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cc: rallo.giovanni@gmail.com
From: "Journal of Irrigation & Drainage Engineering" asceirrigation@gmail.com
Subject: Decision on Manuscript MS IRENG-6899

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Discussion of "Laboratory and field calibration of the Diviner 2000 probe in two types of soil" by J. Haberland, PhD, R. Galvez, C. Kremer, PhD, and C. Carter. DOI: 10.1061/(ASCE)IR.1943-4744.0000687

Giovanni Rallo, PhD, Fellowship researcher; Giuseppe A. Provenzano, PhD, Associate Professor

Dear Prof. Provenzano,

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Discussion of "Laboratory and field calibration of the Diviner 2000 probe in two types of soil" by J. Haberland, PhD, R. Galvez, C. Kremer, PhD, and C. Carter. DOI: 10.1061/(ASCE)IR.1943-4744.0000687
--Manuscript Draft--

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Full Title:	Discussion of "Laboratory and field calibration of the Diviner 2000 probe in two types of soil" by J. Haberland, PhD, R. Galvez, C. Kremer, PhD, and C. Carter. DOI: 10.1061/(ASCE)IR.1943-4744.0000687
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2 **Discussion of “Laboratory and field calibration of the Diviner 2000 probe in two types of soil” by J.**
 3 **Haberland, PhD, R. Galvez, C. Kremer, PhD, and C. Carter.**

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5

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12

13 **Comments to the paper**

14 The authors deal with the quite interesting and actual problem of Diviner 2000 capacitance probe calibration
 15 and present some field and laboratory data obtained on two different layers (0-0.26 cm and 0.26-0.50 cm) of
 16 the same soil profile, characterized by different textural class. The importance of site-specific calibration of
 17 sensors used to monitor soil or plant water status assumes a particular relevance in semi-arid environments
 18 where the application of precision irrigation represents an appropriate management strategy aimed to achieve
 19 high values of water use efficiency (Cammalleri et al., 2013). Moreover in clay soils, physical properties are
 20 strongly influenced by soil water content (Provenzano et al., 2013), so that the correct measurement of this
 21 variable plays a key role to increasing crop yield and preserving water.

22 However, these discussers would focus on some significant points to be corrected in the manuscript and
 23 some others that AA. should have been specified in the methodology and considered in the final discussion,
 24 as following specified, for the benefit of potential readers.

25 The need to install adequately the access tube, aimed to ensure the contact between the tube and the
 26 surrounding soil, is not only to avoid preferential flow of water down the walls of the tube, as considered in
 27 the paper, but also to reduce air gap around the tube and to avoid rough measurements of scaled frequency,
 28 used to estimate soil water contents, whose values depend on the mutual proportion of soil, water and air in
 29 the soil volume investigated by the sensor.

30 With reference to the second part of eq. (2) it is necessary to precise that the function $\theta_w(SF)$ correctly
 31 results:

$$32 \quad \mathcal{G}_w = B \sqrt{\left(\frac{SF}{A}\right)} \quad (1)$$

33 or

$$34 \quad \mathcal{G}_w = aSF^b \quad (1a)$$

35 in which θ_w is the volumetric soil water content, SF is the scaled frequency, $a = \left(\frac{1}{A}\right)^{\frac{1}{B}}$ and $b = \left(\frac{1}{B}\right)$ are
36 two empirical coefficients, generally used when the calibration equation is expressed in terms of $\theta_w(SF)$
37 function.

38 Regarding the methodology, field calibration considered by the AA. followed the general procedure
39 proposed by the manufacturer. When describing the related methodology, AA. should have been specified
40 some soil physical parameters (texture, organic matter, bulk electrical conductivity, etc.) as well as the two
41 depths, in each soil layer, at which they acquired the scaled frequency and then collected the undisturbed soil
42 samples. Moreover, the dimension of the cylindrical samples, used to determine soil bulk density, should
43 have been provided in the manuscript.

44 On the other hands, when referring to the laboratory calibration procedure, samples were prepared by using
45 sieved soil collected in the same layers where field calibration was carried out. After sieving at 5,0 mm and
46 air-dry the soil, three samples of not specified weight, corresponding to a volume of 20 l, were brought to
47 volumetric soil water contents of about 5%, 15% and 35% by adding different amounts of water and then
48 compacted in the plastic container, later on used for laboratory calibration of the sensor. Despite the similar
49 compaction method applied to fill all the containers, these discussers consider questionable the adopted
50 methodology, believing that soil should have been moistened only after filling the container and not before.
51 Actually, the different initial water content characterizing the soil used to fill the containers, could have
52 determined values of soil bulk density different between the samples, and also dissimilar from the actual
53 value measured in the field.

54 In fact, if considering the standard protocol of compaction ASTM D698 (2005), by using a Proctor hammer,
55 it is possible to achieve different values of bulk density depending on the water content of the sieved soil
56 used to fill the containers. Fig. 1a,b shows the values of bulk density obtained in laboratory by applying the
57 standard ASTM D698 protocol of compaction to two sieved soils, i.e. a sandy (PAR) and a clay loam (CAS),
58 prepared at different gravimetric soil water contents (personal unpublished data). As can be observed, in both
59 cases it is possible to detect an optimal value of gravimetric water content to which corresponds a maximum
60 soil bulk density. Of course, considering that the values of bulk density in the soil volume investigated by the
61 sensor, as well as the corresponding variability, were not provided in the manuscript, it is not possible to
62 quantify in which proportion this variable could be responsible of the observed differences between field and
63 laboratory calibration equations, whose coefficients are indicated in table 1 of the original paper.

64 Basically, soil bulk density must be essentially considered a source of uncertainty in estimation of volumetric
65 soil water contents, because it affects the soil dielectric permittivity (Gardner et al., 1998) and also because it
66 governs the relationship between gravimetric and volumetric soil water contents (Geesing et al., 2004).

67 In the following paragraph these discussers will present some unpublished experimental data, demonstrating
68 the effects of soil bulk density on the scaled frequency and consequently on the estimated values of
69 volumetric soil water content.

70 In addition, it is necessary to underline that the parameters A of the default calibration equation proposed by
71 the manufacturer and indicated in the original table 1, must be corrected to 1.263 if soil water content is
72 expressed in cm^3/cm^3 ; in fact, the value $A=0.2746$, obtained on different Australian soils (sands, sandy loams
73 and organic potting), as specified in the Sentek Pty manual (2001), is referred to soil water content expressed
74 in mm (Sentek Environmental Technologies, 2001) and therefore unit transformation must be considered to
75 compare the different calibration equations presented in the original table 1.

76 These discussers strongly believe that in fig. 4a,b, the experimental points and their variability should have
77 been indicated together with the regression functions, in order to recognize the dispersion characterizing the
78 measurements and also to identify the limits of validity of the proposed equations.

79 The following fig. 2, rearranged from fig. 4a,b to adjust the inexistent curves' knee showed in the original
80 version, also illustrates the dimensionally corrected default equation proposed by the manufacturer, whose
81 actual trend, as a consequence, induces to reconsider most of the results presented and discussed in the paper.
82 Moreover, with reference to the misleading figs. 5 and 6, in which it is not clear the meaning of the
83 represented continuous functions, AA. should have been represented the volumetric soil water contents
84 estimated with the different equations versus the corresponding measured in laboratory (fig. 5) or in the field
85 (fig. 6), together with the 1:1 best fitting line, in order to give a more comprehensible representation of the
86 observed differences.

87 The comment on the error of 176% for the highest soil water content (P3) determined according to field
88 experiments in the upper clay loam horizon (probably referred to the original fig. 6a and not to fig. 5, as
89 indicated), attributed to the circumstance "that was not possible to dry the soil sufficiently to obtain a good
90 dispersion of points during the field calibration process", seems to be in contrast with the following sentence
91 evoked by AA. in which, according to Vera et al. (2010), they declared that significant errors could occur
92 when soil water content is estimated "in areas not accounted for during the calibration process".

93 Anyway, the difficulty to dry the soil below certain water content evidenced by AA., has been also observed
94 in field experiments carried out by these discussers, whose results have not been published yet.

95 In particular, field calibration of Diviner 2000 sensor was carried out in two layers (0-40 cm and 40-80 cm)
96 of the same soil profile, by acquiring measurements every 10 cm, from 5 cm to 75 cm depth, according to the
97 procedure suggested in the manufacturer's manual (Sentek Pty manual, 2001). Six 1.20 m long access tubes
98 were installed in order to explore different soil water status, i.e. wet (P1), moist (P2) and dry (P3), during
99 three different periods of the year, i.e. winter (P1), spring (P2), late summer (P3). According to USDA
100 textural soil classification, the upper layer is classified as clay-loam, with a sand, silt and clay content equal
101 to 42.4%, 18.9% and 38.7%, whereas the lower layer is sandy-clay with sand, silt and clay content equal to
102 45.3%, 18.0% and 36.7%, respectively.

103 Fig. 3a,b shows, for each considered soil layer, the experimental $SF(\theta_w)$ data pairs as well as experimental
104 (dashed line) and manufacturer's (solid line) calibration equations. Standard deviations of scaled frequency
105 and volumetric soil water content are also indicated. The former was obtained by considering two
106 measurements acquired at each depth, whereas the latter was evaluated taking into account the values of θ_w

107 determined on three undisturbed soil samples (8.0 cm diameter, 5.0 cm high) collected at the different
108 depths. For each soil sample, the value of θ_w was obviously calculated multiplying the gravimetric water
109 content by the soil bulk density, ρ_b , evaluated on the same undisturbed sample.

110 As can be observed, if in the upper layer it was possible to explore a wide interval of volumetric soil water
111 contents, variable between $0.05 \text{ cm}^3/\text{cm}^3$ and $0.33 \text{ cm}^3/\text{cm}^3$, in the lower layer the variations of θ_w resulted
112 more limited and ranging between $0.20 \text{ cm}^3/\text{cm}^3$ and $0.31 \text{ cm}^3/\text{cm}^3$. Of course, the calibration equation
113 identified for the lower layer cannot be considered valid for values of volumetric soil water content lower
114 than $0.20 \text{ cm}^3/\text{cm}^3$. Moreover, observing fig. 3 a,b it is also possible to notice the great variability of
115 volumetric soil water contents measured at each depth of the soil profile, as a consequence of its spatial
116 variability as well as of the different bulk density characterizing the collected soil samples.

117 For upper and lower layers, fig. 4a,b shows the soil bulk density measured in the field as a function of depth,
118 evidencing that at increasing depth, soil bulk density tends to rise and also that, for a fixed depth, the values
119 of ρ_b are largely variable around their average value justifying, at least in part, the recognized variability of
120 the measured volumetric soil water contents.

121 Finally, considering the quite high clay content characterizing either the soil investigated by these discussers
122 than (probably) those examined in the original paper, another crucial aspect to be investigated should have
123 been related to the shrinkage and swelling phenomena consequent to variations of soil water content that,
124 depending on the clay mineralogy, could have affected both the original field and laboratory $\theta_w(SF)$
125 relationships.

126

127 **Effect of soil bulk density on Scaled Frequency measured by Diviner 2000 probe**

128 With the aim to evaluate the effect of soil bulk density on scaled frequency measured by Diviner 2000 probe,
129 experiments were carried out on different agricultural soils collected in western Sicily, two of which will be
130 presented in this discussion (a sandy soil, PAR and a clay loam soil, CAS). For each investigation site, the
131 collected soil was air-dried, sieved at 5 mm and then used to fill two plastic cylinders (diameter and height
132 equal to 25.0 cm), after placing in axial position a 30 cm long access tube. In order to achieve two quite
133 different values of bulk density, a preliminary analysis on soil compaction properties was carried out by
134 applying the standard D698 ASTM protocol (fig. 1a,b), so to assess the initial soil water content necessary to
135 reach a pre-fixed value of bulk density. Then, two samples were prepared: the first by using air-dried soil
136 (gravimetric water content $U \approx 0.05$) according to which a low bulk density was obtained (MIN), whereas the
137 second was initially moistened to the optimal water content, variable between soils, allowing to reach the
138 maximum bulk density (MAX). After filling the containers, soil was saturated and then the sensor calibration
139 procedure was applied following an air-drying process. For each soil water content from saturation to oven
140 dry, values of scaled frequency, sample weight and heights, the latter measured on eight points on the soil
141 surface, were registered. At the same time, the lateral contraction was determined with analysis of the images
142 captured on the soil surface. In this way it was possible to evaluate, at the end of the experiment, the
143 gravimetric water contents and the corresponding actual values of soil bulk density.

144 Fig. 5a,b shows for both the considered soils the measured scaled frequency as a function of gravimetric soil
145 water content, whereas fig. 5c,d illustrates the soil shrinkage characteristic curves, expressed in terms of
146 variations of soil bulk density with gravimetric soil water contents. In particular, for the sandy soil (PAR),
147 the values of bulk density are almost constant whatever is the gravimetric water content (rigid soil); on the
148 other hands both samples of clay loam soil (CAS) evidenced reductions of bulk density at increasing water
149 content even if, as visible, the extent of reductions is greater for sample with a lower bulk density (MIN).
150 This circumstance is a natural consequence of shrinking phenomena occurring in soils containing a certain
151 percentage of swelling clay.

152 Moreover, as can be observed in fig. 5a,b, for each gravimetric soil water content, greater the soil bulk
153 density higher the scaled frequency measured by the probe. The diverse response of the sensor is an obvious
154 consequence of the different contribute of soil, air and water to the soil dielectric permittivity.

155 When observing the graphs of fig. 6a,b, in which the values of scaled frequency are expressed against
156 volumetric soil water content, it is possible to notice that for the sandy soil (PAR, fig. 6a) two quite different
157 relationships $SF(\theta_w)$ can be identified, whereas for the clay loam soil (CAS, fig. 6b) a certain overlapping of
158 the experimental points obtained in the two samples, as well as a lower variability of the $SF(\theta_w)$ relationships
159 are visible for the higher water contents. This result is consequent to the compensative effect ascribable to
160 the higher values of soil bulk density corresponding to the lower gravimetric water content, as determined
161 according to the soil shrinkage characteristic.

162

163 **References**

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179

FIGURE CAPTIONS

Fig. 1a,b – Values of bulk density obtained applying the standard D698 ASTM compaction protocol to a sieved sandy soil (a, PAR) and to a clay loam soil (b, CAS) prepared at different gravimetric soil water contents.

180

181 Fig. 2 – Relationships $SF(\theta_w)$ presented in fig 4a,b of original paper and corrected Diviner 2000
182 manufacturer's calibration equation

183

Fig. 3a, b – Comparison of field calibration equations in two layers (0-40 cm and 40-80 cm) of a Sicilian soil (CAS) with calibration curve provided by manufacturer.

184

Fig. 4a,b – Values of soil bulk density measured at the different depths, for layers 0-40 cm and 40-80 cm.

185

Fig. 5a,d - Experimental $SF(U)$ and $\rho_b(U)$ data pairs and corresponding regression curves, obtained on samples prepared at different values of bulk density for a sandy (PAR) and a clay loam (CAS) soils

186

Fig. 6a,b - Experimental $SF(\theta_w)$ data pairs and corresponding regression curves, obtained on samples prepared at different values of bulk density for a sandy (PAR) and a clay loam (CAS) soils

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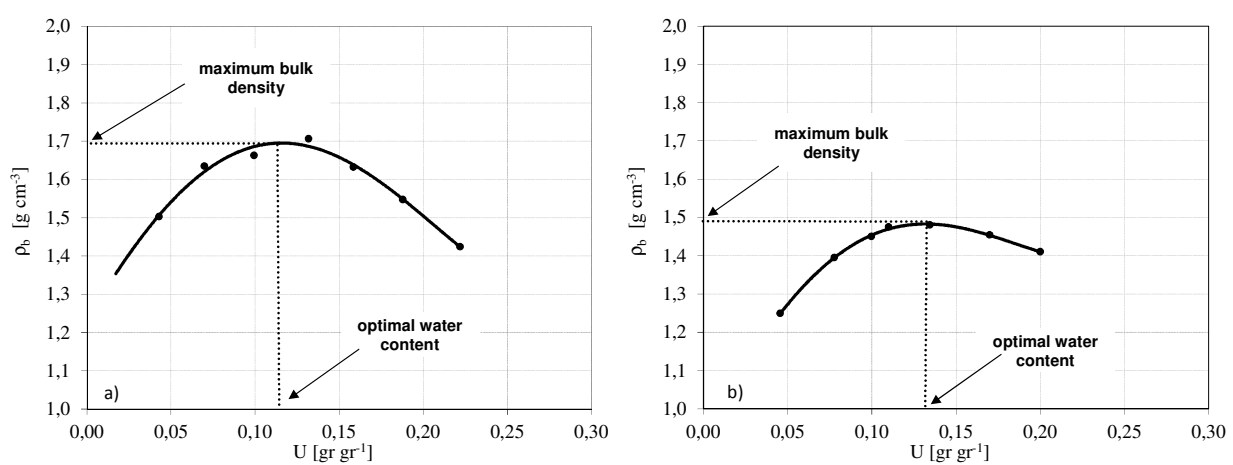


Fig. 1a,b – Values of bulk density obtained applying the standard D698 ASTM compaction protocol to a sieved sandy soil (a, PAR) and to a clay loam soil (b, CAS) prepared at different gravimetric soil water contents.

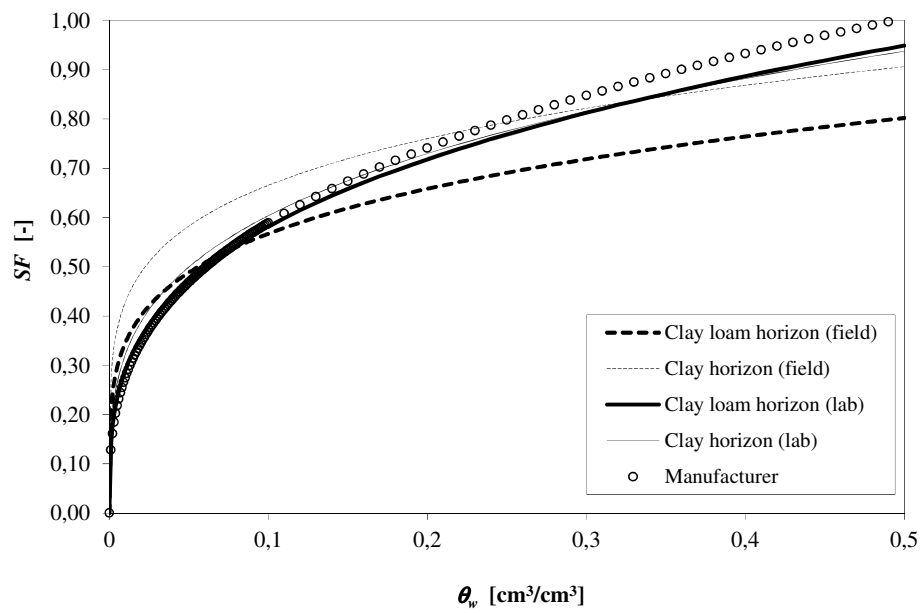


Fig. 2 – Relationships $SF(\theta_w)$ presented in fig 4a,b of original paper and corrected Diviner 2000 manufacturer's calibration equation

Figure 3

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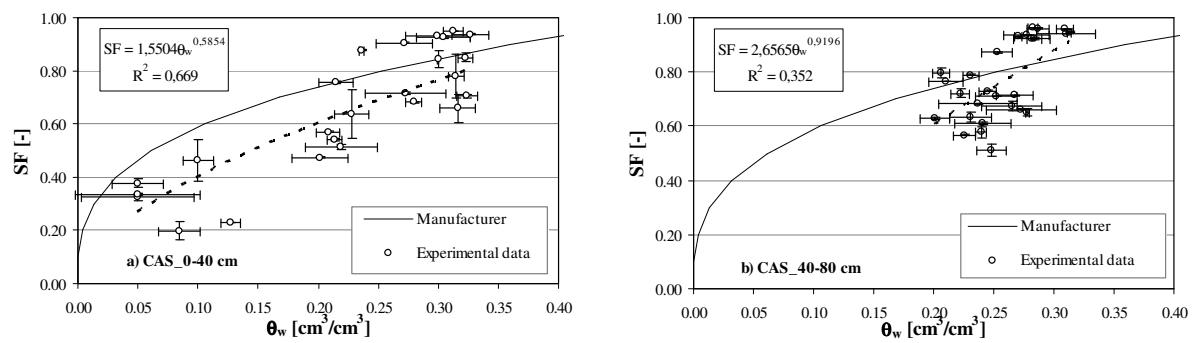


Fig. 3a, b – Comparison of field calibration equations in two layers (0-40 cm and 40-80 cm) of a Sicilian soil (CAS) with calibration curve provided by manufacturer.

Figure 4

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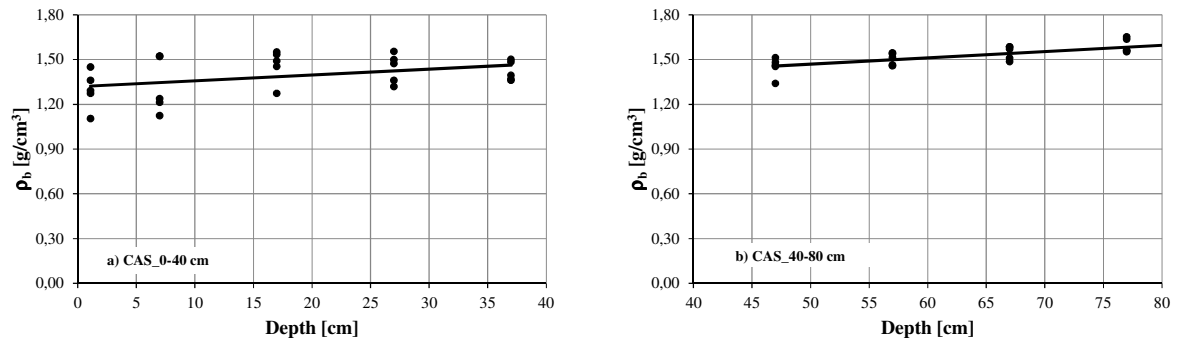


Fig. 4a,b – Values of soil bulk density measured at the different depths, for layers 0-40 cm and 40-80 cm.

Figure 5

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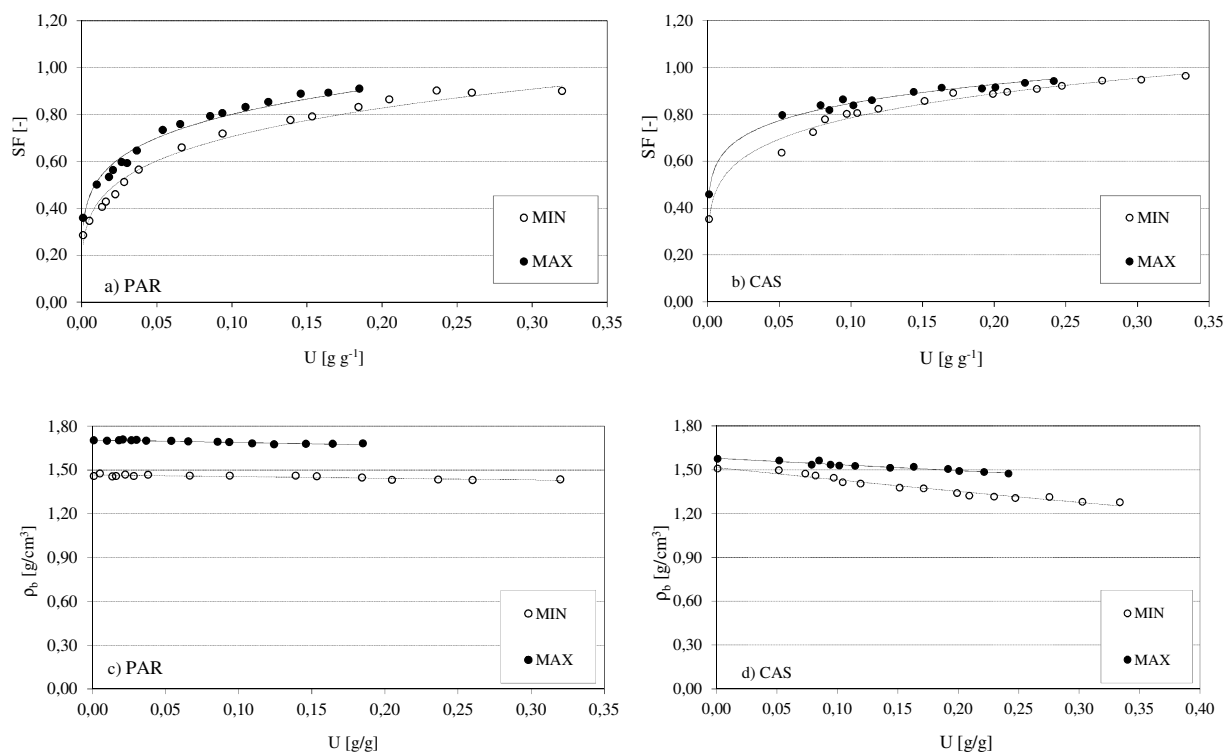


Fig. 5a,d. Experimental $SF(U)$ and $\rho_b(U)$ data pairs and corresponding regression curves, obtained on samples prepared at different values of bulk density for a sandy (PAR) and a clay loam (CAS) soils

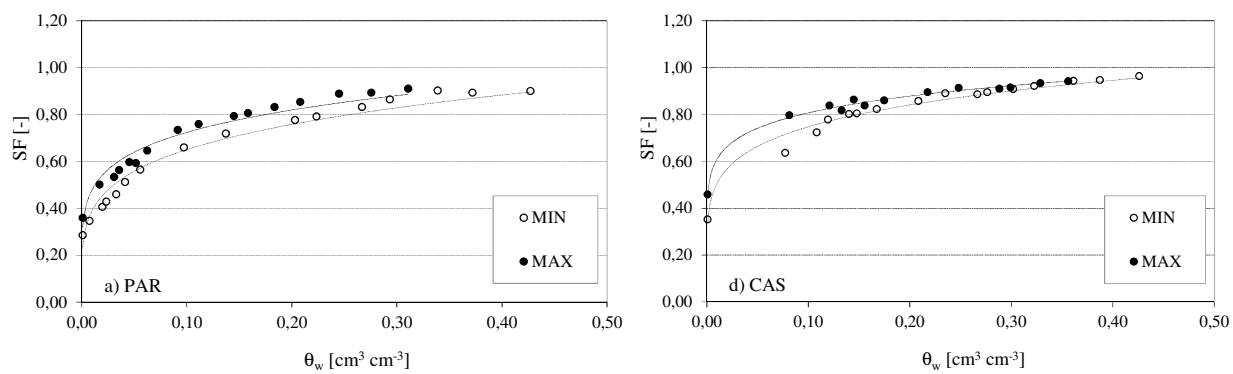


Fig. 6a,b. Experimental $SF(\theta_w)$ data pairs and corresponding regression curves, obtained on samples prepared at different values of bulk density for a sandy (PAR) and a clay loam (CAS) soils