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Estimating hydraulic conductivity of a crusted loamy soil from beerkan experiments in a Mediterranean vineyard

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Abstract

In bare soils of semi-arid areas, surface crusting is a rather common phenomenon due to the impact of raindrops. Water infiltration measurements under ponding conditions constitute a common way for an approximate characterization of crusted soils. In this study, the impact of crusting on soil hydraulic conductivity was assessed in a Mediterranean vineyard (western Sicily, Italy) under conventional tillage. The BEST (Beerkan Estimation of Soil Transfer parameters) algorithm was applied to the infiltration data to obtain the hydraulic conductivity of crusted and uncrusted soils. Soil hydraulic conductivity was found to vary during the year and also spatially (i.e., rows vs. inter-rows) due to crusting, tillage and vegetation cover. A 55 mm rainfall event resulted in a decrease of the saturated soil hydraulic conductivity, K_s, by a factor close to two in the inter-row areas, due to the formation of a crusted layer at the surface. The same rainfall event did not determine a K_s reduction in the row areas (i.e., K_s reduced by a non-significant factor of 1.05) because the vegetation cover intercepted the raindrops and therefore prevented alteration of the soil surface. The developed ring insertion methodology on crusted soil, implying pre-moistening through the periphery of the sampled surface, together with the very small insertion depth of the ring (0.01 m) prevented visible fractures. Consequently, beerkan tests carried out along and between the vine-rows and data analysis by the BEST algorithm allowed to assess crusting-dependent reductions in hydraulic conductivity with extemporaneous measurements alone. Testing the beerkan infiltration run in other crusted soils and

establishing comparisons with other experimental methodologies appear advisable to increase confidence on the reliability of the method, that seems suitable to allow simple characterization of crusted soils.

Keywords: Hydraulic conductivity, water infiltration measurements, soil surface crust, vineyard, BEST procedure

1. Introduction

The impact of raindrops on a bare soil surface can result in physical and chemical changes of the exposed soils. The mechanical alteration of the upper soil aggregates, expressed in terms of compaction, splash and particle detachment, contribute to form a surface crust (Assouline, 2004). This type of crust, named structural crusts, differ from depositional crusts (West et al., 1992), which are formed by deposition of detached, fine particles carried out in suspension by runoff (Fox and Le Bissonnais, 1998). The hydraulic properties of crusts vary significantly (Fox et al., 1998a, 1998b). Different physical rainfall properties may be related with structural crust development, such as intensity (Baumhardt et al., 1990; Freebairn et al., 1991; Morin and Benyamini, 1977), kinetic energy (Eigel and Moore, 1983; Mohammed and Kohl, 1987) and momentum (Brodie and Rosewell, 2007; Rose, 1960). The initial or wetting phase in crust formation is defined as surface sealing (Römkens, 1979). During the drying cycle, this layer consolidates and may differ from the wetting phase in its mechanical and hydraulic properties (Mualem et al., 1990). This drying phase is known as crusting (Römkens, 1979).

The hydrodynamic properties of such a layered system (crust layer, underlying soil) may severely affect the partition between infiltration and runoff at the soil surface, especially in arid and semi-arid areas where crusting is a common phenomenon (Angulo-Jaramillo et al., 2016). Water infiltration measurements constitute a common way for an indirect characterization of sealed/crusted soils (Alagna et al., 2013; Bedaiwy, 2008). The Beerkan Estimation of Soil Transfer (BEST) parameters procedure developed by Lassabatere et al. (2006) is a very attractive method for practical use since it allows an estimation of both the soil water retention and hydraulic conductivity functions. The BEST method focuses specifically on the van Genuchten (1980) relationship for the water retention curve with the Burdine (1953) condition and the

Brooks and Corey (1964) relationship for hydraulic conductivity. BEST estimates shape parameters, which are texture dependent, from particle-size analysis by physical-empirical pedotransfer functions, and scale parameters from beerkan experiments (Haverkamp et al., 1996), i.e. three-dimensional (3D) field infiltration experiments at ideally zero pressure head. BEST substantially facilitates the hydraulic characterization of unsaturated soils, and it is gaining popularity in soil science (Bagarello et al., 2014a; Castellini et al., 2016; Di Prima, 2015; Di Prima et al., 2016b; Gonzalez-Sosa et al., 2010; Mubarak et al., 2010). Alternative algorithms, i.e., BEST-slope (Lassabatere et al., 2006), BEST-intercept (Yilmaz et al., 2010) and BEST-steady (Bagarello et al., 2014b), and field procedures based on BEST method were developed (Alagna et al., 2016; Bagarello et al., 2014c; Di Prima et al., 2016a). The ability of the BEST method to distinguish between crusted and non-crusted soils was demonstrated by Souza et al. (2014). Moreover, Di Prima et al. (2016a) successfully applied a beerkan experiment involving different heights of water pouring on the infiltration surface to explain surface runoff and sealing generation phenomena occurring during intense rainfall events. These authors concluded that if any seal forms at the surface, the beerkan infiltration test should detect its impact on flow and BEST estimates should essentially indicate the hydraulic properties of the surface layer. In fact, the BEST method was developed for non-layered soils that are assumed to be uniform and have a uniform soil water content at the beginning of the infiltration run (Lassabatere et al., 2006, 2009) and should not contain a macropore network (Lassabatere et al., 2014). However, completely homogeneous soils are very rare in natural environments (Reynolds and Elrick, 2002). Therefore, the hydraulic conductivity obtained by an infiltrometer method, such as BEST, should probably be considered as an equivalent conductivity, i.e. the conductivity of a rigid, homogeneous and isotropic porous medium characterized by infiltration rates that are the same as those actually measured on the real soil (Bagarello et al., 2010). For the case of stratified media, the layer with the lowest hydraulic conductivity generally controls the flow and consequently cumulative infiltration at the surface (Alagna et al., 2013). Therefore, water infiltration data can be regarded as representative of the hydraulic behavior of the least permeable layer, and therefore the derived BEST parameters can be assigned to this layer. This approach was proposed by Lassabatere et al. (2010) for a stratified medium with a low permeability sedimentary layer at the surface, by Yilmaz et al. (2010, 2013), for the characterization of crusted reactive materials, and, recently, by Coutinho et al. (2016) for a permeable pavement for stormwater management in an urban area.

In this paper we tested the BEST method in an agricultural setting with general objective to carry out a hydraulic characterization of a loamy soil in a vineyard under conventional tillage located at Marsala (western Sicily, Italy). In particular, both row and inter-row areas were sampled since a crust layer only developed in the latter area. Therefore, the specific objective was to check the ability of the BEST method to yield plausible estimates of saturated hydraulic conductivity of crusted and non-crusted soils.

2. Material and methods

2.1. Study site

The experimental site is located close to Marsala (western Sicily, Italy), in the homeland of Sicilian viticulture (37°48'5.10" N and 12°30'44.79" E). Elevation is 111 m a.s.l. and soil surface is flat. The soil is a typic Rhodoxeralf with a depth of 1 m and a small amount of gravel. According to the USDA classification, the soil texture, determined on two replicated soil samples, is loam (**Table 1**). A weather station is located 5 km away from the sampling site (37°79'35.64"N and 12°56'81.59"E). It is positioned at the same elevation as the sampling site and it is part of a network of stations managed by Servizio Informativo Agrometeorologico Siciliano –SIAS.

At the sampling site, the common soil management for the vineyards of Marsala was applied during the two years of sampling (2015 and 2016) (**Figure 1**). The soil is tilled to a depth of 0.10-0.15 m in October, after the first autumn rainfalls. Faba bean (*Vicia faba* L. var. *minor*) is sown in November between the rows. In March, the legume biomass is cut and immediately incorporated into the soil with a rotary tiller to a depth of 0.20 m. Finally, a new rotary tillage is performed in May and, only for the second year, this was also done in June. This soil management practice is applied between the rows. Along the rows, a mechanical topper is used at each soil tillage date to a depth of 0.10 m.

2.2. Soil sampling

An area of approximately 100 m^2 was sampled on three different sampling campaigns covering two growing seasons. The first two campaigns were carried out at the beginning and the end of September 2015, respectively, and the third campaign was performed at the beginning of July 2016. Between the first two sampling campaigns, the soil was not tilled and a total rainfall of 55 mm fell (**Figure 1**), which is

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approximately 10% of the average annual precipitation for the area. In particular, a 29-mm event occurred during the morning of 9 September, with a maximum recorded intensity of 25 mm h^{-1}. During the same day, a total of 44.6 mm of precipitation was recorded. This rainfall led to the development of a weak but clearly detectable surface crust (thickness of ~4 mm) (**Figure 2**). This phenomenon was only observed between the rows and not along the rows. The second sampling was done one week after the last rainfall event. Finally, a third sampling campaign was carried out during the following dry season in order to sample the soil after the ordinary tillage practices and with moisture conditions comparable to the first sampling date.

On each sampling date, a total of 10 undisturbed soil cores (5 cm in height by 5 cm in diameter) were collected at the soil surface close to the points where the infiltration tests were performed, 5 along the rows and 5 between the rows. These cores were used to determine the dry soil bulk density, ρ_b (g cm^{-3}), and the soil water content at the time of the experiment, θ_i (cm^3 cm^{-3}). The soil porosity was calculated from the ρ_b data, assuming a soil particle density of 2.65 g cm^{-3}. A disturbed soil sample (0–10-cm depth), collected both along and between the rows, was used to determine the particle size distribution (PSD), using conventional methods (Gee and Bauder, 1986). Fine size fractions were determined by the hydrometer method, whereas the coarse fractions were obtained by mechanical dry sieving. The clay, silt and sand percentages were determined from the measured PSD according to the USDA standards.

2.3. Beerkan experiments

For each sampling date, an area of approximately 100 m^2 was chosen and 14 beerkan infiltration runs (Lassabatere et al., 2006) were carried out using a 15 cm inner-diameter ring. Seven runs were carried out along the rows and seven on the bare inter-rows area (**Figure 3**). The steel ring was positioned between two vine stocks along the row and in the same orthogonal direction between the rows. The ring was inserted to a depth of about 0.01 m into the soil surface to avoid lateral loss of the ponded water. On crusted soil, to prevent fracture of the upper layer during ring insertion, the soil outside the hedge of the ring was moistened with 5 cm^3 of water by means of a syringe before insertion. After ten minutes, the ring was carefully inserted to the pre-established short depth applying a slight pressure and a gentle rotation. This site preparation was essential to prevent crust surface perturbation.

According to the guidelines by Lassabatère et al. (2006), for each run a known volume of water (150 mL) was poured in the cylinder at the start of the experiment and the elapsed time during its infiltration was measured. When the amount of water had completely infiltrated, another identical volume of water was poured on the confined infiltration surface and the time needed for the complete infiltration was logged. The procedure was repeated 15 times for each run by applying water at a small distance (3 cm of height) from the infiltration surface. As is commonly suggested in practical application of a ponding infiltration method, the energy of the water due to the application was dissipated on the fingers of a hand in order to minimize soil disturbance (Reynolds, 2008).

Di Prima et al. (2016b) showed that all BEST algorithms, i.e. BEST-slope, BEST-intercept and BEST-steady, led to similar results in most cases. However, BEST-slope appeared to yield more accurate estimates, especially of the saturated soil hydraulic conductivity, K_s (mm h^{-1}), but it was affected by a failure rate higher than others algorithms (Bagarello et al., 2014b). In this study, such a problem did not occur and, therefore, the BEST-slope algorithm (Lassabatere et al., 2006) was considered to estimate the whole set of parameters of the hydraulic conductivity function. BEST focuses specifically on the Brook and Corey (1964) relationship:

$$\frac{K(\theta)}{K_s} = \left(\frac{\theta - \theta_r}{\theta_s - \theta_r}\right)^{\eta} \qquad (1)$$

where K (L T^{-1}) is the soil hydraulic conductivity, θ (cm^{3}cm^{-3}) is the volumetric soil water content, θ_r (cm^{3}cm^{-3}) is the residual volumetric soil water content, θ_s (cm^{3}cm^{-3}) is the saturated volumetric soil water content, and η is a shape parameter linked to the soil textural properties. In BEST, η is estimated from the analysis of the PSD with the pedotransfer function included in the procedure, whereas θ_s, θ_r and K_s are scale parameters. BEST considers θ_r to be zero, and θ_s was assumed to coincide with soil porosity in this investigation, as suggested by many authors (Bagarello et al., 2011; Di Prima, 2015; Di Prima et al., 2016a; Mubarak et al., 2010; Xu et al., 2009). In particular, Di Prima et al. (2016a) demonstrated that the assumed coincidence between saturated soil water content and porosity did not practically affect the K_s estimation.

BEST-slope estimates sorptivity, S (mm h$^{-0.5}$), by fitting the experimental cumulative infiltration data on the explicit transient two-term equation by Haverkamp et al. (1994):

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$$I(t) = S\sqrt{t} + \left[A(1-B)S^2 + B\, i_s\right] t \tag{2}$$

where I (mm) is 3D cumulative infiltration and t (h) is the time. Then, K_s (mm h^{-1})is estimated as a function of S as follow:

$$K_s = i_s - AS^2 \tag{3}$$

where i_s (mm h^{-1}) is the experimental steady-state infiltration rate, which is estimated by linear regression analysis of the last data points describing steady-state conditions on the I vs. t plot and corresponds to the slope of the regression line. The constants A (mm^{-1}) and B can be defined for the specific case of a Brooks and Corey relation (Eq. 1) and taking into account initial soil water content, θ_i (cm^{3}cm^{-3}), as (Haverkamp et al., 1994):

$$A = \frac{\gamma}{r(\theta_s - \theta_i)} \tag{4a}$$

$$B = \frac{2-\beta}{3}\left[1-\left(\frac{\theta_i}{\theta_s}\right)^{\eta}\right] + \left(\frac{\theta_i}{\theta_s}\right)^{\eta} \tag{4b}$$

where γ (parameter for geometrical correction of the infiltration front shape) and β are coefficients that are commonly set at 0.75 and 0.6 for $\theta_i < 0.25\,\theta_s$, and r (mm) is the radius of the source.

2.4. Data analysis

Data sets were summarized by calculating the mean, M, and the associated coefficient of variation, CV. In particular, the cl, si, sa, ρ_b, θ_s values were considered site specific and therefore they were determined only in duplicate (cl, si, sa, N = 2) or, considering their low variability (ρ_b, θ_s), the arithmetic mean and the associated CV were calculated (**Table 1**). Temporal variability of θ_i was determined on the basis of ten replicate samples on each sampling date (**Table 2**). The K_s data were assumed to be log-normally distributed since the statistical distribution of these data is generally log-normal (Lee et al., 1985; Warrick, 1998). The geometric mean and the associated CV were therefore calculated to summarize K_s values using the appropriate ‘‘log-normal equations” (Lee et al., 1985). Statistical comparison between two sets of data was conducted using two-tailed t-tests, whereas the Tukey Honestly Significant Difference test was applied to compare three sets of data. The ln-transformed K_s data were used in the statistical comparison. A probability level, P = 0.05, was used for all statistical analyses.

3. Results and discussion

In this paper, the BEST method was applied in an agricultural setting. In particular, the hydraulic properties of a loamy soil were determined in a vineyard under conventional tillage located at Marsala (western Sicily, Italy). The investigation was specifically aimed at checking the ability of the BEST method to yield plausible estimates of saturated hydraulic conductivity of crusted and non-crusted soils, since a limited experimental information is still available in the scientific literature (Souza et al., 2014). Consequently, both row and inter-row areas were sampled since a crust layer developed only in the latter portion of the field site. The 42 infiltrations runs were analyzed with the BEST-slope algorithm, yielding positive K_s values in all cases. In addition, the fitting of the infiltration model to the transient phase of the infiltration run always yielded relative errors lower than 5.5% (Lassabatere et al., 2006), denoting an acceptable error for transient cumulative infiltration (**Figure 4**).

3.1. Impact of surface crusting on hydraulic conductivity in vineyards

During the second field campaign, the crust layer only affected water infiltration between the rows (**Table 3**), suggesting that the protective role of vegetation along the rows was effective. The cover intercepted raindrop energy preventing surface sealing (Dunne et al., 1991). The protective role along the vine-rows is well known, while in vine inter-rows the mulching practice is commonly applied to protect soil from raindrop impact (Celette et al., 2008; Prosdocimi et al., 2016). For the second campaign, the mean K_s value obtained between the rows was 1.6 times lower than the one obtained along the rows (**Figure 5**). In particular, this latter value, equal to 212.4 mm h^{-1}, did not significantly differ from those of the first and third sampling dates (**Table 3**). On the other hand, during these last two campaigns, beerkan runs carried out along and between the rows also yielded similar K_s values, due to the absence of a crust between the rows. This experimental information suggested that the crusting occurrence, the adopted soil management and the cover influenced both the temporal and the spatial variation of the soil hydrological characteristics at the field-scale.

Bradford et al. (1987) reported for 20 soils (varying in texture from sand to clay) a reduction in infiltration rate after 60 min of simulated rainfall (intensity of 63 mm h^{-1}), due to the effect of surface sealing on infiltration. Bagarello et al. (2014c), Alagna et al. (2016) and Di Prima et al. (2016a) applied on five soils having different texture a BEST derived procedure to explain surface runoff and disturbance phenomena at the soil surface occurring during intense rainfall events. These authors reported saturated hydraulic conductivity values of the disturbed soil from nine to 33 times lower than the undisturbed soils. In particular, Di Prima et al. (2016a) applied this methodology in a vineyard with a sandy-loam texture. These authors compared this simple methodology with rainfall simulation experiments establishing a physical link between the two methodologies through the kinetic energy of the rainfall and the gravitational potential energy of the water used for the beerkan runs. They also indirectly demonstrated the occurrence of a certain degree of compaction and mechanical breakdown using a mini disk infiltrometer (Decagon, 2014). With this device, they reported a reduction of the unsaturated hydraulic conductivity by 2.3 times due to the seal formation. In another investigation carried out in Brazil with the BEST procedure, non-crusted soils were three times more conductive than the crusted soil (Souza et al., 2014).

3.2. Seasonal dynamics in hydraulic conductivity

For the first and the third campaign, the beerkan runs carried out between the rows yielded comparable and statistically similar (**Table 3**) K_s values (**Figure 5**). In both cases, the average K_s values were approximately 20 times higher than the expected saturated conductivity on the basis of the soil textural characteristics alone (e.g., K_s = 10.4 mm h^{-1} for a loam soil according to Carsel and Parrish, 1988). This circumstance suggested that soil macroporosity generated by soil tillage in the ploughed horizon likely influenced measurement of K_s (Alagna et al., 2016; Di Prima et al., 2016a; Josa et al., 2010). In these conditions, the soil structure is expected to be particularly fragile, especially with reference to macroporosity, and hence unstable (Jarvis et al., 2008), which implies that clogging of the largest pores at the soil surface, as a consequence of the aggregates breakdown occurring during a rainstorm, can easily mitigate tillage effects on soil hydraulic properties (Ciollaro and Lamaddalena, 1998).

As discussed in the former section, the presence of the crust layer during the second field campaign clearly affected water infiltration between the rows. In particular, the presence of this layer implied that K_s was 1.5-1.8 times lower than that measured in the absence of the crusted layer (**Figure 5**). Crusting at the

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soil surface determined an increased hydraulic resistance to water penetration into soil (Alagna et al., 2013) since differences between the K_s datasets (second against first and third sampling campaigns) were statistically significant. Crusting also resulted in a decrease of the lowest measurable K_s values, while the highest values remained unchanged (**Table 3**).

The tillage practices carried out in the spring 2016 removed any existing soil crust and thereby increased soil infiltration properties (**Figure 5**) (Chahinian et al., 2006; Ndiaye et al., 2005; Pare et al., 2011; Strudley et al., 2008; Xu and Mermoud, 2001; Zhai et al., 1990), suggesting a cycling occurrence of crusting phenomena within the year.

Many studies in the literature have reported similar dynamics, even in vineyards. In fact, infiltration experiments constitute an indirect measurement closely associated with sealing or crusting (Römkens et al., 1990), and the saturated hydraulic conductivity may vary considerably during the year if these phenomena occur. In particular, rainfall and wetting–drying cycles favor soil reconsolidation and soil-surface sealing or crusting, whereas tillage removes existing layering (Pare et al., 2011). For instance, Biddoccu et al. (2017) studied temporal variability of soil hydraulic properties in a vineyard on a silt loam soil. These authors reported hydraulic conductivity values measured during the summer four times lower than those measured during the wet season, due to the presence of a structural crust resulting from rainfall events following the late spring tillage.

3.3. Applicability of the beerkan runs for the assessment of the crusted soil

The results reported in this investigation were in agreement with those by Souza et al. (2014) and therefore the supported the suggestion that the beerkan-based methodology should be usable to distinguish between crusted and non-crusted soils.

Indeed, the hydrodynamic properties of both the crust and the underlying soil play a key role during a rainstorm, affecting the partition between infiltration and runoff (Assouline and Mualem, 2002, 2006). However, transient methods, as the beerkan one, appears appropriate to characterize crusted soils, since the properties of the surface layer play a major role at early stages of the infiltration process (Vandervaere et al., 1997). Recently, Di Prima et al. (2016b) showed that BEST-slope is less sensitive to the attainment of steady-state and allows to obtain accurate estimates of saturated soil hydraulic conductivity with less water

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and hence shorter experimental times than the other two BEST algorithms. For these reasons, BEST-slope appears suitable, among the alternative algorithms, to characterize a crust layer. The applied methodology in this investigation seems suitable to explore in the future the functional dynamics of the crust layer under natural rainfall conditions.

A perplexity on the possibility to collect reliable data on crusted soils by a ponding infiltration experiment is related to the need to insert the ring into the soil. The doubt is that ring insertion could determine fractures in the crusted layer and these fractures could directly connect the ponded depth of water during the run with the underlying, non-crusted, soil layer (Vandervaere et al., 1997). In other terms, ring insertion could impede, in practice, measurement of fluxes though the crusted layer. In this investigation, fractures were not visually detected at the soil surface, perhaps because the soil was not very dry when the experiment on the crusted layer was performed (**Table 2**), the ring insertion depth was small (0.01 m), and insertion was carried out a few minutes after moistening the insertion circumference. Other ponding infiltration techniques, such as the single-ring pressure infiltrometer (Reynolds and Elrick, 1990) or, particularly, the simplified falling head technique (Bagarello et al., 2004), presuppose appreciably deeper insertions of the ring and, consequently, more risk to disrupt or alter the fragile crust layer at the soil surface during ring insertion. Therefore, the beerkan run seems a more appropriate ponding infiltration run to prevent, or minimize, substantial alteration of the surface to be sampled. Obviously, this conclusion needs additional testing but the premises are encouraging, also considering that beerkan runs were successfully conducted in other crusted soils (Souza et al., 2014).

4. Conclusions

A loam soil was sampled in a Mediterranean vineyard located at Marsala (western Sicily, Italy), with beerkan infiltration experiments carried out along the rows direction and in the inter-rows within two consecutive growing seasons. Beerkan tests along with BEST-slope algorithm led to accurate estimates in both crusted and un-crusted conditions, allowing to assess the effect of the cycling occurrence of crusting due to rainfalls and wetting–drying cycles on the vineyard inter-rows.

A sampling strategy implying beerkan tests carried out along and between the vine-rows was successfully applied. This strategy allowed to assess the reduction in hydraulic conductivity with extemporaneous measurements alone. Its main advantage is that it allows a rapid assessment of crusting severity affecting water infiltration. At the sampled site, the impact of crusting on saturated soil hydraulic conductivity was moderate.

In conclusion, the hypothesis that the beerkan runs are suitable enough to detect the effect of the crust on flow and BEST estimates appeared reasonable. In the future, the beerkan-based methodology should be checked in other crusted soils. Comparisons should also be established with other experimental methodologies.

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Figure 1. Precipitation and soil management program during the study period. The sapling dates are reported.

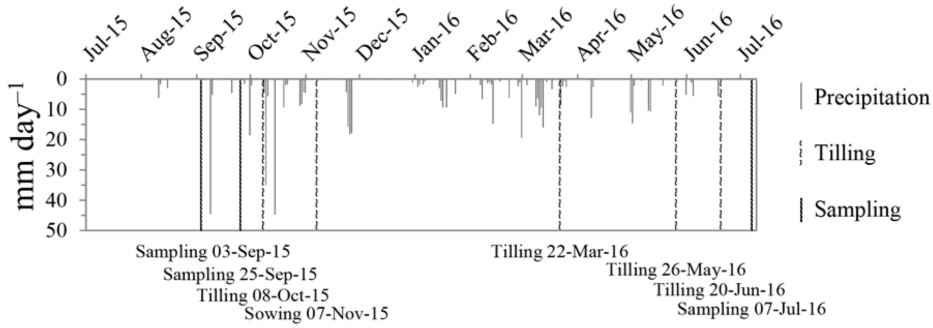

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Figure 2. Surface crust layer developed after the intense storms fallen in September 2015.

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Figure 3. Beerkan infiltration runs carried out **(a)** along the rows and **(b)** on the bare inter-rows area.

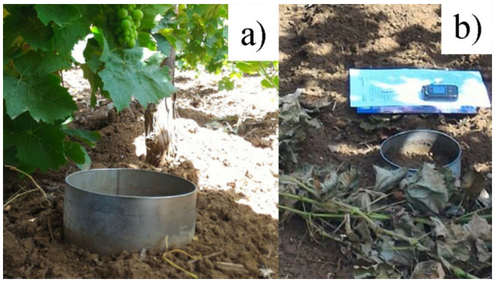

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Figure 4. Cumulative frequency distribution of the relative errors, E_r (%), of the fitting of the infiltration model to the transient phase of the infiltration runs.

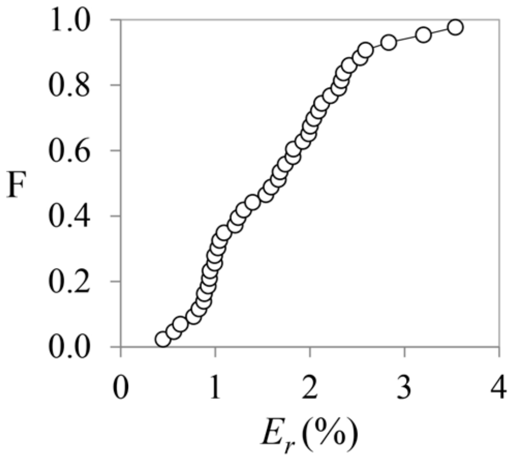

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Figure 5. Box plots of the saturated soil hydraulic conductivity, K_s (mm h^{-1}), values obtained from BEST experiments carried out along and between the rows on different sampling dates and for different initial soil water content, θ_i (cm^{3}cm^{-3}), values. On the box plots, boundaries indicates median, 25th and 75th quantiles, the top and bottom whiskers indicate the minimum and maximum values.

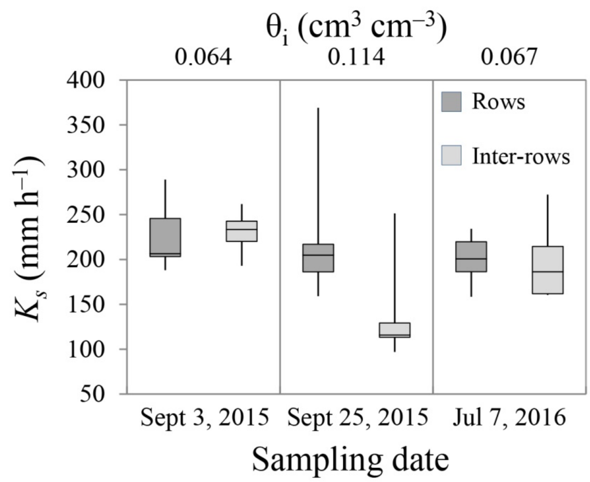

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Table 1. Clay (%), silt (%) and sand (%) content (USDA classification system), soil textural classification, dry soil bulk density, ρ_b (g cm^{-3}), and saturated soil water content, θ_s (cm^{3}cm^{-3}), of the sampled vineyard soil. Coefficient of variation (%) in brackets.

Variable	Site characteristic
clay	19.7
silt	49.6
sand	30.7
Textural classification	loam
ρ_b	1.128 (5.1)
θ_s	0.575 (3.8)

Table 2. Sample size (N), minimum (Min), maximum (Max), mean, and coefficient of variation (CV, in %) of the soil water content at the time of sampling, θ_i (cm^3cm^{-3}), values for different sampling dates.

Statistic	Sept 3, 2015	Sept 25, 2015	Jul 7, 2016
N	10	10	10
Min	0.051	0.093	0.047
Max	0.073	0.133	0.087
Mean	0.064 A	0.114 B	0.067 A
CV	12.0	10.9	18.1

The values in a row followed by the same upper case letter were not significantly different according to the Tukey Honestly Significant Difference test (P = 0.05). The values followed by a different upper case letter were significantly different.

Table 3. Sample size (N), minimum(Min), maximum (Max),mean, and coefficient of variation (CV, in %) of the saturated soil hydraulic conductivity, K_s (mm h^{-1}), values obtained from BEST experiments carried out along and within the rows on different sampling dates.

Variable	Position	Statistic	Sept 3, 2015	Sept 25, 2015	Jul 7, 2016
K_s	Rows	N	7	7	7
		Min	188.1	159.1	158.4
		Max	289.1	369.1	234.2
		Mean	223.6 a A	212.4 a A	199.2 a A
		CV	15.4	27.6	14.1
	Inter-rows	N	7	7	7
		Min	193.0	97.0	160.6
		Max	261.8	251.3	272.3
		Mean	229.5 a A	129.3 b B	192.5 a A
		CV	10.3	31.7	20.2

The values in the column followed by a different lower case letter were significantly different according to a two tailed t test (P = 0.05). The values in a row followed by a different upper case letter were significantly different according to the Tukey Honestly Significant Difference test (P = 0.05).