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STUDIUL DISTRIBUȚIEI SPAȚIALE A CURBELOR CARACTERISTICE ALE APEI DINTR-UN SOL CU TEXTURĂ LUTO-NISIPOASĂ ȘI CONSECINȚELE REFERITOARE LA APLICAREA IRIGĂRII ÎNTR-O LIVADĂ INTENSIVĂ DE PRUN

INVESTIGATING SPATIAL DISTRIBUTION OF THE SOIL–WATER CHARACTERISTIC CURVES AND CONSEQUENCES IN IRRIGATION APPLICATION WITHIN A SANDY-LOAM SOIL IN AN INTENSIVE PLUM TREE ORCHARD

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Abstract

The orchard plot has plum trees (Stanley cultivar grafted on Saint Julien rootstock), six years old, with 4 m between tree rows (ITR) and 2.25 m between trees in the row (IR). The relief is a gentle hillside with a slope of 0.075 m m^{-1}. Undisturbed soil samples were taken at field capacity (FC) from both IR and ITR positions, between 0 and 1 m depth, with a 0.1 m depth step, in cylinder metal cores of 0.05 m in both sizes. Soil water characteristic curves between the matric potential (soil suction, ψ, expressed as pF) and SWC (m^3 m^{-3}) were determined in the lab according to van Genuchten's method. BD for each sample was also determined. Highly significant correlations were found between the main soil physical indices used in irrigation application and bulk density. Thus, soil compaction in orchards deteriorates soil structure and decreases water supply to the fruit trees. Only about one quarter of the total water capacity of a soil is usually used as available water for plants. Most of this capacity for the investigated soils contains either immobile water (equivalent of the wilting point) or drainage water (from total capacity to field capacity). From the available soil water capacity, only half (i.e. 12.5% of total soil water capacity) is easily available, the rest being increasingly more difficult available to plants. Soil matric potential is lower and lower with decreasing soil water content within the available soil water capacity, or otherwise soil suction increases more and more under the same conditions. Thus, soil water availability decreases dramatically from field capacity to the wilting point, for uniform decreases in soil water content, and irrigation application under water stress reduces dramatically soil water availability for plants compared to fully irrigation.

Cuvinte cheie: potential matricial, densitate aparenta, capacitate diferentiala a apei in sol
Keywords: matric potential, bulk density, differential soil water capacity

1. Introduction

In orchards, soil bulk density (BD) varies both vertically due to the pedologic and geologic diversity of soil layers, and horizontally as a function of distance from tree rows due to the technological traffic (Paltineanu et al., 2015).

Soil–water characteristic curve, or water retention curve, was first reported for various textured soils by Buckingham (1907). This curve characterizes the soils and represents a relationship between the soil water content (SWC, frequently having the symbol θ), and the soil water potential (ψ) (https://en.wikipedia.org/wiki/Water_retention_curve). One of the most famous models that describe this curve is the van Genuchten model (van Genuchten, 1980). Other famous scientists who contributed to the study of the soil–water characteristic curve are: Richards and Weaver (1944), Mualem (1976), Brady (1999), etc.

Soil–water characteristic curve allows determination of various soil physical properties for each soil layer and soil profile, with implication in irrigation application. Being a difficult soil physical analysis it is rarely done on a large-scale in labs, and even less in orchards that have heterogeneous soil properties.

The purpose of this paper is to highlight the spatial distribution of soil-water characteristic curves in a sandy-loamy soil with intensive plum tree orchard, derive the soil physical indices, test a correlation between these indices and BD, and emphasize the magnitude of the differential soil water capacity (C) between the soil physical indices for further use in irrigation application.

2. Material and method

The orchard plot has plum trees (Stanley cultivar grafted on Saint Julien vegetative rootstock), six years old, with 4 m between tree rows (ITR) and 2.25 m between trees in the row (IR). The relief is a gentle hillside with a slope of 0.075 m m^{-1}.

The soil is a sandy-loam aric antrosol (symbol ATad, Florea and Munteanu, 2012) with a gley influence in the subsoil (water table at 2.5-3.0 m depth), at Maracineni, district Arges.

Undisturbed soil samples were taken at field capacity (FC) from both IR and ITR positions, between 0 and 1 m depth, with a 0.1 m depth step, in cylinder metal cores of 0.05 m in both sizes.

Soil water characteristic curves between the matric potential (soil suction, ψ, expressed as pF) and SWC (m^3 m^{-3}) were determined in the ICPA lab according to van Genuchten's method (van Genuchten, 1980). BD for each sample was also determined according to SR EN ISO 11272: 2014 (Florea et al., 1987).

The average BD values over the 0-0.5 m depth were as much as 1.41 and 1.50 Mg m^{-3} in IR and ITR, respectively, higher in ITR due to the technological traffic; however, over the entire 0-1 m depth, BD was almost equal in IR and ITR (1.52 versus 1.53 Mg m^{-3}), with big differences between soil layers. The clay content ranged between 14 and 16% kg kg^{-1}.

SWC values corresponding to the main soil physical indices used in irrigation application, such as: total soil water capacity (TC = pF 0, saturation), air entry value (AEV, Brooks and Corey, 1964), field capacity (FC, considered at pF 2.52 or at 33.1 kPa as reported by Veihmeyer and Hendrickson, 1931), wilting point (WP, considered at pF 4.2 or at 1585 kPa), as well as various fractions of the available soil water capacity (ASWC): (3/4) of ASWC, (1/2) of ASWC or the management allowed depletion = MAD, and (1/4) of ASWC, for each soil core in both IR and ITR were determined, and some of these indices were correlated with BD. In this paper, we considered the exact corresponding values of pF, namely a soil matric potential of 1.585 MPa for pF 4.2, and not 1.5 MPa (as frequently found in literature) that fit to a pF of 4.1761.

The differential soil water capacity, or specific soil water capacity, C (expressed as m^{-1}), was calculated as follows (Klute, 1956; Canarache et al., 2006):

$$C = d\theta / d\psi$$

between the soil physical indices, with ψ expressed in m H_2O column, and θ (or SWC) in m^3 m^{-3}.

The regression equations between the variables investigated were obtained by help of Microsoft Office Excel software using the least squares method. The statistical significance of determination coefficient (R^2) was established by using the t-test (Aïvazian, 1970). SWC spatial distribution was also determined across the soil profile.

3. Results and discussion

Soil water characteristic curves for the undisturbed soil samples taken with a depth step of 0.1 m down to 1 m in both IR and ITR positions in the intensive plum orchard studied, at Maracineni, are shown in Fig. 1. One can see that the curves are spatially disposed in the graphs according to BD values, with the highest BD as possessing the lowest SWC at the same pF.

This suggested a possible correlation between the indices described above and BD, and the regression equations are shown in Fig. 2. TC (pF 0) appeared to correlate with BD as a functional relationship (R^2 = 1) and this was so because it corresponded to the total porosity (TP) calculated as:

$$TP = (1 – BD / D)$$

with D, soil density, equal to 2.64 Mg m^{-3}, because (1/2.64) = 0.37878, and this is just the coefficient from the graph. The other regression equations between the soil physical indices and BD were also highly significant for these soil layers with similar texture. It was also found that the higher the indices the higher R^2 for these relationships.

The main idea from this graph is that soil compaction, attributed to the technological traffic in orchard, causes high BD values, and the storing capacity of the soils, regardless the type of indices, tends to decrease, with negative consequences for these soils in supplying water to the fruit tree roots.

The reduction of physical indices due to soil compaction, either natural or man-made, was also seen on other soils (Paltineanu et al., 1985), for instance between FC and BD.

According to Canarache (1990), the usual method to determine WP in Romania was to multiply the hygroscopic coefficient with 1.5 as proposed by Kacinski (1947), and checked practically by Motoc (1962), whereas in the western countries Richards and Weaver (1944) proposed soil–water characteristic curve to determine these indices. Consequently, WP was in the first case only a function of soil texture;

however, in the light of the present procedure WP, as all the other soil physical indexes described above, was found to be correlated with BD.

One can see that only a narrow range of TC can be used by plants in the case of these soils, i.e. between FC and WP (24.8% of TC). SWC from saturation (0 kPa) to FC (33 kPa) is prone to rapid drainage, however being important (41.4% of TC), while SWC less than WP, also important (33.8% of TC), is unavailable, immobile water. From ASWC, only about half (i.e. 12.5% of TC) is easily available (from FC to MAD), the rest being increasingly difficult available.

One can also see that even if ASWC was split into four equal intervals (Table 1), i.e. from FC to (3/4)×ASWC, from (3/4)×ASWC to (1/2)×ASWC, from (1/2)×ASWC to (1/4)×ASWC and from (1/4)×ASWC to WP, the soil matric potential (suction, having negative values) decreased more and more with the decrease in SWC: -33 kPa for FC, -68 kPa for (3/4)×ASWC, -166 kPa for MAD or (1/2)×ASWC, -476 kPa for (1/4)×ASWC and -1585 kPa for WP. One can also remark that most of the devices used to measure soil suction in the field can determine this to only about 200 kPa, namely up to SWC values corresponding to MAD.

Table 1 shows that for a soil depth of 1 m, about 44.6 mm of soil water is lost easily from soil, from the largest macropores (from saturation to AEV), after intensive storms or moderate rainfall after irrigation application, about 127 mm is lost by rapid drainage between AEV and FC and cannot practically be used by plants, and for each fraction of ASWC correspond about 26 mm, and if MAD is used as a threshold in irrigation scheduling, about 51 mm (510 m^3 ha^{-1}) can be applied as an irrigation event by microsprinkler or sprinkler irrigation, according to scheduling.

An interesting question is how easily the soil can supply water to the plants, or how strong the plants should develop forces to extract water from the soil for a certain amount. This is given by the differential soil water capacity (C), shown between various fractions of TC, Fig. 4: a) C for pF 0 to 1 and for pF 1 to 2.52, b) C for various fractions of ASWC as described above.

The essence of these graphs consists in the order of magnitude corresponding to each SWC interval. Thus, C between pF 0 and 1 is as much as 0.36 to 0.60 m^{-1}, while C between pF 1 and 2.52, corresponding to the rapid drainage in terms of the largest macropores, is about ten times lower (Fig. 4a). Within ASWC (Fig. 4b), one can see that the soil water availability decreases dramatically from the upper values, about 3.5 – 4.0×10^{-4} (from FC and 3/4×ASWC) to the lower values (from 1/4×ASWC to WP), reaching practically 0 near WP.

In fruit growing the best irrigation methods are localized (such as drip irrigation, porous clay pots, porous pipes, and perforated plastic sleeves) or microsprinkler irrigation. These methods allow precise application of exact amounts of water to trees.

When using the fully irrigation regime in drip irrigation, only a part of the area is irrigated (about 1/4 to 1/3 of the orchard plot) and the irrigation water should be reduced accordingly. Some farmers often apply a daily water amount that is equal to the optimum rate as derived from Allen's metod (Allen et al., 1998), as a function of reference evapotranspiration and crop coefficient. In this case, in the region for plum tree orchards only about 5-6 mm (50-60 m^3 ha^{-1}) of water could be used daily as an irrigation application event (Paltineanu et al., 2007), preferably keeping a high value of SWC (between FC and MAD) if there is no problem of water excess in the soil; this water amount should also be reduced according to the irrigated area. However, for a better option how to use this threshold value of ASWC, additional recommendations obtained from physiological experiments, such as tree trunk contractions or leaf water potential should be also considered. In the case of waterlogging soils (this is not the case here), then drainage and soil aeration should be the first management priority, as minimum 10% of total porosity should be air-filled (Canarache, 1990).

This is also important in plant nutrition and physiology as well as in irrigation application, specifically when the regime is not as fully irrigation, but as stress irrigation. In the last situation, because the fruit trees are not irrigated on a regulate basis, there are periods when the soil dries more than MAD, and we just showed that the drier the soil the more effort from fruit trees to uptake water, specifically if withdrawn fom deeper layers. Thus, it is also important the depth of dried soil, because the tree roots usually grow down to about 1 m (Paltineanu et al., 2015). The trees being stressed in this situation, one however accounts for how much the soil could be allowed to dry. Due to the stress allowed, fruit yield usually decreases, and farmers take into consideration the fruit loss versus the water saved.

4. Conclusions

Highly significant correlations were found between the main soil physical indices used in irrigation application and bulk density. Thus, soil compaction in orchards deteriorates soil structure and decreases water supply to the fruit trees.

Only about one quarter of the total water capacity of a soil is usually used as available water for plants. Most of total soil water capacity for the investigated soils contains either immobile water (equivalent of the wilting point) or drainage water (from total capacity to field capacity). From the available soil water capacity, only half (i.e. 12.5% of total soil water capacity) is easily available, the rest being increasingly more difficult available to plants.

Soil matric potential is lower and lower with decreasing soil water content within the available soil water capacity, or otherwise soil suction increases more and more under the same conditions. Thus, soil water availability decreases dramatically from field capacity to the wilting point, for uniform decreases in soil water content, and irrigation application under water stress reduces dramatically soil water availability for plants compared to fully irrigation.

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Tables and figures

Table 1. Soil water reserves (mm) draining out or coming in through rainfall or irrigation application between the remarkable soil physical indices: TC = total capacity of soil water, AEV = air entry value, FC = field capacity, WP = wilting point, and various fractions of the available soil water capacity (ASWC=FC-WP), with MAD = management allowable depletion (considered at 1/2 × ASWC)

Soil Depth	TC-AEV	AEV-FC	FC-(3/4) ASWC	(3/4)-(1/2) ASWC	FC-MAD	(1/2)-(1/4) ASWC	(1/4) ASWC-WP	Sum ASWC
(m)	mm							
-0.1	5.35	13.85	2.7	2.7	**5.4**	2.7	2.7	**10.8**
-0.2	5.44	13.90	2.7	2.7	**5.4**	2.7	2.7	**10.8**
-0.3	5.10	13.45	2.6	2.6	**5.2**	2.6	2.6	**10.5**
-0.4	4.53	12.25	2.7	2.7	**5.3**	2.7	2.7	**10.7**
-0.5	3.52	11.70	2.4	2.4	**4.8**	2.4	2.4	**9.6**
-0.6	4.78	13.35	2.6	2.6	**5.3**	2.6	2.6	**10.6**
-0.7	4.19	12.95	2.6	2.6	**5.2**	2.6	2.6	**10.4**
-0.8	3.59	11.75	2.4	2.4	**4.8**	2.4	2.4	**9.6**
-0.9	3.86	11.85	2.4	2.4	**4.8**	2.4	2.4	**9.7**
-1.0	4.21	11.80	2.4	2.4	**4.9**	2.4	2.4	**9.7**
0-1 m	**44.6**	**126.9**	**25.6**	**25.6**	**51.1**	**25.6**	**25.6**	**102.3**

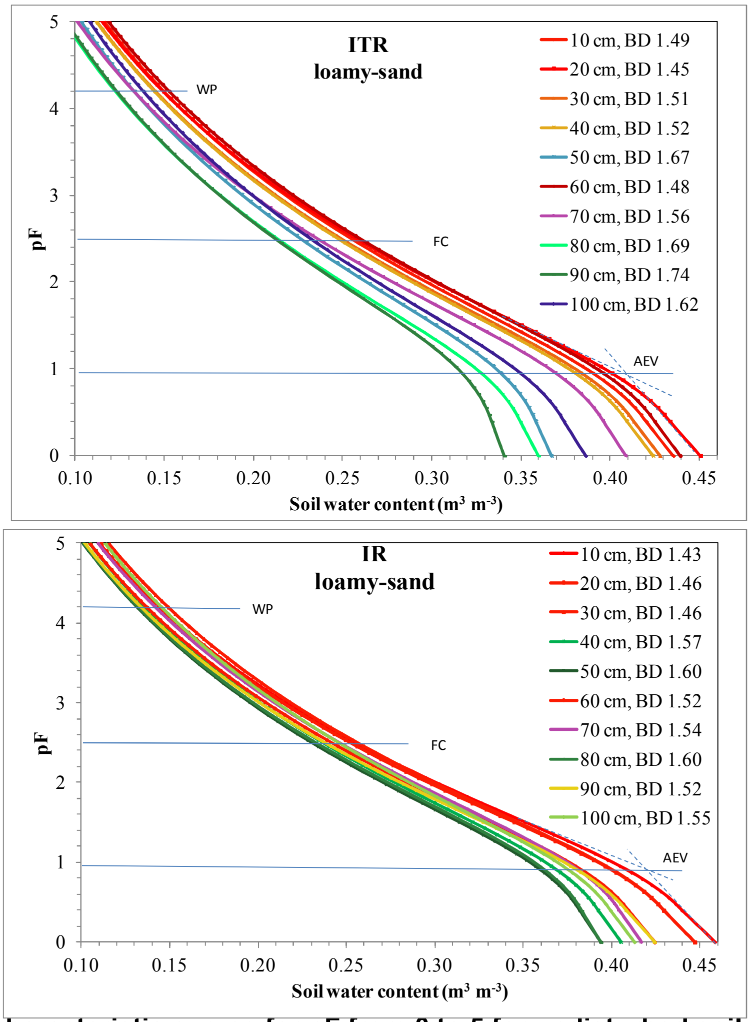


Fig. 1. Soil water characteristic curves for pF from 0 to 5 for undisturbed soil samples taken with a depth step of 0.1 m to 1 m, both in-row (IR) and inter-row (ITR) positions, in an intensive plum orchard, Maracineni; Soil depths and BD values for each sample, as well as soil water total capacity (TC, at pF = 0), air entry value (AEV, pF = 1), field capacity (FC, pF = 2.52) and wilting point (WP, pF = 4.2) for each curve are also shown in the graphs

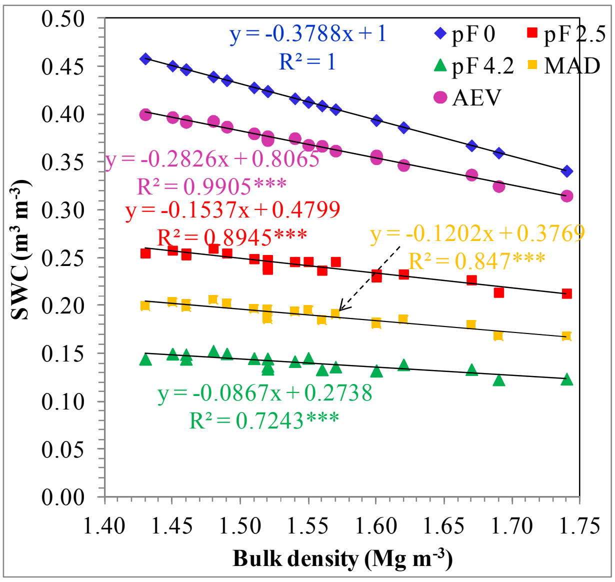


Fig. 2. Correlation between BD and the soil physical indices used in irrigation application: pF 0 (TC), AEV, pF 2.52 (FC), management allowed depletion (MAD, and pF 4.2 (WP)

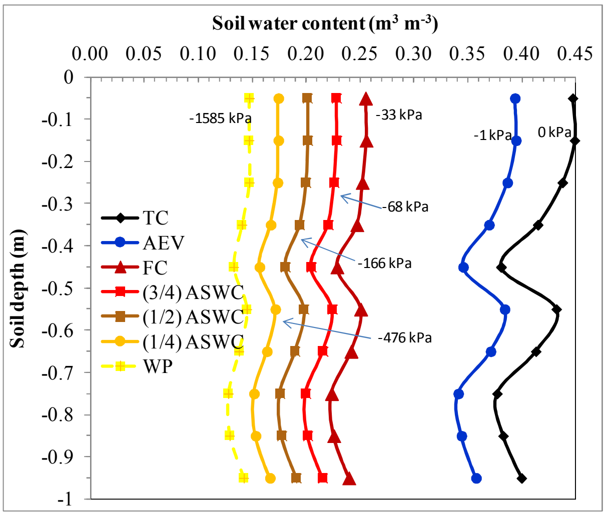
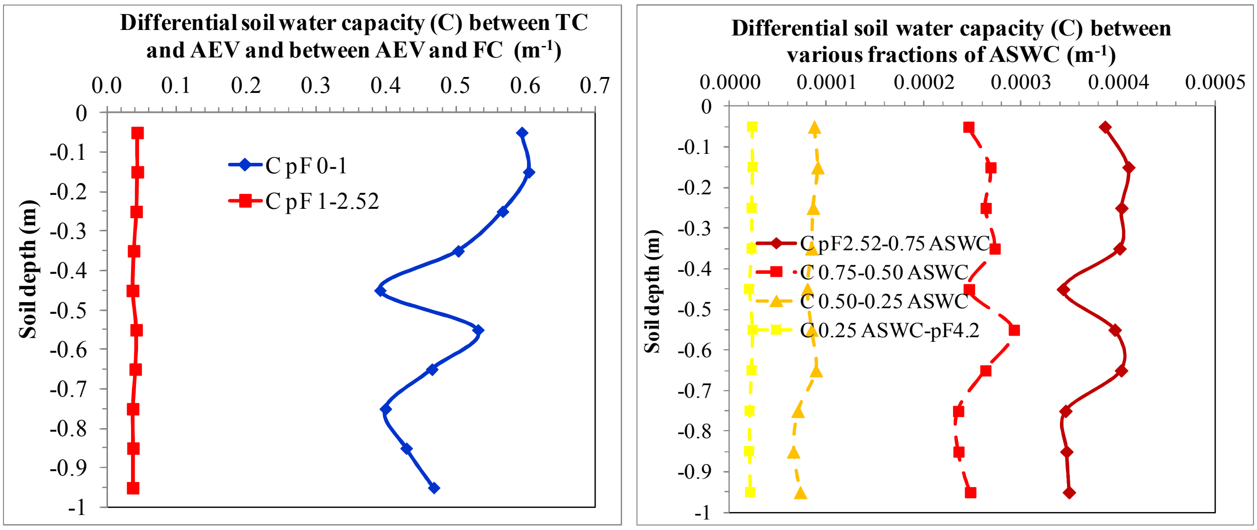


Fig. 3. Distribution of the soil physical indices as SWC values with depth in the sandy-loamy textured soil investigated; the soil matric potential (kPa) is also shown for each of indices



a) b)

Fig. 4. The differential soil water capacity (C) between various fractions of TC: a) C for pF 0 to 1 and for pF 1 to 2.52, b) C for various fractions of ASWC