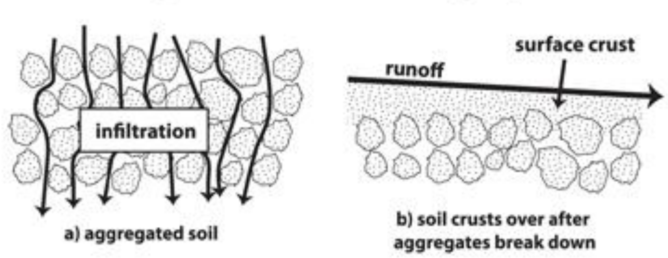
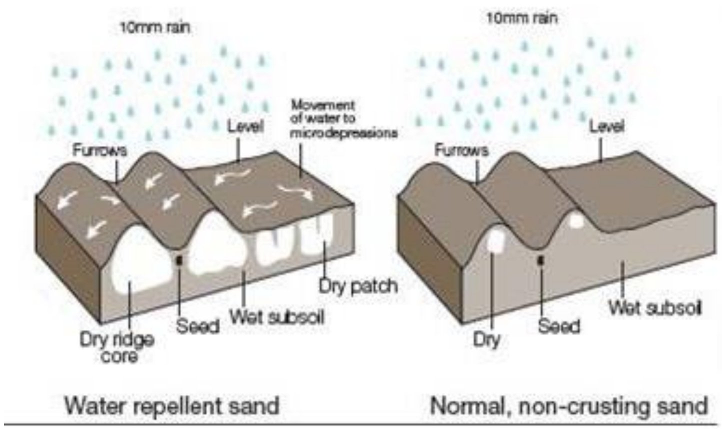
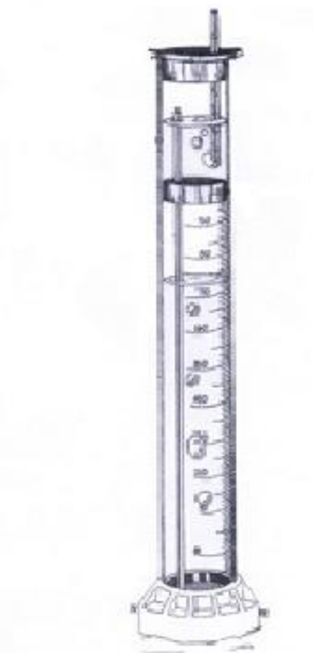
Influence of Soil Surface Sealing and Hydrophobicity on Water Infiltration







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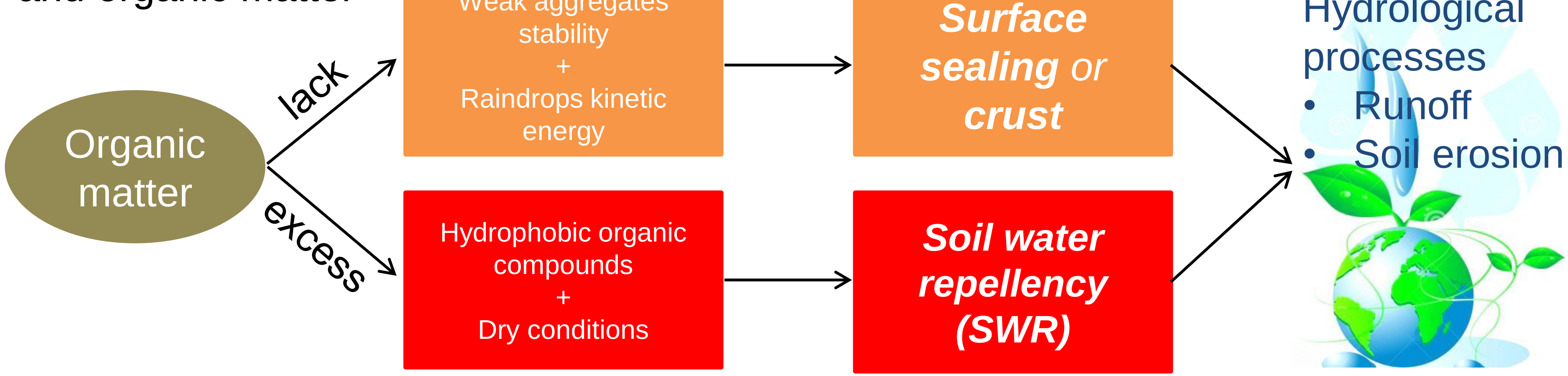
Problem definitions

Infiltration is the physical process involving downward movement of **water** through the boundary surface where the atmosphere interfaces with the soil. The phenomenon has many important implications:

- ✓ partition of rainfall between infiltration and runoff
- ✓ profile recharge rate
- ✓ solute transport

Furthermore, it is essential to agricultural production.

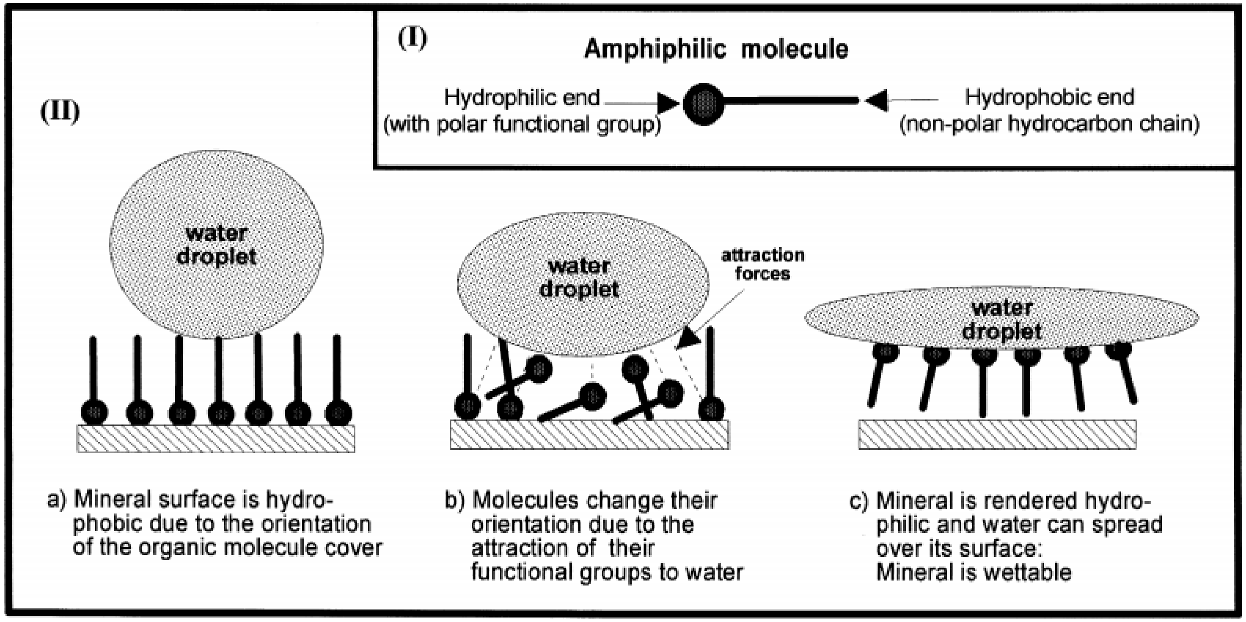
The unimpeded flow of water through the soil depends by its transmission properties which are related to soil texture and structure but also influenced by soil water content and organic matter



Problem definitions

- ✓ ***Sealing*** (or ***crust***) is a soil surface layer, ranging in thickness from a few millimeters to some centimeters, which is characterized by a greater density, higher shear strength, and lower hydraulic conductivity than the underlying soil.

- ✓ ***Hydrophobicity*** (or ***Soil Water Repellency***, *SWR*) is a surface property of soil particles due to their coating with hydrophobic organic compounds that reduces or prevents water infiltration into the soil.



Problem definitions
<u>Why this research</u>?

Soil hydraulic properties, i.e. the water retention curve and the hydraulic conductivity function, can be altered by the occurrence of the two phenomena.

Soil hydraulic characterization can be conducted both in laboratory and field but the use of field methods are mandatory on crusted or hydrophobic soils in order to accurately account for the effects of these two phenomena and evaluate the influence that they have on the infiltration process.

Several field infiltrometer techniques have been developed but the choice of the most appropriate measuring method depending on its peculiarities and on the phenomenon to be quantified.

Assessing the <u>negative impact of surface crust and SWR on hydrological processes</u> is particularly important in Mediterranean regions where the weather conditions are frequently extreme with hot and dry spells in summer time and high intensity rainfalls in autumn which <u>can cause flooding and soil erosion</u>.

Objectives

The main objective of the thesis was to estimate, through the use of infiltration measurements, how the occurrence of crusting and hydrophobicity affect soil hydraulic properties and water infiltration processes in Mediterranean areas

In particular:

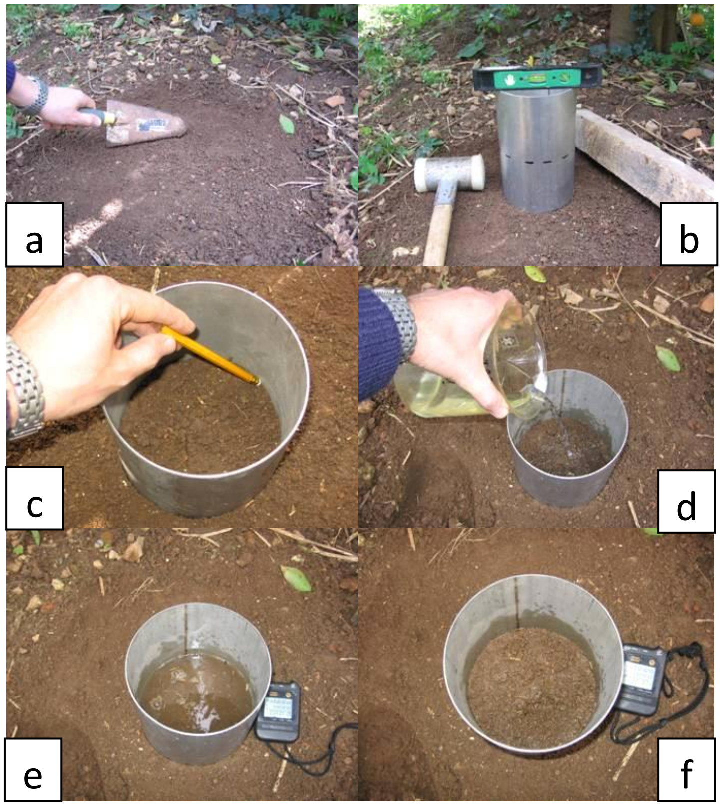
- ✓ for hydraulic characterization of crusted soils, different techniques were proposed, including, a simplified method, a simple approach using extemporaneous measurements, as well as indirect methods alternative to the most known procedures
- ✓ for hydrophobic soils, new indices based on infiltration experiments are proposed and validated as an alternative to traditional tests

Contents

Part A: Field infiltration experiments for soil hydraulic characterization

A. 1 Infiltrometer devices

The infiltration methods can be divided in **ponded** and **tension** infiltration techniques according to the specific devices used. These methods are engineered to monitor the cumulative volume of infiltrating water, *I* (L), into the porous media against the time, *t* (T).



BEST, SFH, BB


PI


TI


MDI

Theory

Philip's (1957) one-dimensional infiltration model

$$I = C_1\sqrt{t} + C_2 t \qquad (1)$$

Haverkamp et al. (1994) 3D infiltration equation

$$C_1 = S_0 \qquad (2)$$

$$C_2 = \frac{2-\beta}{3}K_0 + \frac{\gamma S_0^2}{r(\theta_0 - \theta_i)} \qquad (3)$$

$$I = S_0\sqrt{t} + \left[\frac{2-\beta}{3}K_0 + \frac{\gamma S_0^2}{r(\theta_0 - \theta_i)}\right]t \qquad (4)$$

- $S_0\sqrt{t}$ → Vertical capillary flow
- $\frac{2-\beta}{3}K_0$ → Gravity flow
- $\frac{\gamma S_0^2}{r(\theta_0 - \theta_i)}$ → Lateral capillary flow

Vandervaere et al. (2000) proposed two approaches for data linearization *Cumulative Linearization*, CL, and *Differentiated Linearization*, DL:

$$\frac{I}{\sqrt{t}} = C_1 + C_2\sqrt{t} \qquad (5)$$

$$\frac{dI}{d\sqrt{t}} = C_1 + 2C_2\sqrt{t} \qquad (6)$$

Beerkan estimation of Soil Transfer parameters (BEST)

van Genuchten (1980)

$$\frac{\theta - \theta_r}{\theta_s - \theta_r} = \left[1 + \left(\frac{h}{h_g}\right)^n\right]^{-m}$$

$$m = 1 - \frac{2}{n}$$

Brooks and Corey (1964)

$$\frac{K(\theta)}{K_s} = \left(\frac{\theta - \theta_r}{\theta_s - \theta_r}\right)^\eta$$

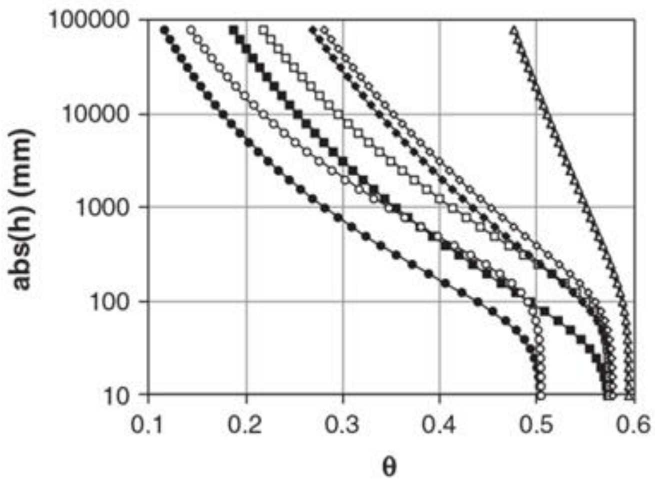
$$\eta = \frac{2}{m \times n} + 2 + p$$

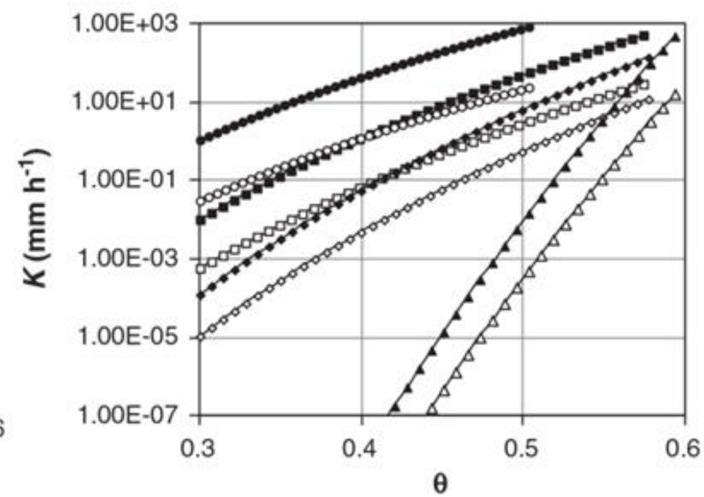
Shape parameters:

- n, m, η → PSD + pedotransfer function

Scale parameters:

- θ_s → ρ_b
- $h_g = -\dfrac{S^2(\theta_i, \theta_s)}{c_p(n, m, \eta)(\theta_s - \theta_i)\left[1 - \left(\dfrac{\theta_i}{\theta_s}\right)^\eta\right] K_s}$
- S, K_s → Infiltration experiment + Haverkamp eq.
- θ_r → 0





Although BEST procedure has recently received a wide interest by the scientific community however few comparisons with others infiltrometer techniques can be found in literature.

Objective

✓ Comparing the soil hydraulic properties predicted by BEST procedure with those obtained by other infiltrometer techniques

Results

Ten replicated infiltration runs at randomly selected points within a 150 m² area
BEST
PI
TI
MDI (20 replicated runs)
SFH
BB

Method	Mean duration (min)	Mean K_s (mm h^{-1})	CV (%)
TI	25	284.3	
MDI	6	236.9	
SFH	4	170.9	122.1
BB	51	131.6	98.7
BEST	25	111.5	114.3
PI	112	97.6	113.4

= **1.20**

Soil disturbance during the infiltration run

Duration of the run

Variability of K_s

Alagna, V., Bagarello, V., Di Prima, S., Iovino, M. (2016). Determining hydraulic properties of a loam soil by alternative infiltrometer techniques. Hydrol. Process, 30, 263–275

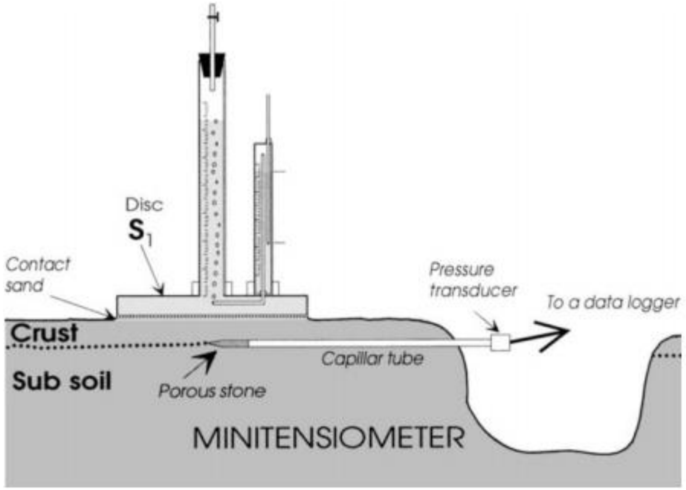
Part B: Effect of sealing process and surface crust on water infiltration

B. 1 Background

Hillel and Gardner (1969)

$$R_C = \frac{L_c}{K_c}$$

Vandervaere et al. (1997)

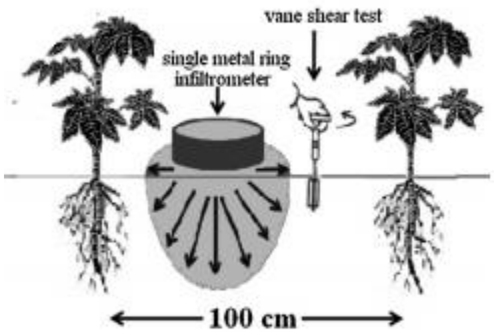


Insertion of minitensiometer may be difficult due to the fragility of the crust

Touma et al. (2011)

The two experiments do not sample the same area

Souza et al. (2014)



Part B: Effect of sealing process and surface crust on water infiltration

B. 2 A simple field method to measure the hydrodynamic properties of soil surface crust

Objective

✓ To develop and test a simplified method to determine the hydrodynamic properties of the surface crust

Procedure

- Knowledge of subsoil hydraulic properties *θ(h)*, *K(h)*
- MDI experiment on crust at $h_0=0$
- $K(h_s)$ of subsoil
- h_s of crust-subsoil interface inverting *K(h)* relationship

$$q_c = -K_c \frac{h_s}{L_c} = -\frac{h_s}{R_c}$$

$$q_s = K(h_s)$$

$$R_c = -\frac{h_s}{K(h_s)} \qquad R_c = -\frac{h_s - L_c}{K(h_s)}$$

Alagna, V., Bagarello, V., Di Prima, S., Giordano, G., Iovino, M. (2013). A simple field method to measure the hydrodynamic properties of soil surface crust. Journal of Agricultural Engineering 2013; XLIV(s2):e14. doi:10.4081/jae.2013.(s1):e14

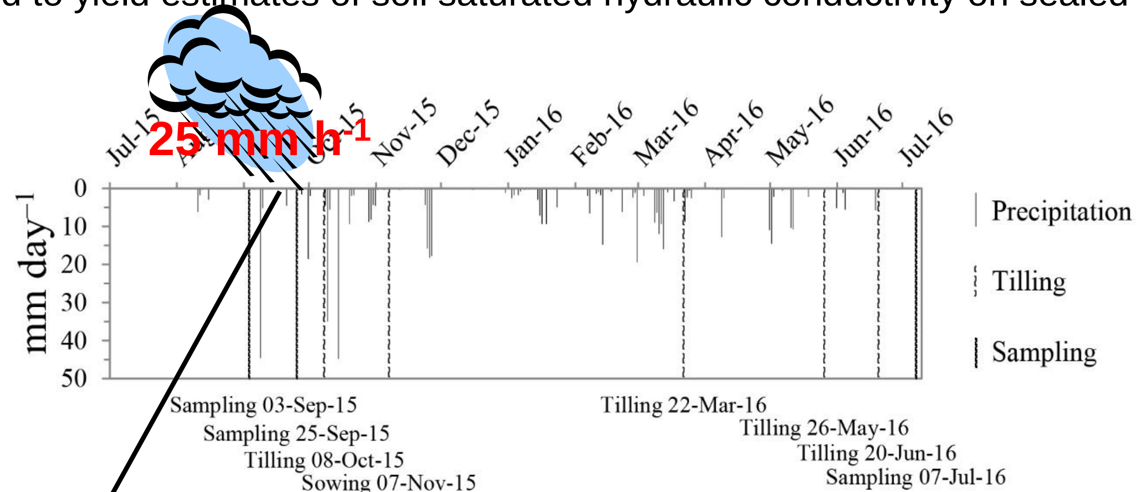
Results

	n	m	η	θ_{fs} ($m^3 m^{-3}$)	h_g (mm)	K_{fs} (mm h^{-1})	q_c (mm h^{-1})
site 1 sandy loam N = 11							
min	2.149	0.069	15.6	0.576	-180	193	390
max	2.159	0.074	16.4	0.649	-26	623	755
mean	2.154	0.071	16.0	0.615	-87	346	561
CV (%)	0.2	2.5	2.2	5.0	61.0	43.5	23.2
site 2 clay N = 15							
min	2.067	0.032	30.5	0.514	-886	14	117
max	2.073	0.035	33.0	0.622	-51	1777	200
mean	2.070	0.034	31.4	0.557	-241	731	147
CV (%)	0.1	2.4	2.3	5.8	118.0	86.6	18.7

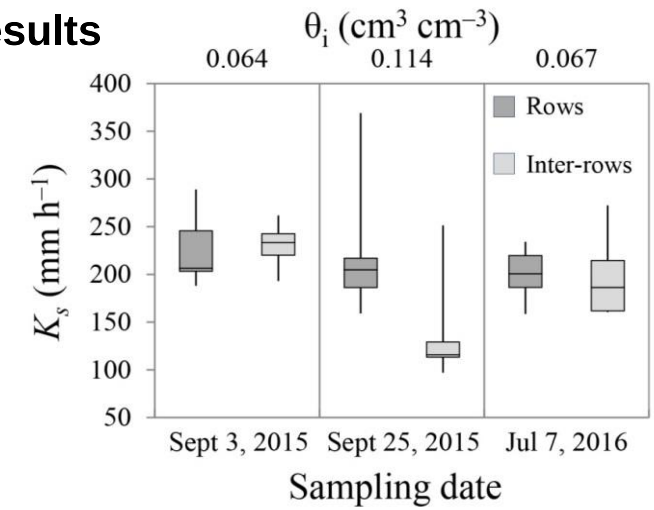
site 2 clay $q_c/K_{fs} < 1$	q_c/K_{fs}	h_s (mm)	L_c (mm)	R_c (h) — L_c negligible	K_c (mm h^{-1}) — L_c negligible	R_c (h) — L_c not negligible	K_c (mm h^{-1}) — L_c not negligible
N = 10							
min	0.09	-263	5	0.385	2.68	0.41	2.62
max	0.84	-77	7	2.241	12.97	2.29	12.18
mean	0.24	-180	6	1.312	5.77	1.35	5.53
CV (%)	97.6	35.5	11.1	47.8	53.5	47.0	51.9

Objective

- ✓ To check the ability of the BEST method to yield estimates of soil saturated hydraulic conductivity on sealed and non-sealed soils



Results



Sealed soil

K_s < 1.5 – 1.8

Alagna, V., Bagarello, V., Cerdà, A., Di Prima, S., Guaitoli, F., Iovino, M., Keesstra,S. (2016). Estimating hydraulic conductivity of a sealed loamy soil from Beerkan experiments in a Mediterranean vineyard. Under review on Soil-2016-79

Part B: Effect of sealing process and surface crust on water infiltration

B. 4 Testing infiltration run effects on the water transmission properties of a sandy-loam soil

The measurement and prediction of infiltration in crusted soils can be difficult, therefore identify procedures to investigate the development of surface sealing as a consequence of a perturbative event seems necessary.

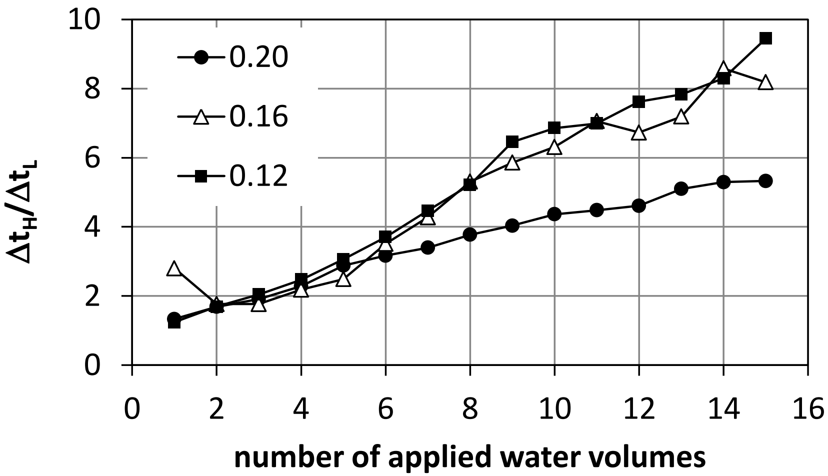
Objective

✓ To propose an indirect method to characterize the development of soil surface sealing by applying water with different energy levels at the soil surface

Twenty BEST infiltration experiments at randomly selected points within a 150 m² area

- Diameter of source 0.08 m
- Low runs, L, 0.03 m
- High runs, H, 1.50 m

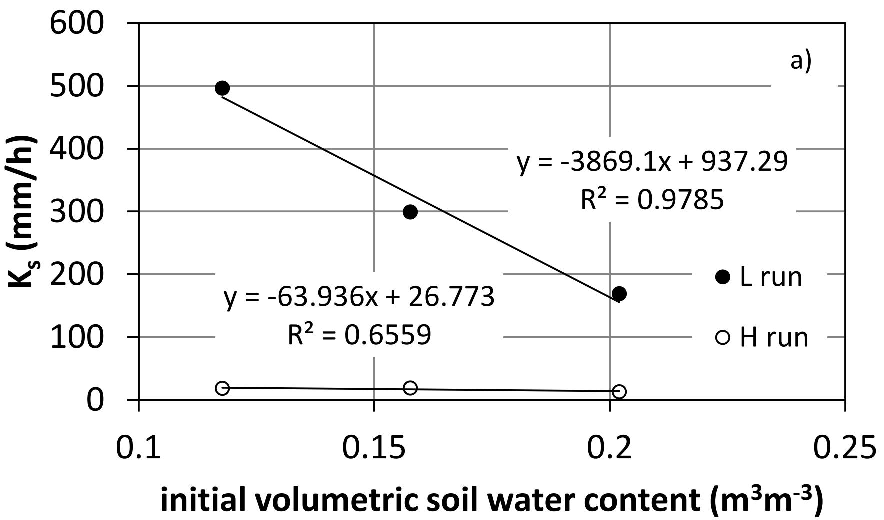
Results

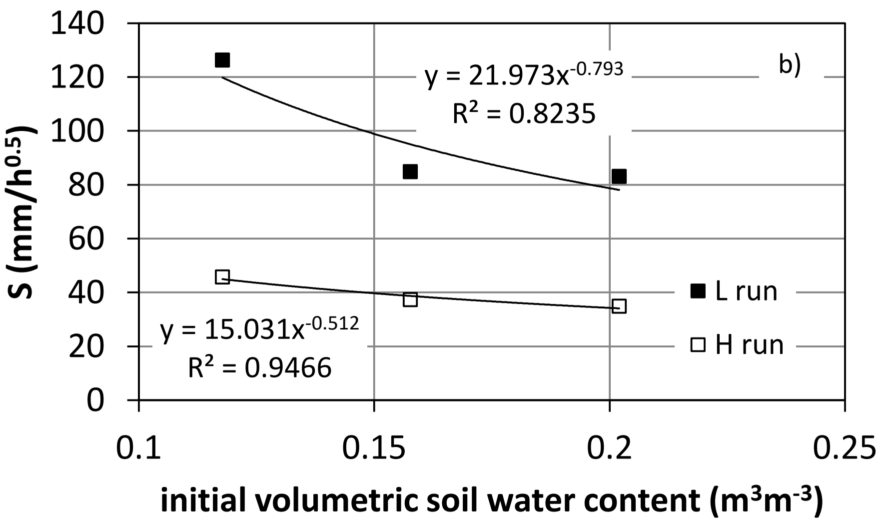


Ratio between the mean infiltration time for a water application height of 1.5 (Δt_H) and 0.03 (Δt_L) m during the BEST runs plotted against the number of the applied volumes of water

Δt_H increased more than Δt_L at each successive water application, supporting the hypothesis of a progressive deterioration of the infiltration surface with the repeated application of a given volume from a great height.

Alagna, V., Bagarello, V., Di Prima, S., Giordano, G., Iovino, M. (2016). Testing infiltration run effects on the estimated water transmission properties of a sandy-loam soil. Geoderma, 267, 24-33.





Effect of the initial volumetric soil water content on the mean values of a) the saturated soil hydraulic conductivity, K_s, and b) the soil sorptivity, S, for both the low (L) and high (H) infiltration runs

Results

Saturated soil hydraulic conductivity

- Height of water pouring had more appreciable effects on K_s in the initially drier soil conditions
- The perturbing experiment (high infiltration runs) reduced the dependence of K_s on the initial soil water content as compared with the low and less perturbing runs.

Soil sorptivity

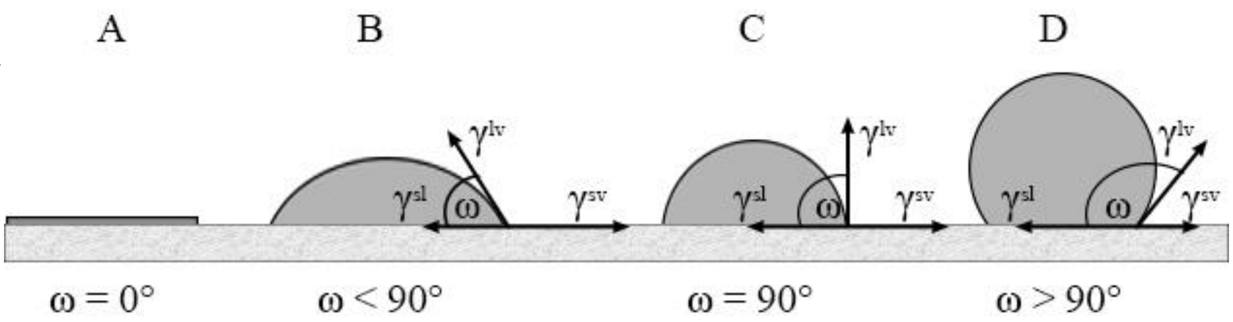
- In general, the variability for S was smaller than for K_s
- Low runs yielding higher values than the high ones and the differences were dependent on θ_i

Part C: Effect of water repellency on infiltration processes

C. 1 Background

The contact angle, ω, between the liquid and soil surface is defined by Young's equation (1855):

$$\cos\omega = \frac{\gamma^{sv} - \gamma^{sl}}{\gamma^{lv}}$$



Drop scale

- ✓ ***WDPT*** (s) (Van't Woudt, 1959) measures the ***persistence*** of water repellency by means a pure water droplet
- ✓ ***MED*** or ***EP*** (Letey, 1969) measure the ***degree*** of SWR. The test consists in finding the surface tension of the mixture water-ethanol which is able to wet a soil with contact angle of 90°.

Repellency class based on WDPT (s)	Bisdom et al., (1993)
Wettable	<5
Slightly repellent	5-60
Strongly repellent	60-600
Severely repellent	600-3600
Extremely repellent	>3600

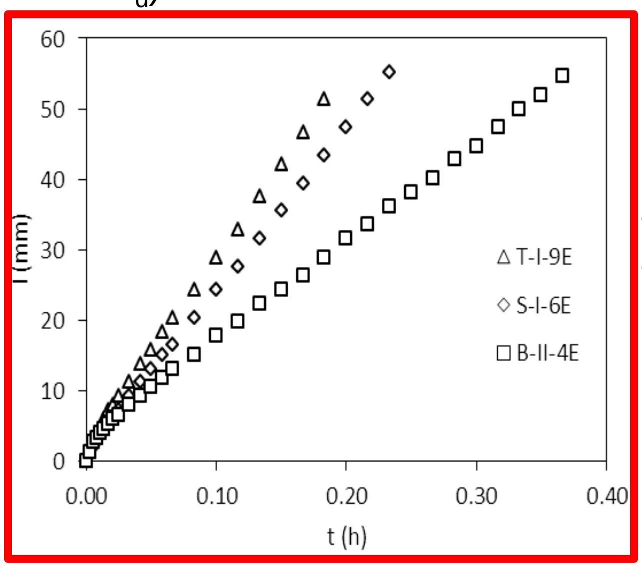
$$RI = 1.95\frac{S_e}{S_w}$$

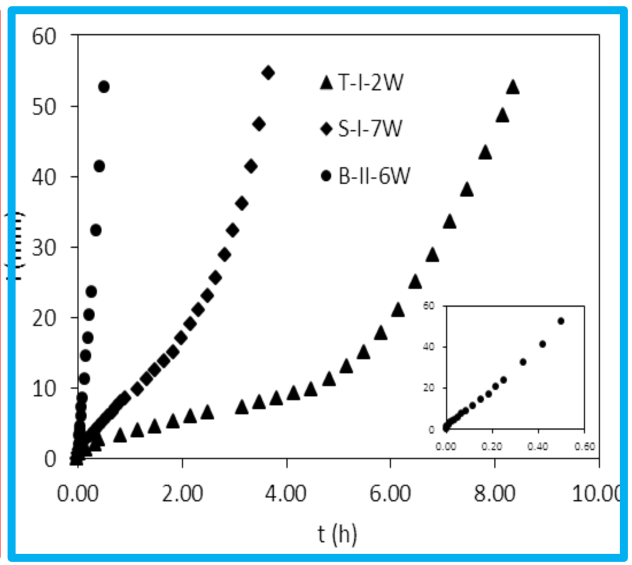
The repellency index, ***RI***, describes the **degree** of SWR and it can be estimated by the adjusted ratio between the soil-ethanol and soil-water sorptivities (S_e, S_w) (Tillmann et al., 1989)

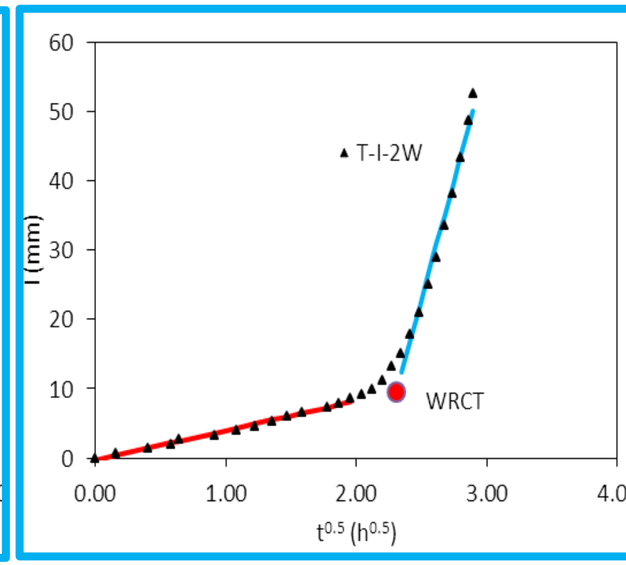
Soil sorptivity, *S*, is estimated as the slope of the straight line describing the cumulative infiltration, *I*, vs. the square root of the time, *t*, during the early stage of infiltration process (Philip, 1957)

- due to the effect of the antecedent soil water content *S* measurements cannot be conducted at the same site
- to account for spatial variability, S_e and S_w values should be averaged over a large number of sites (aggregated RI – RI_a)

Pekarova et al. (2015) proposed to consider the influence of spatial heterogeneity of soil properties by estimating the *m*×*n* values of RI obtained from the combination of *m* values of S_e and *n* values of S_w (distributed RI - RI_d)







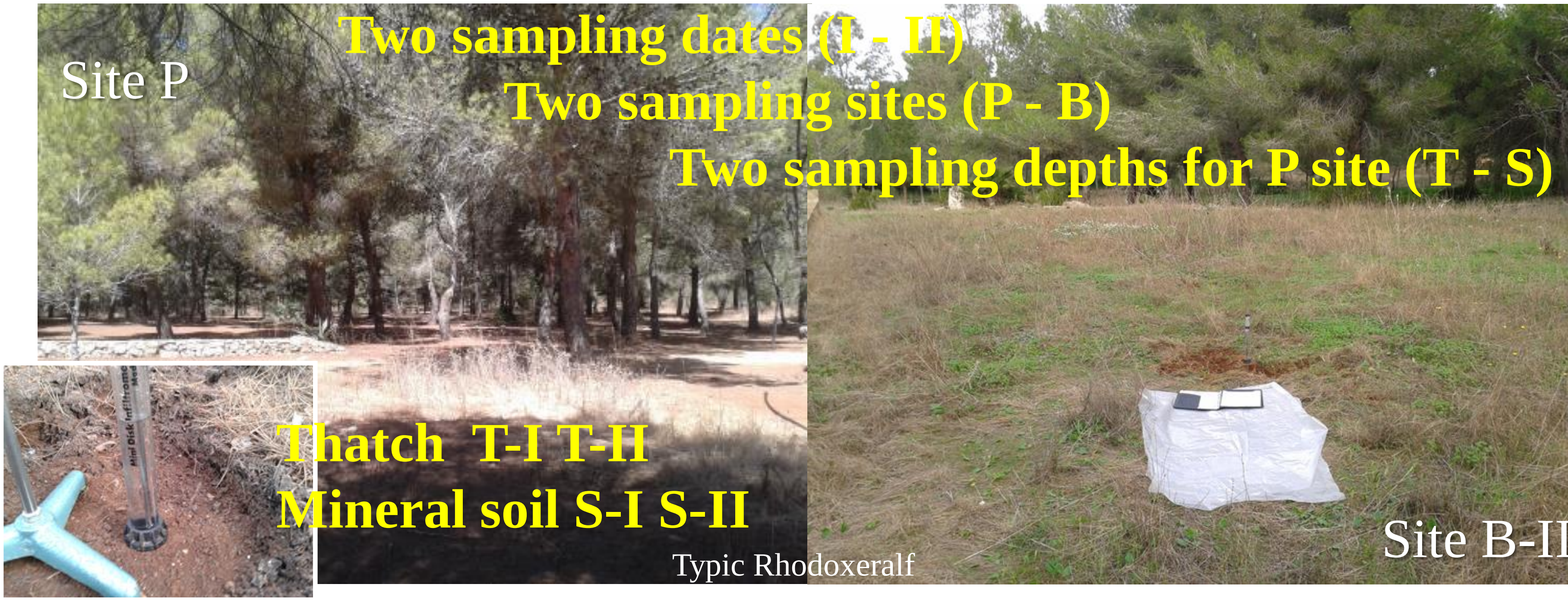
- Cumulative infiltration for ethanol tests in accordance to the infiltration theory
- Plots *I* vs. *t* for water exhibit an upward convex shape indicative of a reduction in water repellency as infiltration proceeds
- Plots *I* vs. $t^{0.5}$ show a clear "hockey-stick-like" shape (Lichner et al., 2013)
- Estimation of the Water Repellency Cessation Time (WRCT)

Part C: Effect of water repellency on infiltration processes

C. 2 Investigation on soil water repellency in a Mediterranean managed pine woodland

Objective

✓ To investigate the soil water repellency in a Mediterranean managed pine woodland at two sampling depths in the soil profile (thatch and mineral soil) and different water contents



- 20 replicated MDI runs (10 ethanol 95% V/V and 10 distilled water)
- 30 replicated WDPT (s)
- 10 undisturbed soil cores
- Scrubbed soil samples for OM determination

Clay loam (USDA classification)
30 years old Pinus pinaster

Alagna, V., Bagarello, V., Giordano, G., Iovino, M. (2016). Investigation on soil water repellency in a Mediterranean managed pine woodland. Quaderni di idronomia Montana, EdiBios, 34, 379-391

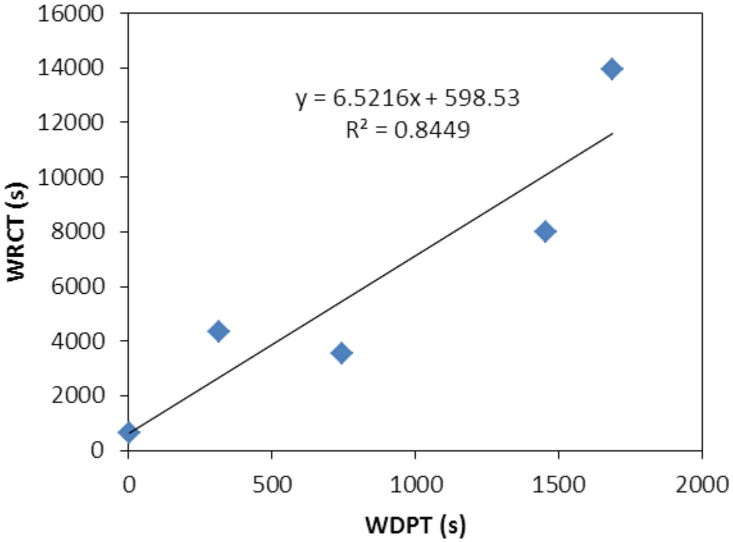
Part C: Effect of water repellency on infiltration processes

C. 2 Investigation on soil water repellency in a Mediterranean managed pine woodland

Results	T - I	T - II	S - I	S - II	B - II
Initial water content, θ_0 ($cm^3\ cm^{-3}$)					
GM	0.128 (a),(c)	0.175 (a),d	0.166 b,(c)	0.169 b,d,(e)	0.281 (e)
CV (%)	16.89	8.01	6.33	5.8	7.51
Organic matter content, OM (%)					
GM	20.03 a, (c)	21.48 a, (d)	4.66 (b),(c)	3.93 (b),(d),(e)	4.71 (e)
CV (%)	7.04	1.07	2.41	3.11	6.02
Water drop penetration time, WDPT (s)					
GM	1689 a,(c)	1454 a,(d)	317 (b),(c)	745 (b),(d)	<5
CV (%)	48.41	182.00	63.78	136.67	-
Water repellency cessation time, WRCT (s)					
GM	13933 (a),(c)	8007 (a),(d)	4344 b,(c)	3534 b,(d),(e)	631 (e)
CV (%)	25.35	49.34	44.98	56.40	21.48
Distributed repellency index, RI_d					
GM	55.12 (a),(c)	32.48 (a),(d)	6.10 (b),(c)	9.72 (b),(d),(e)	2.71(e)
CV (%)	68.82	69.74	70.52	54.61	26.11
Repellency index, RI, according to Tillman et al. (1989)					
	57.23	27.96	6.48	9.85	2.73

For a given variable, mean value followed by the same letter enclosed in parenthesis are significantly different according to a t-test (P = 0.95)

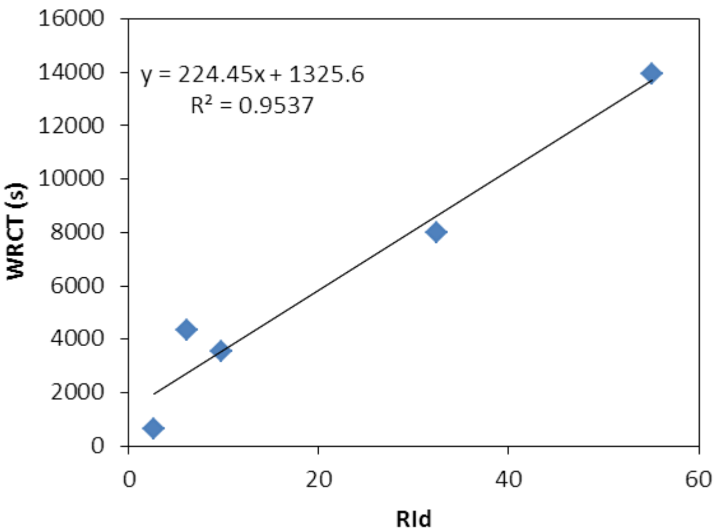
Results



Significant positive correlation between WDPT and WRCT → both are measurements of the persistence of SWR

The discrepancies between WRCT and WDPT were more pronounced for low values of SWR and decreased as hydrophobicity increased

- increased sensitivity of WRCT to detect weak SWR therefore it is more suitable to assess "sub-critical" conditions of water repellency

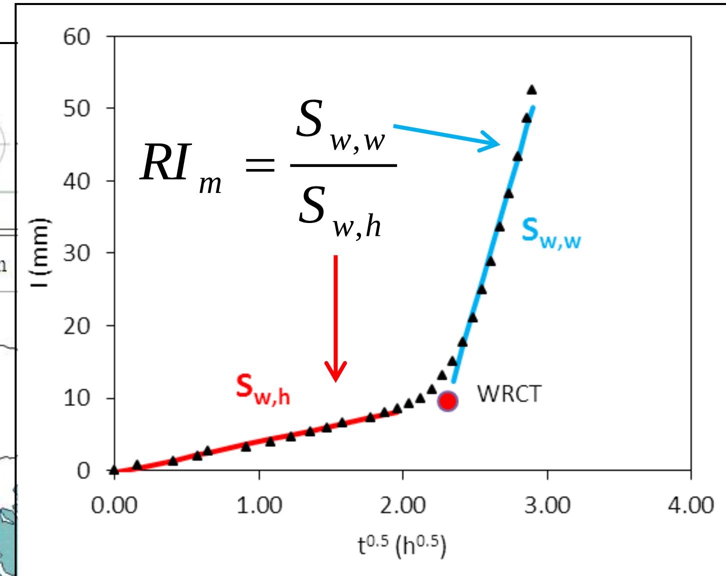


WRCT is suited for a «hydrological based» assessment of SWR

C. 3 Application of minidisk infiltrometer to estimate water repellency in Mediterranean pine forest soils

Objective

✓ To test alternative indices for assessing SWR from infiltration experiments conducted with the MDI using either ethanol and water or water alone



One sampling campaign at Javea

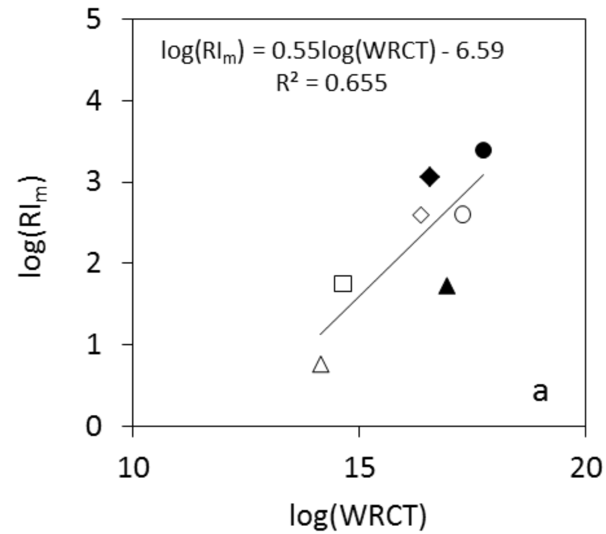
- *Silty clay (USDA classification)*
- *40 years old Pinus halepensis*

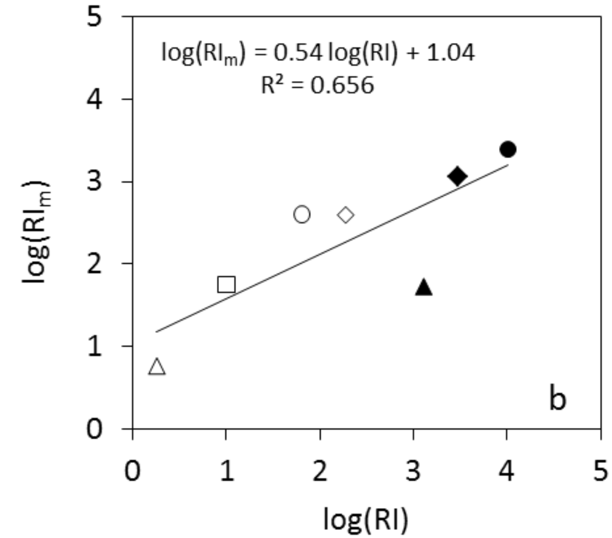
Alagna, V., Iovino, M., Bagarello V., Mataix-Solera, J., Lichner, Ľ. (2016). Application of minidisk infiltrometer to estimate water repellency in Mediterranean pine forest soils. Accepted by Journal of Hydrology and Hydromechanics, published online, DOI: 10.1515/johh-2017-0009

C. 3 Application of minidisk infiltrometer to estimate water repellency in Mediterranean pine forest soils

Results

	Ciavolo					Javea	
	CFO1	CFO2	CFM1	CFM2	CGM2	JFO1	JFM1
Water drop penetration time, WDPT (s)							
N	30	30	29	30	30	30	29
min	868	150	113	100		480	1
max	3534	6890	855	4425		7517	18
geometric mean	1689 a,(c)	1454 a,(d)	300 (b),(c)	745 (b),(d)	<5	2139 (e)	5 (e)
CV (%)	48.4	182.0	53.6	136.7		116.1	106.1
Water repellency cessation time, WRCT (s)							
N	10	9	10	10	10	10	10
min	9736	4653	2446	1701	479	2496	169
max	20204	13678	8502	8772	861	11250	761
geometric mean	13933 (a),(c)	8908 (a),(d)	4344 b,(c)	3534 b,(d),(e)	631 (e)	6268 (f)	386 (f)
CV (%)	25.4	35.3	45.0	56.4	21.5	64,2	54,2
Repellency index, RI (–)							
N	100	100	100	100	100	100	100
min	11.9	10.3	1.9	3.3	1.4	5.7	0.4
max	224.0	129.6	27.7	31.2	4.7	79.5	4.3
geometric mean	55.1 (a),(c)	32.5 (a),(d)	6.1 (b),(c)	9.7 (b),(d),(e)	2.7 (e)	22.4 (f)	1.3 (f)
CV (%)	68.8	70.5	69.7	54.6	26.1	63.7	64.8
Mean repellency index, RI (–), according to Tillman et al. (1989)							
	57.2	28.0	6.5	9.9	2.7	22.5	1.2
Modified repellency index, RI_m (–)							
N	8	10	10	8	10	10	9
min	16.8	6.3	6.9	10.4	4.6	2.8	1.7
max	60.3	57.3	23.2	17.8	7.9	14.2	3.6
geometric mean	29.7 a,(c)	21.3 a,(d)	13.5 b,(c)	13.4 b,(d),(e)	5.8 (e)	5.6 (f)	2.1 (f)
CV (%)	48.2	76.1	43.3	15.8	16.3	53.1	24.1





RI_m appears inherently more robust and less subjective than the estimation of a single point characterizing the transition from hydrophobic to wettable conditions as in the case of WRCT

Objective

✓ To establish the best applicative procedure to assess water repellency index from water/ethanol sorptivity measurements conducted by the MDI

Soil sorptivity, *S*, estimated from the Philip (1957) horizontal equation by the early-time linear regression of the *I* vs. $\sqrt{t}$ data neglects the effects of gravity and lateral capillary flux at the edge of the infiltration source.

An unbiased estimation of soil sorptivity is possible by fitting the two-term cumulative infiltration equation proposed by Haverkamp et al. (1994)

Different approaches to estimate S_e and S_w:

1. infiltration rate measured during the first minute of infiltration (S1 approach)
2. slope of the straight line describing the *I* vs. $\sqrt{t}$ relationship during the early stage of infiltration process according to Philip (1957) (SL approach);
3. intercept of the regression line fitting the linearized infiltration data in the form of $I/\sqrt{t}$ vs. $\sqrt{t}$ (CL approach)
4. intercept of the regression line fitting the linearized infiltration data in the form of $dI/d\sqrt{t}$ vs. $\sqrt{t}$ (DL approach).

Alagna, V., Iovino, M., Bagarello V., Mataix-Solera, J., Lichner, Ľ. (2016). Alternative analysis of transient infiltration experiment to estimate soil water repellency. Submitted to Hydrological Processes in 2016.

Results

Ethanol

		S1	SL	CL	DL
Sorptivity, S_e (mm $h^{-0.5}$)	N	85	85	84	84
	Min	10.2	10.9	0.4	0.7
	Max	163.0	128.4	61.7	68.4
	Mean	45.1a	37.8b	18.6c	19.0c
	CV	67.5	60.4	71.3	74.2

- S1 and SL approaches were statistically different according t-test
- CL and DL approaches were also applicable and they were not significant different
- S_e values estimated by CL and DL were lower than those obtained using S1 and SL approaches

Water

		S1	SL	CL	DL
Sorptivity, S_w (mm $h^{-0.5}$)	N	49	85	80	82
	Min	5.1	0.9	0.2	0.2
	Max	76.4	63.9	60.1	61.5
	Mean	18.0a	11.5b	9.0b	8.0b
	CV	93.8	115.6	133.1	147.3

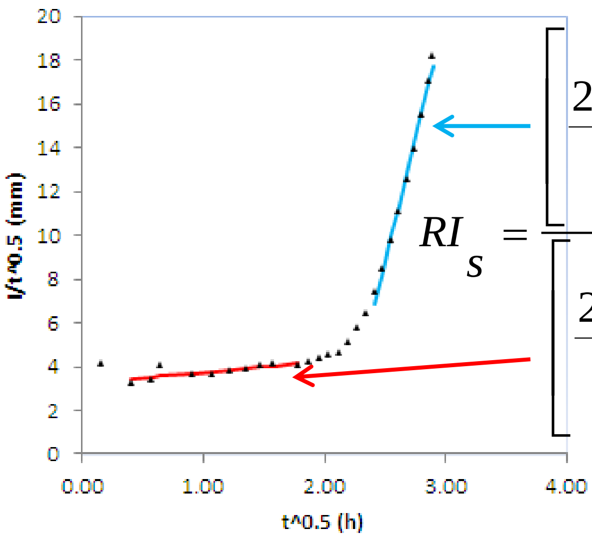
- In 42% of cases water flow out of the MDI did not start during the first 1 min
- In the remaining runs (49), *S* estimated by S1 approach was statistically different than other approaches
- SL approach yielded an overestimation of S_w but the mean values were statistically equivalent to those obtained by the CL and DL methods

RI index calculated according to Tillmann et al. (1989) tended to overestimate the SWR with SL approach particularly under sub-critical SWR conditions. The CL and DL yielded more similar estimates of RI and can therefore be considered more reliable

Part C: Effect of water repellency on infiltration processes

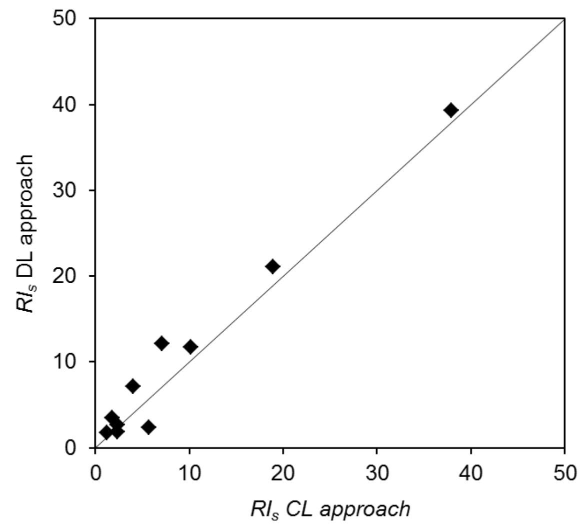
C. 4 Alternative analysis of transient infiltration experiment to estimate soil water repellency

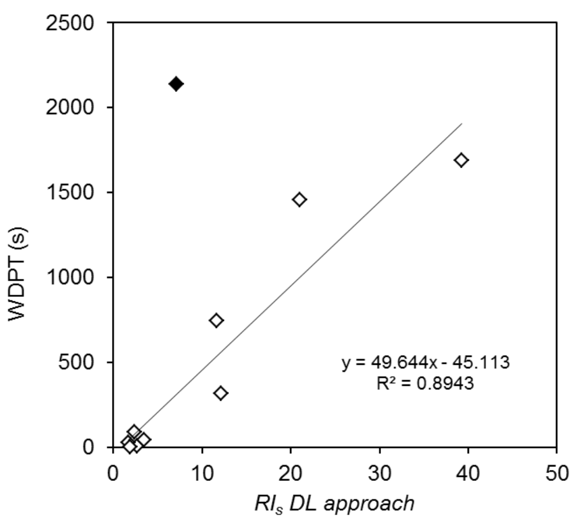
Proposal of a new repellency index RI_s



$$RI_s = \frac{\left[\dfrac{2-\beta}{3}K_w + \dfrac{\gamma S_w^2}{r\Delta\theta}\right]}{\left[\dfrac{2-\beta}{3}K_r + \dfrac{\gamma S_r^2}{r\Delta\theta}\right]}$$

Cumulative water infiltration data linearized in the form of both CL or DL approach, always showed a typical “hokey-stick-like” shape in repellent soils



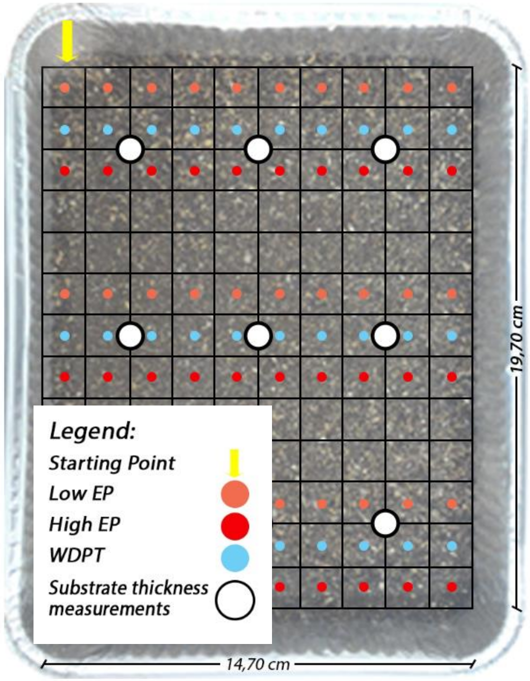


RI_s includes information on both sorptivity and conductivity measured in the wettable and repellent stages of the infiltration process and can be therefore considered more directly linked to the hydrological processes affected by soil water repellency.

Objective

✓ To compare the degree of SWR induced by reforestations with both exotic and native trees

Forest soil	Vegetation stand	Age of trees	OM (%)[a]
L	*Quercus ilex*	30	33.68 (1.1)
R	*Quercus pubescens*	40	33.13 (2.0)
P	*Pinus pinaster*	30-35	46.27 (1.0)
E	*Eucaliptus camaldulensis*	30-35	49.28 (2.8)



WDPT and EP tests were performed in order to:

- Explore the transition from hydrophobic to wettable conditions
- Investigate the effect of leaching of hydrophobic compounds

Alagna, V., Iovino, M., Bagarello V. (2016). Impact of reforestations with exotic and native species on water repellency of forest soils.

Results

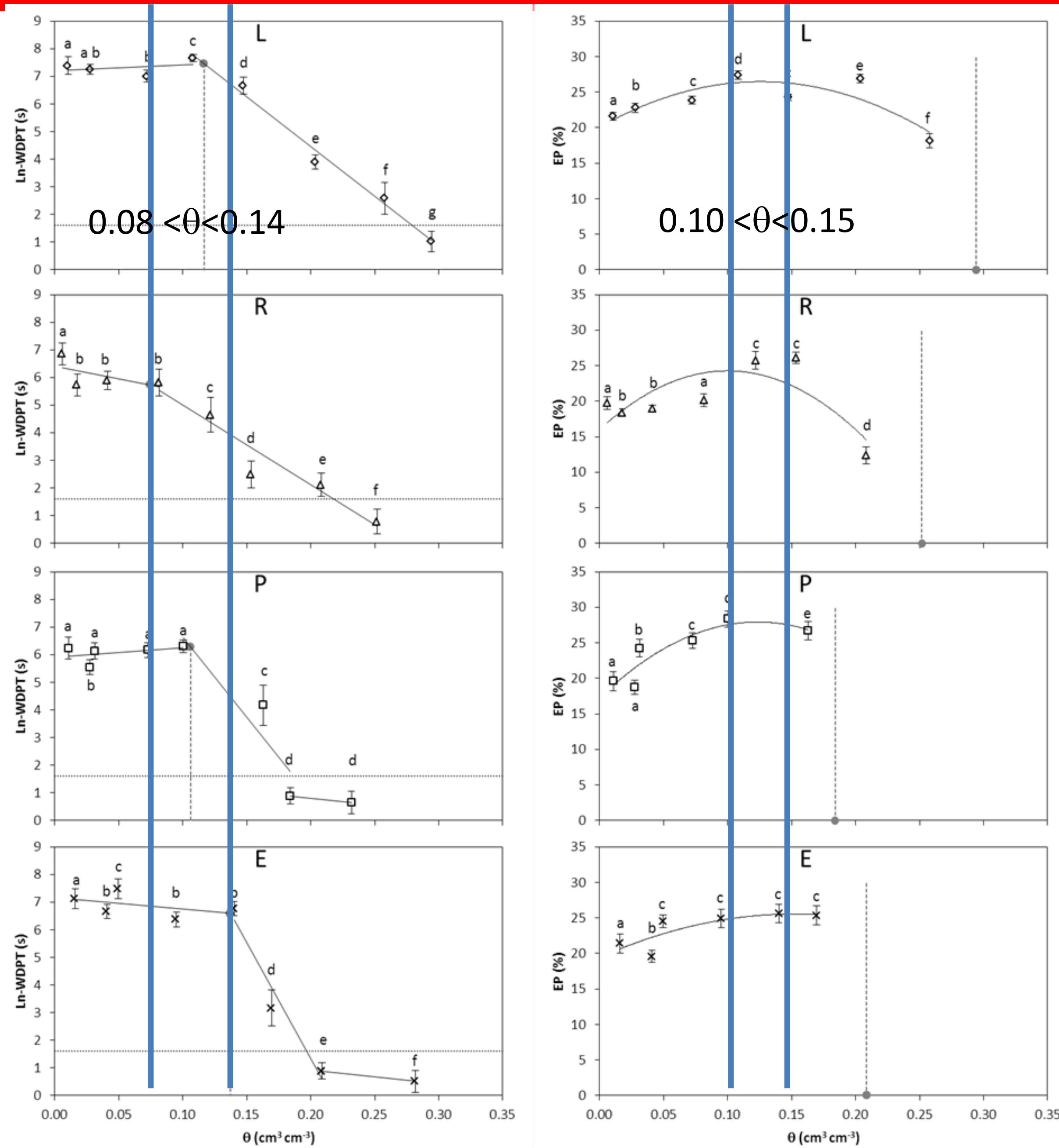
Transition from hydrophobic to wettable conditions

WDPT test

- For low of θ the Ln(WDPT) values were constant and independent by water content
- For θ > CWC hydrophobicity showed a transition zone and WR decreased linearly until the substrates become wettable
- Exotic trees (P and E) had CWCW values lower than those native species

EP test

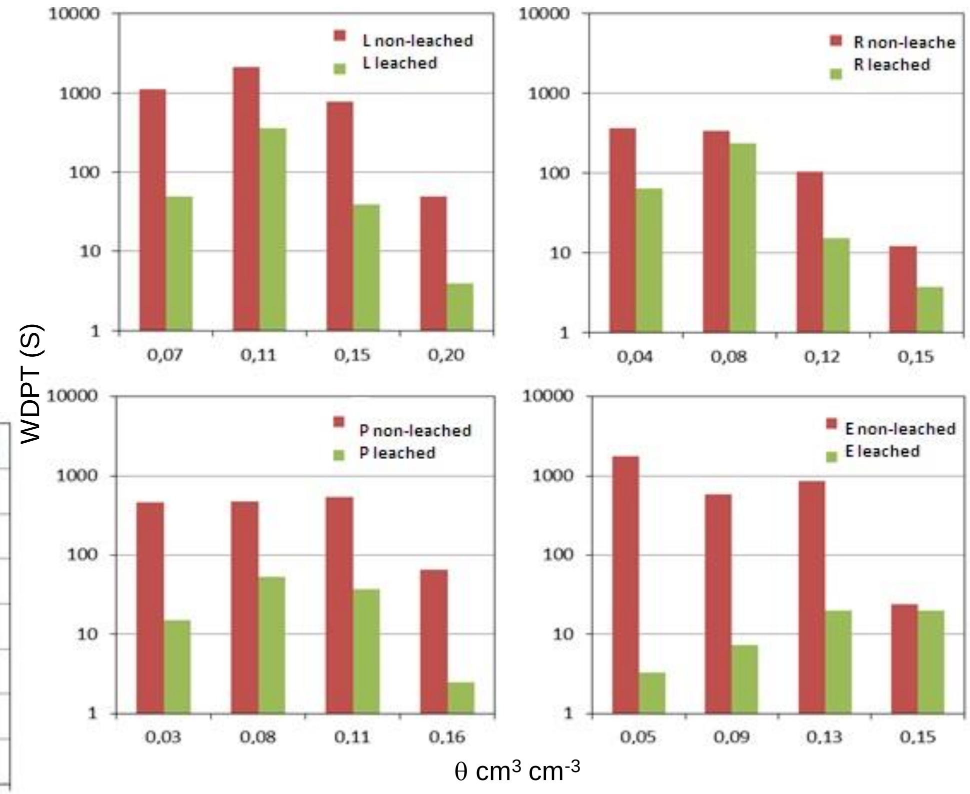
- The EP increased for 0<θ<0.15 cm^3 cm^{-3} with a significant differences compared to WDPT
- The severity of WR of exotic species vanished before than the native tree species confirming the findings obtained by WDPT test

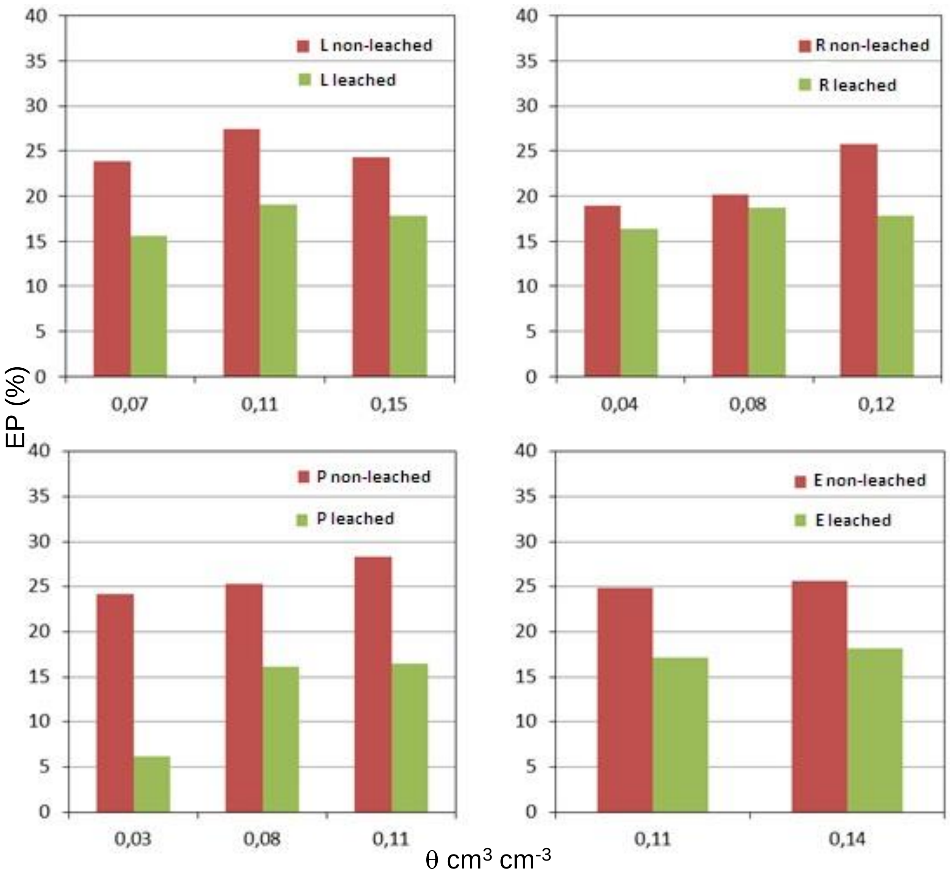


Results

Effect of leaching of hydrophobic compounds

- Generally, the persistence of WR always decreased after leaching. The treatment was less effective in R duff while in E duff the reduction of WDPT range from 50 to 500 times





- Leaching induced a more limited reduction of the degree of WR. In particular the ratio between EP in non-leached and leached duff samples varied between 1.1 and 4

Conclusions

- BEST method yields estimates of K_s statistically similar to those obtained by pressure infiltrometer, tension infiltrometer, minidisk infiltrometer, simplified falling head technique, and bottomless bucket method.
- The simplified method which uses a combination of two infiltrometer techniques (MDI and BEST) to determine the hydraulic resistance of the soil surface crust was able to discriminate between different levels of crust hydraulic resistance.
- The use of extemporaneous measurements carried out by a simple infiltrometer technique under ponded condition and application of the BEST procedure were capable to evaluate the influence of sealing on infiltration process.
- The perturbation determined by the high height of water pouring can be considered a viable approach to characterize the effect of water application on the development of sealing process which can affect the estimation of soil hydraulic properties.
- The hypothesis that the application of minidisk infiltrometer is a valid tool to estimate water repellency indices was demonstrated.
- The new index, RI_s obtained by a single MDI experiment carried out with water allow to identify sub-critical water repellency and to overcome the drawbacks of the RI index, therefore can be proposed as an alternative procedures for SWR assessment.

In conclusion, the field infiltration experiments applied in this thesis and the new procedures and indices proposed were able to evaluate the effects of sealing and hydrophobicity on infiltration process and, consequently, they are potentially suitable to assess their impact on hydrological behavior of the ecosystems affected by these phenomena.

However, new procedures and indices need to be further tested on other soil types and in different areas to confirm their reliability before they can be considered as a generally applicable techniques.

THANK YOU FOR YOUR ATTENTION