as very fine sand (Table 8).

The middle values of kfs are 9.81-10.05 cm $sec^{-1}\times10^{-4}$ in not-saturated field and 3.83-4.65 cm $sec^{-1}\times10^{-4}$ in saturated field, with a mean of 6.82-7.35 cm $sec^{-1}\times10^{-4}$, respectively, recorded from areas mineral fertilized and from those amended with compost.

In Table 6 the above mentioned values are expressed as m sec^{-1}, so corresponding to unit of measure 10^{-6}, the soil is classified as fine-sand. Using the unvaried test to analyze the absolute *values of Kfs* no significant difference was found among the theses, while the same values, changed in logarithmic values and elaborated with the final speed of infiltration, resulted significant to 0.452%, due to the difference in practices of fertilization. The highest values have been recorded in the thesis organically treated (Figure 13).

Matric flux potential

The matric flux potential (ϕ) is the quantity of water removed from the soil for unit of area (potentially available for the plants). This parameter fellows shape similar to that of the conductivity at saturation point, in fact it is higher in organically treated areas than in the mineral fertilized ones (Figure 14). The mean values of the matric potential flux of the medium are 8.18-8.37 $cm^2\times10^{-3}$ in not-saturated field and 4.38-5.31 $cm^2\times10^{-3}$ in saturated field, respectively in mineral and in organic amended field, with a total mean of 6.56 $cm^2\times10^{-3}$. The differences are statistically significant, to 0.424 %, probably as effect of the different practices of fertilization.

Hydraulic cumulated conductivity

The *infiltration cumulated parameter* differs in significant way (0.034%) (Figure 15). The mean final values at 5 cm for organic and mineral fertilized soil are 838.7-636.12, respectively.

Bibacity (B) or sorptivity (S)

The *bibacity* value is low and almost constant at 5 and at 10 cm of depth in the compost dunged areas (1.83-0.79 cm $*sec^{-1/2}$) compared with that recorded in mineral fertilized areas (2.22-0.92 cm $sec^{-1/2}$) (Figure 16).

The sorptivity or bibacity characterized the first phases of infiltration process, depending either on the intrinsic permeability of the soil, on the ability of the soil to store water, or on the difference of pressure power between the water in surface and the water into the soil, at the starting state (Nigrella, 1994). The bibacity changed in significant way when correlated with depth and with the relation between depth and type of manure. The bibacity showed a higher decrease in areas amended with compost, overall at 5 cm of depth, and less at 10 cm in saturated areas.

Comparing data of Kfs, K(Vmedia) and K(R) in mm h^{-1} with data

Table 6. Table of different values of saturated hydraulic conductivity (Ks) cm h^{-1} (Falciai, 1993).

Soil texture	Ks (cmh^{-1})
Clay	0.1-0.5
Loam	0.5-2
Silty (medium texture)	2-6
Loamy-sand	6-12
Sand	12-25
Sandy-coarse	25-100

Table 7. Table of different values of saturated hydraulic conductivity (Ks) in different kinds of soil).

Soil texture	Ks (cmh^{-1})
Gravely coarse grained sand	42-208
Average sand	4-21
Medium texture – fine sand	4-12
Medium texture – clay at compact texture	2-8
Medium texture	0.8-20
Medium texture – clay at loose texture	0.008-0.8
Compact clay	<0.008

Table 8. Coefficient of permeability (reported by USACE, 1999).

	Type of soil	K (m sec^{-1})
Coarse grained soils	Clean gravel	$10^{-1} \div 1$
	Clean sand, sand and gravel	$10^{-5} \div 10^{-2}$
	Very fine sand	$10^{-6} \div 10^{-4}$
Fine grained soils	Loam	$10^{-8} \div 10^{-6}$
	Homogeneous clay	$<10^{-9}$

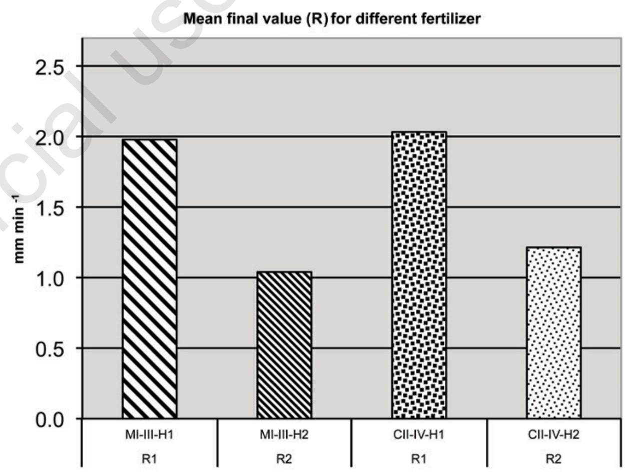

Figure 10. Mean final coefficients (R).

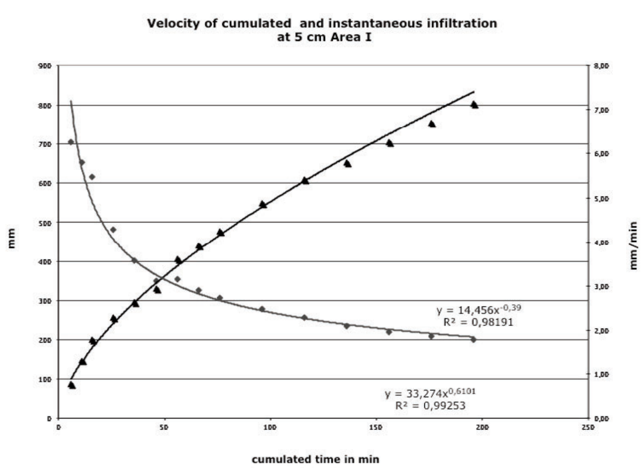

Figure 11. Cumulated and instantaneous hydraulic conductivity of Area I.

reported by Bianchi (2003), the soil studied can be classified as very permeable; however, considering data in saturated areas at 10 cm of depth, this soil can be placed among very permeable, permeable and mediately permeable ones with a fine sand texture (Tables 9 and 10).

The hydraulic flow in porous medium or soil permeability

The Q(Kfs) values are in the average: 17.5 l h^{-1} in not-saturated field at 5 cm of depth, and of 7.5 l h^{-1} in saturated field; Q(Vmean) values are in the average: 24 l h^{-1} in not-saturated field at 5 cm of depth, and of 8.2 l h^{-1} in saturated field and Q(R) values are in the average: 20.8 l h^{-1} in not-saturated field at 5 cm of depth, and of 7.9 l h^{-1} in saturated field (Table 9).

The intensity rain in sprinkler irrigation considering different systems (Bertolacci, 2008) changes from 3 mm h^{-1} to 20 mm h^{-1} (rarely reaching 80 L/h).

In the field studied, the values of Kfs, K(Vmedia) and K(R) always exceeded 100 mmh^{-1} of permeability (Table 9); furthermore, with the actual irrigation systems there are not limits for intensity rain. Areas III and IV showed lower values at 10 cm of depth (31 and 56 mmh^{-1}), exceeding the limit of 20 mmh^{-1} of intensity rain (Tables 9 and 10).

Figure 17 shows the relation between the logarithm of infiltration intensity at the saturation point (log Ks) and the hydraulic flow Q(K) of water typical of the examined soil.

The value of the coefficient of permeability at constant permeability (Ks), calculated by kfs is equivalent to that obtained by formulae given at the course on hydrogeology K(V mean) and K(R), even if the latter gives lower values of soil permeability. Therefore, the curve of water flow obtained by K(R) is lower compared with the other, but the present study suggests that it could be more convenient considering the lower value, which avoids the risk of an over-evaluation of water flow and of speed of infiltration at the saturation point.

Conclusions

The effect of the organic amendment, used only one time, is present in all parameters, even if with a low statistical significance (P<1-5%).

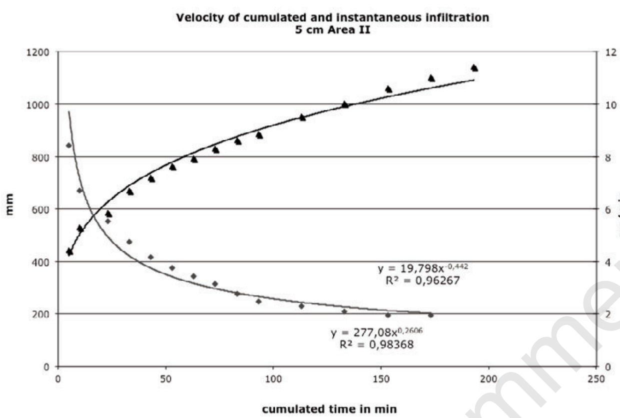

Figure 12. Cumulated and instantaneous hydraulic conductivity of Area II.

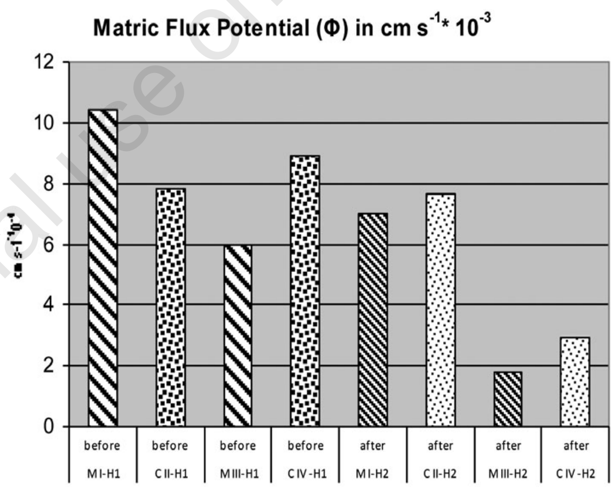

Figure 14. The matric flux potential (Φ).

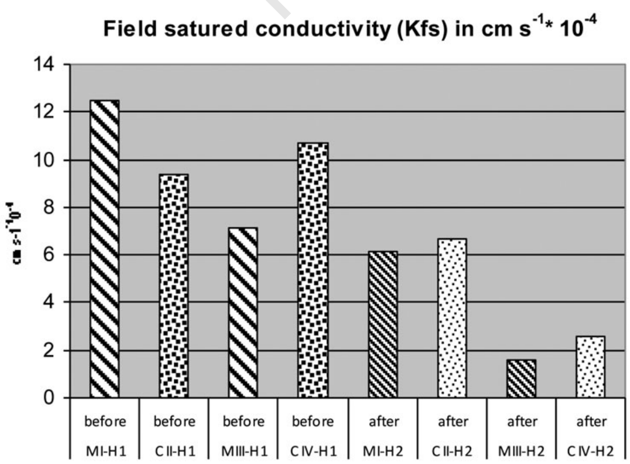

Figure 13. Saturated hydraulic conductivity or permeability Kfs.

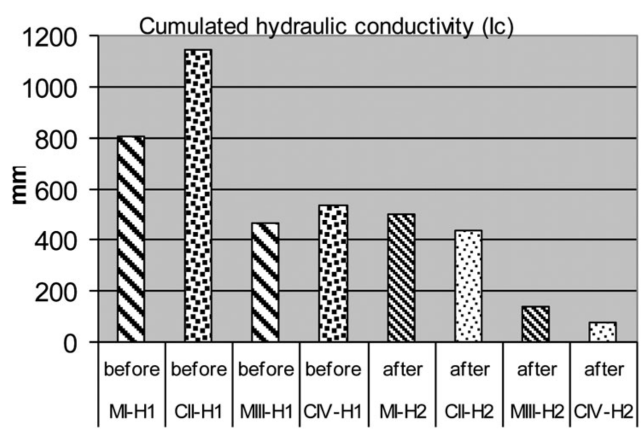

Figure 15. Cumulated hydraulic conductivity (Ic) in mm.

Table 9. Flow rate and hydraulic conductivity values found in the experimental station of Scafati (SA, Italy).

Treatments	Kfs mm h^{-1}	K(Vmean) mm h^{-1}	K(R) mm h^{-1}	Q(Kfs) L h^{-1}	Q(K(Vmean) L h^{-1}	Q(R) L h^{-1}
MI-H_1	312.05	393.60	241.92	22.06	27.82	26.14
CII-H_1	235.11	481.92	183.17	16.62	34.06	19.79
MIII-H_1	178.47	218.88	138.24	12.62	15.47	14.94
CIV-H_1	267.17	264.00	207.36	18.89	18.66	22.41
Mean M	245.26	306.24	190.08	17.34	21.65	20.54
Mean C	251.14	372.96	195.26	17.75	26.36	21.10
Mean	248.20	339.60	192.67	17.54	24.00	20.82
MI-H_2	152.76	181.74	131.98	10.80	12.85	14.26
CII-H_2	167.57	166.92	132.54	11.84	11.80	14.32
MIII-H_2	38.97	48.36	30.89	2.75	3.42	3.34
CIV-H_2	64.69	67.86	56.16	4.57	4.80	6.07
Mean M	95.86	115.05	81.43	6.78	8.13	8.80
Mean C	116.13	117.39	94.35	8.21	8.30	10.20
Mean	106.00	116.22	87.89	7.49	8.22	9.50

Table 10. Reported by Bianchi, 2003.

Type of soil	K mm h^{-1}	cm sec^{-1}	Granulometric categories
Very permeable	>150	>0.0042	Fine sand
Permeable	50÷150	0.0014÷0.0042	Fine sand
Middle permeable	15÷50	0.0004÷0.0042	Loamy sand+ fine sand
Moderately permeable	5÷15	0.0001÷0.0004	Loamy sand
Few permeable	1.5÷5	0.00004÷0.0001	Loam+loamy sand
Very few permeable	<1.5	<0.00004	Loam

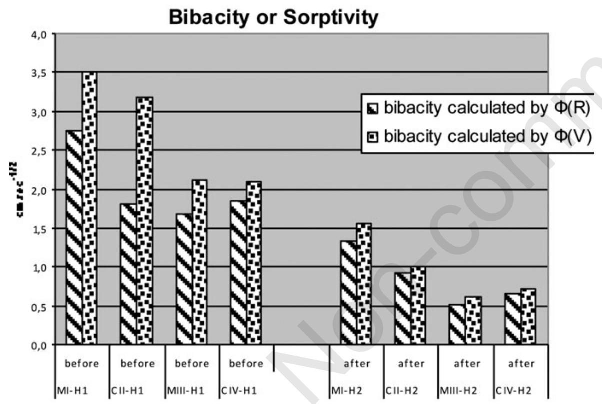

Figure 16. Bibacity (B) or sorptivity (S).

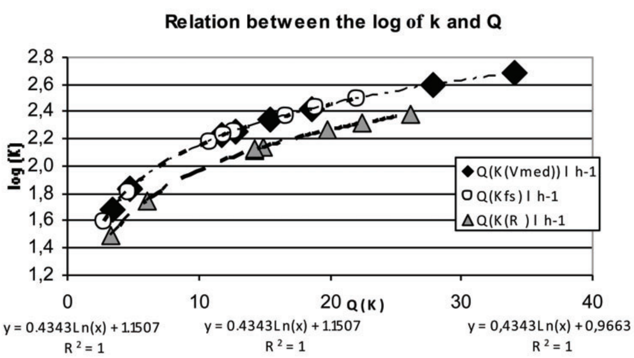

Figure 17. Relation between the hydraulic flow (Q) and log of saturated hydraulic conductivity (Ks).

This biomass stores a better water reserve and causes a lower avidity for water (bibacity) and a better speed of percolation of exceeding water, with considerable advantage for the plants. The results showed that the field was divided in two parts, having lower values in one part compared with the other one; for this reason it is relevant to examine the variation of saturated hydraulic conductivity along field.The organic matter used in the past, before this experience, decreased the variability of soil. In conclusion, the soil analysed showed to be almost permeable and did not have big problems in intensity rain of currently used sprinkler irrigation systems, even if it was present a large variation in field.

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