DE GRUYTER OPEN

INTERNATIONAL Agrophysics
www.international-agrophysics.org

*Int. Agrophys., 2016, 30, 339-348*
doi: 10.1515/intag-2016-0001

# Root density of cherry trees grafted on prunus mahaleb in a semi-arid region**

*Cristian Paltineanu*[1]*, *Leinar Septar*[2], *Corina Gavat*[2], *Emil Chitu*[3], *Alexandru Oprita*[2], *Cristina Moale*[2], *Gheorghe Lamureanu*[2], *and Andrei Vrinceanu*[1]

[1]National Research Institute for Soil Science, Agrochemistry and Environmental Protection - ICPA, Bucharest, Bd-ul Marasti, No. 61, sector 1, postal code 011464, Romania
[2]Research Station for Fruit Growing Constanta, str. Pepinierei, No. 1, Valu lui Traian, judetul Constanta, Romania
[3]Research Institute for Fruit Growing Pitesti-Maracineni, comuna Maracineni, judetul Arges, Romania

*Received February 26, 2016; accepted June 28, 2016*

A b s t r a c t. Root density was investigated using the trench method in a cherry (*Prunus avium* grafted on *Prunus mahaleb*) orchard with clean cultivation in inter-rows and in-row. Trenches of 1 m width and 1.2 m depth were dug up between neighbouring trees. The objectives of the paper were to clarify the spatial distribution of root density of cherry trees under the soil and climate conditions of the region to expand knowledge of optimum planting distance and orchard management for a broad area of chernozems. Some soil physical properties were significantly worsened in inter-rows versus in-row, mainly due to soil compaction, and there were higher root density values in in-row versus inter-rows. Root density decreased more intensely with soil depth than with distance from trees. The pattern of root density suggests that the cherry tree density and fruit yield could be increased. However, other factors concerning orchard management and fruit yield should also be considered. The results obtained have a potential impact to improve irrigation and fertilizer application by various methods, considering the soil depth and distance from trees to wet soil, in accordance with root development.

K e y w o r d s: Calcaro-Calcic Chernozem, soil properties, root distribution, generative rootstock, Trench method

## INTRODUCTION

Understanding root growth and distribution has long been recognized as one of the more challenging and laborious aspects of understanding plant growth and development, particularly in large perennial plants such as fruit trees (Black *et al.*, 2010). The cherry tree is investigated because it is an important fruit tree species in the south-eastern part of Romania.

The trench method was among the most used approaches in investigations of fruit tree orchards concerning the rooting system, and Oskamp and Batjer (1932) reported details on trench dimensions for mature trees and classified tree roots after diameter. Dragavtsev (1936) also used the trench or profile method and the monolith method at various distances from the trees. Other authors *eg* Kolesnikov (1971), used different root dimensions with the same method.

The rooting system of a crop is determined by many factors, such as soil properties, type of cultivar and rootstock, as well as by orchard management (Atkinson and Wilson, 1980; Atkinson, 1983). Various scientists (for instance Gliński *et al.*, 2008; and Lipiec *et al.*, 2011) reported relationships between tree roots and some soil properties.

Böhm (1979) synthesized the several existing root measuring methods in fruit growing, *ie* excavation methods, monolith methods, auger methods, profile wall methods, glass wall methods, container methods, indirect methods, and other methods. More recently, among others, Williamson *et al.* (1992) and Parker and Meyer (1996) studied root distribution in peach orchards. Using mini-rhizotrons, Glenn and Welker (1993) studied the growth of tree rooting systems in the north-eastern part of the USA, and concluded that the deep roots helped maintain the surface root system when the surface soil was dry.

In the region, Indreias (1997) investigated the effect of rootstocks on the distribution of some fruit tree roots on chernozems, while more recently Paltineanu *et al.* (2015, 2016) reported the magnitude of root distribution of mature apricot trees and peach trees as well as the effect of the technological traffic on soil properties. The common planting scheme in the region was based on the rootstock type,

*Corresponding author e-mail: cristian_paltineanu@yahoo.com
**This work was financial supported by the Romanian Ministry of Agriculture and Rural Development: the project ADER 1.1.13. – Zonation of fruit species, rootstocks and cultivars depending on soil and climate conditions as well as on social-economic conditions in the fruit growing basins of Romania, 2013-2014.

canopy shape, solar angle at noon, orchard management, and soil fertility (Ceausescu *et al.*, 1982). Yet, no experiment was conducted to recommend optimum planting schemes in the semi-arid climate conditions of the region from the viewpoint of the root system. The present study was therefore needed because there was scarce information concerning the distribution of root systems in fully mature cherry orchards necessary for optimizing the planting scheme.

The main objectives of the paper were to:

– test the hypothesis that the roots of fully mature cherry trees planted within the commonly used layout occupy the whole planting scheme soil volume,
– clarify the spatial distribution of root density under the soil and climate conditions of the region and see if a root repulsive effect occurred,
– know the spatial distribution of root density and get information on the influence of soil properties on root density,
– emphasize the rootedness of cherry trees in this ecosystem in order to expand knowledge of optimum planting distance and improved orchard management for a broad area of chernozems in south-eastern Europe.

## MATERIAL AND METHODS

The present investigation was performed in a cherry tree orchard in the region of Dobrogea, Romania, close to the Black Sea coast. The relief is represented by a tableland and the land slope generally ranges between 0.01 and 0.03 m $m^{-1}$. The experiment was carried out in late August 2014 at the Research Station for Fruit Growing Constanta, Romania, in the village of Valu lui Traian located near the Black Sea coast at the 44° 10' N and 28° 29' E. The elevation of the site is about 70 m a.s.l.

According to Köppen-Geiger classification, the general climate of the city of Constanta is a *Cfa* type, with the mean annual air temperature of 12.0°C and the mean annual precipitation of 426 mm, for the period between 1980-2010 (Romanian National Meteorological Administration, Bucharest). The mean annual values of Penman-Monteith reference evapotranspiration (ETo) and the climatic water deficit are 828 mm and 402 mm, respectively.

The soil of the experiment is a mollic type (Calcaro-Calcic Chernozem, World Reference Base for Soil Resources, 2006) with a vermic character lying over a thick loess deposit. The soil was deeply ploughed at about 0.5 m depth at orchard establishment. About two decades ago, after the first orchard clearing, the soil was deeply loosened and then cultivated with field crops to rest for fruit growing. The present cherry tree orchard was established in the autumn of 2003.

As a function of the climate conditions, phyto-sanitary treatments were applied in the cherry orchard at least 10-12 times a year. Tractors of about 2.0-2.5 Mg weight and 48-55 kW power were used, with spraying pumps to apply pesticides against diseases and pests. The soil management system was clean cultivation both in inter-row (ITR) and in-row (IR). In ITR, ploughing was usually performed in the autumn, and disking and rotary-hoeing were carried out during the growing season. Herbicides were occasionally applied in the rows. The technological traffic of tractors and machines in the orchard frequently occurred when the near-surface soil was not wet. Sprinkler irrigation was applied annually from June to August under a mild water stress, with 65-70 mm per irrigation event and a total amount of 150-200 mm of water.

Disturbed soil samples were taken in plastic bags down to 1 m depth with a step of 0.1 m in order to determine particle-size distribution, humus content (organic carbon multiplied with 1.724), carbonate content, pH, and some plant available forms of macronutrients (P and K). To characterize the soil state of the cherry orchard, undisturbed soil samples were taken in four replicates from the same depths as above in metal cores of 0.05 m in both height and diameter from both IR and ITR. In the lab, the following soil properties were determined: bulk density (BD), penetration resistance (PR), macro-porosity (soil porosity containing pores larger than 50 µm, P50), and saturated hydraulic conductivity (Ksat). PR was determined at a volumetric soil water content equal to half of the total soil water capacity, *ie* most frequently within the lower part of available soil water storage capacity. The standard methods of analysis used were: SR EN ISO 11272: 2014 for BD, SR EN ISO 11274: 2014 for P50 as international standards, and STAS 7184/17-88 for PR and STAS 7184/15-91 for Ksat as Romanian standards, described by Florea and Munteanu (2012).

The soil is well structured in topsoil. The humus content is around 0.03 kg $kg^{-1}$, gradually decreasing with depth to about 0.006 kg $kg^{-1}$ at 1 m depth (Table 1).

The soil texture is loamy, and the clay content ranges from 0.19 to 0.25 kg $kg^{-1}$ over the whole soil profile. Calcium and magnesium carbonates are contained even in topsoil at about 0.1 m depth and, being slightly low, amount to as much as 0.18-0.20 kg $kg^{-1}$ in the carbonate-accumulated Cca 1 and Cca 2 layers from the subsoil. pH increases from 7.96 in topsoil to 8.5 in Cca 1 and Cca 2 horizons at about 0.8-1.0 m depth, respectively, mainly due to the presence of Ca and Mg carbonates.

The Boambe de Cotnari cultivar trees were grafted on a *Prunus mahaleb* rootstock and were planted in a 5x5 m scheme with north-south row orientation in 2003. This rootstock is most commonly used in the region for cherry trees. In early spring, fertilization with N, P, and K (40 kg $ha^{-1}$ active substance) and pruning were applied uniformly in the orchard.

The trees used for the study were selected from areas in which there are relatively homogeneous Calcaro-Calcic Chernozem soils. First, in the studied cherry orchard, the tree trunk diameters and the horizontal diameters of canopy

**T a b l e 1.** Main soil properties for the Calcaro-Calcic Chernozem soil in the cherry tree orchard investigated, Valu lui Traian, Constanta district, Romania

| Soil horizon | Soil depth (m) | Clay (kg kg$^{-1}$) | Humus (kg kg$^{-1}$) | pH | Carbonate (kg kg$^{-1}$) | K avail. (mg kg$^{-1}$) | P avail. (mg kg$^{-1}$) |
|---|---|---|---|---|---|---|---|
| Am1 | 0.0-0.10 | 0.225 | 0.037 | 7.96 | 0.047 | 226 | 18 |
| | 0.10-0.20 | 0.237 | 0.037 | 8.17 | 0.051 | 188 | 16 |
| | 0.20-0.30 | 0.241 | 0.033 | 8.24 | 0.060 | 86 | 10 |
| Am2 | 0.30-0.40 | 0.246 | 0.032 | 8.32 | 0.082 | 77 | 8 |
| | 0.40-0.50 | 0.242 | 0.031 | 8.34 | 0.125 | 65 | 8 |
| Cca 1 | 0.50-0.60 | 0.234 | 0.021 | 8.38 | 0.122 | 64 | 4 |
| | 0.60-0.70 | 0.230 | 0.020 | 8.38 | 0.130 | 58 | 3 |
| Cca 2 | 0.70-0.80 | 0.225 | 0.013 | 8.40 | 0.163 | 59 | 2 |
| | 0.80-0.90 | 0.214 | 0.013 | 8.45 | 0.177 | 52 | 1 |
| Cca 3 | 0.90-1.00 | 0.191 | 0.007 | 8.51 | 0.200 | 52 | 1 |

Symbols stand for soil horizons (A, C); Clay – clay content, Humus – humus content, Carbonate – carbonate content; plant available: K avail. – potassium content, and P avail. – phosphorous content.

trees were measured for more tree rows. Two pairs of consecutive trees with a similar trunk diameter and an assumed rooting system were selected for this study. The investigated trees were relatively homogeneous, with a mean trunk diameter of 24.1 ± 3.26 cm. The average tree height was 6.4 ± 0.36 m, while the canopy horizontal diameter was 4.46 ± 0.6 m. The tree canopy shape was a vase, and tree crowns generally occupied all the space in the row.

To determine the root density of the cherry trees, we used the trench (profile) wall technique (Böhm, 1979; Dragavtsev, 1936; Oskamp and Batjer, 1932) modified to accommodate the planting scheme. After application of large irrigation of 80 mm, when the soil reached the field capacity, 1 m-wide and 1.2 m-deep trenches were dug up between the two neighbouring trees as follows: one 5 m long trench along the tree rows (IR) and two other 2.5 m long trenches perpendicular to these trees in inter-row (ITR); a 0.5 m horizontal distance from each tree was left intact near the trees to protect them. There were two such replicates containing four investigated trees.

Callipers were used to measure the root diameter of the cherry trees. Along each of the trenches between the trees, determinations of root density for all diameters investigated were made using 1 m long square frames with a 0.1 m square grid network. The studied diameters were as follows: < 1 mm (fine roots), 1-3, 3-5, > 5 mm, and all diameters combined (all or total roots). Exact individual values for the roots with diameters larger than 5 mm were written down. The data of counted roots were considered spatially in the centres of each 0.1 m square of the grid. About 1 cm thick soil was removed with thin-blade pointed knives from the trench walls between trees to make the roots visible. All the roots of various diameters were numbered and noted in a notebook. Along the transects, the roots were measured at 0.1 m vertical and horizontal increments, and root density (RD) for various diameter classes from each 0.1 m grid square were expressed as the number of roots 100 cm$^{-3}$ of soil volume. The field study was carried out in late August and early September, 2014.

From practical considerations of the irrigation application in fruit cultivation, the depth of 1 m was chosen for these measurements. Observations were also done for deeper roots (1.2-1.5 m depth). The 0.5 m sides near the tree trunks in the trenches were assumed to be similar to the main parallel sides between trees and were taken into consideration to represent the complete wall sampling area. We also investigated the density of root cross-sectional area (RCSA) for each diameter class within each grid square. RCSA was estimated using the mean diameter of each class (*ie* 0.5, 2.0 and 4 mm) after considering the root sections as circles, and then multiplying with root density for the same diameter. For diameters > 5 mm, RCSA was calculated from the individual diameter values used to estimate each elliptical RCSA multiplied with root density, because the shape of the cross-sections for these roots was generally elliptical.

SPSS 14.0 software for a split-plot design with three factors was used to process the experimental data of roots and soil. These following experimental factors referred to the density of total roots (the sum of the number of all roots of different diameters) factors:

A – the position versus the cherry tree row, with a1 – IR and a2 – ITR;

B – soil depth, with 10 graduations from the soil surface to 1 m depth using a 0.1 m step;

C – distance from the tree trunk, with 25 graduations from the trunk to the half distance between the trees.

As already mentioned, there were four cherry tree replicates. Thus, the total number of data for each root diameter was: 1 x 10 x 25 x 4 = 1000 for both IR and ITR positions, in total 2000 for each root diameter. Confidence intervals of 95% were calculated.

Soil properties were investigated with a two-factor ANOVA and Duncan multiple range test, with factors A and B having the same graduations as above and four replicates, and the total number of cores studied was 2 (IR, ITR) x 10 (depths) x 4 (trees) = 80 for each soil property studied. SURFER 8 Program (Golden Software Inc. Colorado, USA) was utilized for mapping the root density and the density of RCSA.

The Microsoft Office Excel Program was used for graphs and regression equations between the variables investigated using the least squares method from the same program. More regression equation types were tested to fit the measured data. The relationships showing the maximum values of $R^2$ were selected as appropriate for the investigated data points. The statistical significance of $R^2$ (the determination coefficient) was established using the t-test in comparison with tabulated values at the desired significance level, using a two-sided t-test and (n-2) degrees of freedom (Aïvazian, 1970).

## RESULTS

The main soil physical properties found in the two positions IR and ITR are shown in Table 2.

From the statistical point of view, no significant differences were found on average between IR and ITR over the whole soil profile studied, except for some sub-layers. However, soil physical properties were generally worsened in ITR versus IR, and this was an important finding of this study. Thus, BD and PR were higher and P50 and Ksat were lower in ITR versus IR, respectively, at both the 0-0.5 m and 0.5-1.0 m depths. Nevertheless, there were significant differences, as mentioned above, only for some soil depths in the Am horizon between the soil physical properties investigated *eg* for the 0-0.1 m depth all physical properties were significantly different between IR and ITR, for the 0.2-0.3 m depth PR and Ksat were also significantly different, as well as for the 0.4-0.5 m depth in the case of P50.

The influence of the tree position (IR versus ITR) on RD differing in the diameter in the cherry orchard studied is shown in Fig. 1. There were significant differences between

**Table 2.** Main soil physical properties in two positions of tree rows and soil layers

| Horizon | Soil depth (m) | BD | | P50 | | PR | | Ksat | |
|---|---|---|---|---|---|---|---|---|---|
| | | IR | ITR | IR | ITR | IR | ITR | IR | ITR |
| Am1 | 0.00-0.10 | 1.21b | 1.32a | 24.14a | 22.58b | 2.24b | 3.19a | 25.22a | 13.88b |
| | 0.10-0.20 | 1.25a | 1.30a | 23.55a | 22.38a | 2.70a | 3.04a | 23.62a | 12.78a |
| Am2 | 0.20-0.30 | 1.29a | 1.36a | 23.28a | 21.85a | 3.07b | 3.92a | 33.70a | 17.91b |
| | 0.30-0.40 | 1.31a | 1.35a | 22.60a | 22.83a | 4.36a | 4.76a | 42.00a | 18.20a |
| | 0.40-0.50 | 1.23a | 1.26a | 25.25a | 23.00b | 3.20a | 2.95a | 49.44a | 40.75a |
| AC | 0.50-0.60 | 1.05a | 1.13a | 25.10a | 24.90a | 2.97a | 2.57a | 52.59a | 44.14a |
| | 0.60-0.70 | 1.11a | 1.13a | 26.45a | 25.48a | 2.43a | 2.69a | 52.71a | 48.58a |
| | 0.70-0.80 | 1.10a | 1.05a | 26.18a | 25.78a | 2.40a | 2.18a | 62.20a | 57.43a |
| Cca 1 | 0.80-0.90 | 1.14a | 1.16a | 26.28a | 25.90a | 2.29a | 2.34a | 43.36a | 46.80a |
| Cca 2 | 0.90- 1.00 | 1.16a | 1.11a | 26.15a | 26.08a | 2.21a | 2.40a | 22.79a | 31.74a |
| Mean-1 | 0.00-0.50 | 1.26a | 1.32a | 23.76a | 22.52a | 3.11a | 3.57a | 34.80a | 20.70a |
| Mean-2 | 0.50-1.00 | 1.18a | 1.22a | 24.90a | 24.08a | 2.79a | 3.00a | 40.76a | 33.22a |

IR – in-row, ITR – inter-row, BD – bulk density (Mg $m^{-3}$), P50 – macro-porosity (%), PR – penetration resistance (MPa), Ksat – saturated hydraulic conductivity (mm $h^{-1}$). Different letters in the table show significant differences between IR and ITR positions for the probability $p \leq 0.05\%$ according to Duncan multiple range test.

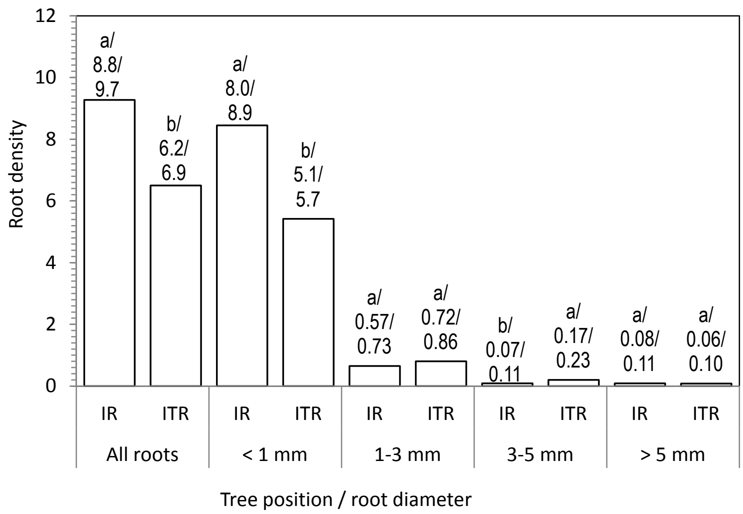


**Fig. 1.** Influence of the tree position (IR versus ITR) on RD differing in diameter (number of roots 100 cm$^{-3}$ of soil volume) in the cherry orchard studied; different letters in or above the columns in the graph represent significant differences ($p < 5\%$) between IR and ITR within each class of root diameter according to the 95% confidence intervals: lower bound/upper bound values shown as fractions.

IR and ITR in the case of the finest roots (< 1 mm diameter) and of all roots. For the other root diameters, the differences in root density were not significant (except for the 1-3 mm diameter, and this was in the opposite sense). From all the root classes, the finest roots prevailed.

For both IR and ITR positions, the relationships for root density obtained from the cherry experiment had a curvilinear and inverse shape (Table 3) and were much stronger with soil depth (D) than with distance (d) from the tree trunk, except the > 5 mm diameter roots. This finding is illustrated by the $R^2$ values. For the finest roots and all roots, we also compared this type of relationships for the IR and ITR positions separately and found significantly different relationships.

In addition to the statistical analysis done for the 1.0 m soil depth, it is worth mentioning that large roots (> 5 mm in diameter) were found deeper in the soil, at least to about 1.5 m depth, for each of the four cherry trees investigated.

Relationships were calculated to describe the cumulative percentage of density for total roots depending on both depth and distance from the tree trunk (Fig. 2). Density for total roots found in the space allocated by the planting layout was considered to be 100%. The regression equations had also a curvilinear shape, were direct and highly significant, and showed high $R^2$ values for both depth with 0.94 and distance with 0.97.

Contour lines for the means of root density of all roots are shown in Fig. 3a for IR and 3b for ITR. The whole space of the cherry trees contains roots, specifically in the upper part of the sampling section, where the contour lines are denser. The mean density of total roots decreased from about 22-25 100 cm$^{-3}$ of soil near the ground surface and tree trunks to 6-8 roots 100 cm$^{-3}$ of soil in the subsoil. After the 11-year period of the cherry orchard, the entire soil volume was practically occupied with tree roots.

Comparing the two positions, one can see that the RD was lower in ITR versus IR within almost all the soil space between the fruit trees. Thus, values of 6-8 roots 100 cm$^{-3}$ prevailed in IR versus 4-6 roots 100 cm$^{-3}$ in ITR.

The spatial distribution of the cherry RCSA is shown in Fig. 4a, b for the two positions. RCSA was much more heterogeneously distributed in space compared with root density, thus showing a greater effect related to the distance from the tree trunk than root density. The larger RCSA was mainly located at the first *ca.* 0.2-0.8 m depth and 0.5 m distance from the tree trunk in both positions, with values of more than 500 mm$^2$ 100 cm$^{-3}$ of soil volume. Nevertheless, IR presented higher contour line values of RCSA versus ITR.

The relationships between root density (all roots and roots < 1 mm diameter) and some soil properties: pH, carbonate content, humus content, and content of plant available K and P, respectively, are shown in Table 4. The relationships between root density and soil pH as well as between root density and soil carbonate had a curvilinear shape and were inverse and highly significant. There were direct linear relationships between root density and the soil humus content, available K and P, and most of them were highly significant; there were also direct but non-significant relationships between root density and clay content (not shown), due to the narrow range of the clay content for the soils in the experiment.

**T a b l e 3.** Root density depending on soil depth (D, m) and distance (d, m) from the tree trunk for both IR and ITR; root density for IR versus ITR for all roots and for roots < 1 mm diameter

| Root diameter (mm) | Regression equation | $R^2$ | Significance |
|---|---|---|---|
| All roots | y = -4.393 ln(D) + 3.642 | 0.314 | *** |
| < 1 | y = -3.985 ln(D) + 3.086 | 0.292 | *** |
| 1-3 | y = -0.326 ln(D) + 0.407 | 0.062 | *** |
| 3-5 | y = -0.093 ln(D) + 0.058 | 0.033 | *** |
| > 5 | y = 0.0105 ln(D) + 0.092 | 0.001 | N.S. |
| All roots | y = -0.938 ln(d) + 7.819 | 0.017 | *** |
| < 1 | y = -0.737 ln(d) + 6.883 | 0.012 | *** |
| 1-3 | y = -0.099 ln(d) + 0.715 | 0.007 | ** |
| 3-5 | y = -0.031 ln(d) + 0.145 | 0.004 | * |
| > 5 | y = -0.072 ln(d) + 0.077 | 0.038 | *** |
| All roots-IR | y = -4.963 ln (D) + 4.477 | 0.329 | *** |
| < 1 -IR | y = -4.687 ln (D) + 3.920 | 0.322 | *** |
| All roots-ITR | y = -3.824 ln (D) + 2.807 | 0.339 | *** |
| < 1 -ITR | y = -3.282 ln (D) + 2.251 | 0.311 | *** |
| All roots-IR | y = -0.379 ln (d) + 9.2435 | 0.002 | N.S. |
| < 1 -IR | y = -0.198 ln (d) + 8.433 | 0.001 | N.S. |
| All roots-ITR | y = -1.496 ln (d) + 6.395 | 0.060 | *** |
| < 1 -ITR | y = -1.275 ln (d) + 5.332 | 0.055 | *** |

$R^2$ – coefficient of determination, N.S. – not significant. Meaning of stars in all tables and illustrations: *significant, **distinctly significant, ***highly significant.

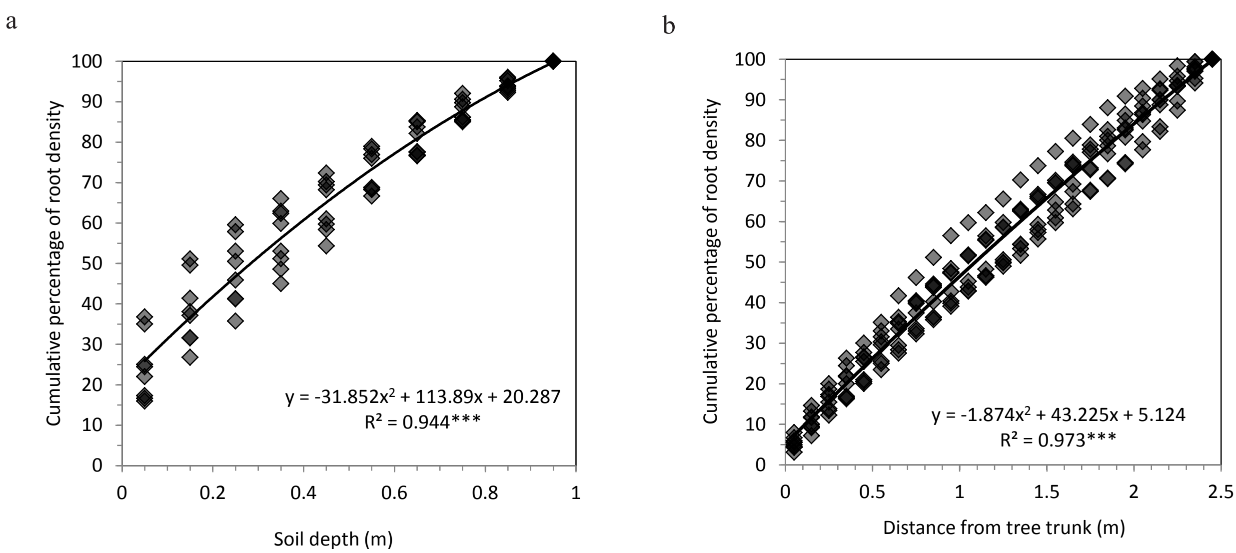


**Fig. 2.** The relationships between the cumulative percentage of root density for all roots as a function of: a – depth, and b – distance from the tree trunk, in the cherry orchard studied.

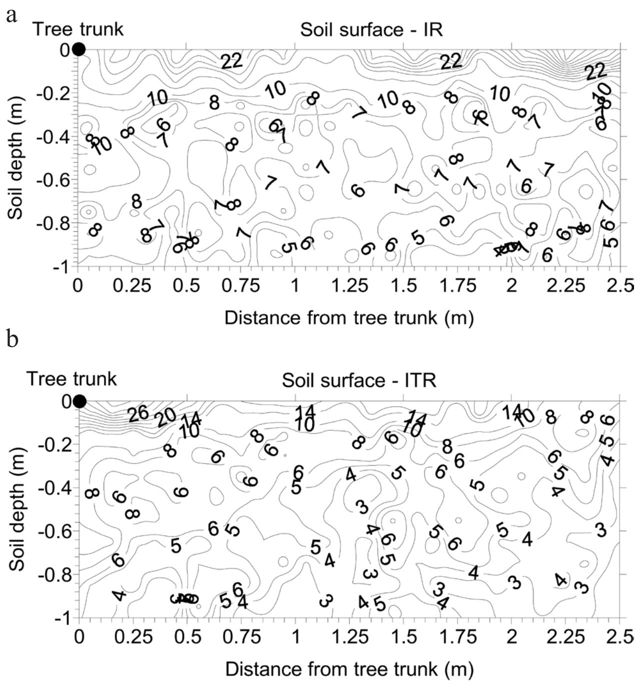


**Fig. 3.** Contour lines for the means of RD (number of all roots 100 $cm^{-3}$ of soil volume) for: a – IR and b – ITR for all roots, cherry trees within the vertical experimental soil section studied.

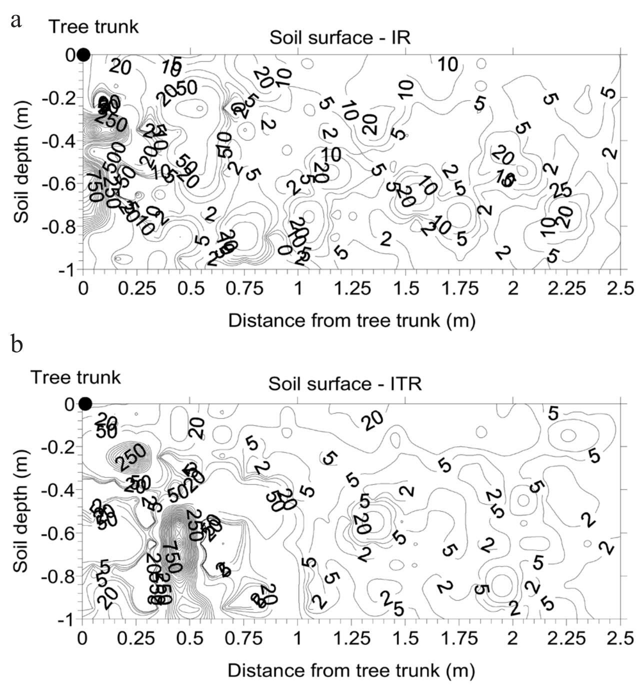


**Fig. 4.** Contour lines for the means of RD cross-sectional area ($mm^2$ 100 $cm^{-3}$ of soil volume) for: a – IR and b – ITR for all roots, cherry trees within the vertical experimental soil section studied.

**T a b l e 4.** Root density depending on some soil properties for total roots and roots < 1 mm diameter

| Relationship between root density and | Root diameter (mm) | Regression equation | R² | Significance |
|---|---|---|---|---|
| pH | All roots | y = -211 ln (x) + 454.81 | 0.319 | *** |
| | < 1 mm | y = -191.7 ln (x) + 412.86 | 0.297 | *** |
| Carbonates content (kg $kg^{-1}$) | All roots | y = -6.292 ln (x) - 6.414 | 0.215 | *** |
| | < 1 mm | y = -5.599 ln (x) - 5.791 | 0.192 | *** |
| Humus content (kg $kg^{-1}$) | All roots | y = 250.79 x + 1.776 | 0.151 | *** |
| | < 1 mm | y = 222.51 x + 1.514 | 0.134 | *** |
| Available K content (mg $kg^{-1}$) | All roots | y = 0.0654 x + 1.818 | 0.317 | *** |
| | < 1 mm | y = 0.0592 x + 1.449 | 0.293 | *** |
| Available P content (mg $kg^{-1}$) | All roots | y = 0.6053 x + 3.588 | 0.264 | *** |
| | < 1 mm | y = 0.5431x + 3.078 | 0.240 | *** |

Explanations as in Table 3.

The finest roots and total roots combined presented the highest $R^2$ and differed in magnitude for each soil property. The same relationships had the highest absolute values of equation slopes, revealing the greatest sensitivity of the finest roots to the basic soil properties. The other root-diameter classes followed as magnitude and had generally lower $R^2$ values (not shown). The largest roots presented non-significant $R^2$ values.

## DISCUSSION

Soil physical properties have worsened in ITR versus IR after a period of 11 years of existence of the cherry orchard studied, even if this soil type has a mollic and vermic character and is relatively resilient to agricultural technological traffic (Dumitru *et al.,* 1999). These differences were not significant for some of the soil horizons and soil properties studied. This worsening was real and could be attributed to the technologies applied for this period. However, the studied soil physical properties still presented decent values within the IR and ITR positions. Thus, BD did not exceed 1.36 g $cm^{-3}$ even in ITR, P50 ranged between about 22 and 26%, and Ksat presented values that were generally greater than 13 mm $h^{-1}$. These values showed, in addition to the specific land slope of the relief, why high precipitation always occurred without ponding and with low runoff.

Our present results regarding the worsening of soil properties in cherry orchards are consistent with results obtained by other scientists for other species of fruit trees (Ferrero *et al.*, 2005; van Dijck and van Asch, 2002). Thus, the evolutionary trend of soil properties after long-term orchard exploitation, *eg* 10 to 15 years more, involves worsening in soil physical properties even in fertile soils like the Calcaric Calcic Chenrozems of this region. However, unlike other older orchards with various species (*eg* apricot, 15 years old and peach, 22 years old) in the region (Paltineanu *et al.,* 2015, 2016), the soil physical properties from the cherry orchard show more favourable properties. This finding emphasizes the fact that the duration of orchard works, the soil type, and the planting distance of trees may have contributed to different soil compaction levels. Thus, the soil of the cherry plot was initially more fertile (Vermic Calcaric Calcic Chenrozem) than the soils (Calcaric Calcic Chenrozems) in the plots of the other fruit tree species, and the larger the distance between tree rows the less severe the soil compaction because the tractors are not forced to pass over the same tracks.

The practical recommendations used for orchards in this country and other countries as well are to perform deep ploughing in soils at about 0.5-0.6 m before orchard establishment. Consequently, the soil horizons are mixed, and the humus from the more fertile top horizons, where most of the fine roots are present, is usually moved deeper towards the subsoil. However, there are other practices to alleviate the soil state in orchards after land clearing made by deep loosening at the end of the orchard period. Thus, the soil could be cropped for a few years with some ameliorative plants like peas, alfalfa, or other similar species, as suggested by Dumitru *et al.* (1999).

From all root diameter-classes studied, most were fine roots at all depths and distances from the tree trunk as shown above, and this was consistent with previous authors findings (Basile *et al.*, 2007; Black *et al.*, 2010; Williamson *et al.*, 1992).

Root density was found to significantly decrease much more strongly with soil depth than with the distance from the tree, and this decline is described by the regression equations above. Regression equations between root concentration and soil depth and distance from trees were also published by Williams *et al.* (1992), but their results were different from ours in terms of the relationship weight and regression coefficients.

The cumulative percentage of the density of total roots in the cherry orchard studied was relatively precise and determined by the regression equations above, with very high $R^2$ values. This percentage varied with depth as follows: within the 0-0.2 m depth there were about 40-45% of total roots, within 0-0.5 m layer there were *ca*. 70%, and within 0-0.6 m depth there were about 80% of total roots. The decline in the density of total roots with distance from the tree trunk followed this distribution: at the distance of 0.5 m there were about 25% of total roots, at the 1.0 m distance there were more than 40%, and at the 2.0 m distance there were *ca*. 80% of total roots.

Various authors reported results concerning the spatial distributions of fruit tree roots for different species under different conditions. For instance, Ruiz-Sánchez *et al.* (2005) reported that almost all of the roots were located in the first 0.75 m of soil depth, with 91% in the first 0.50 m. The percentage of thin roots was higher than 75% of the total roots in that case.

Because the typical irrigation regime was under water stress in the region in order to save water, specifically in late summer after harvest, the deep roots were important for water uptake specifically during drought conditions. Such deep roots were also found in this experiment, and these results were consistent with those of Glenn and Welker (1993), who explained that the appearance of roots was not correlated to the plant available soil water levels at the 0 to 0.9 m depth, due to the deep penetration of the root system in soil to depths beyond the 0.9 m.

As shown, the density of total cherry roots was significantly higher for IR versus ITR. Thus, the worsening process in soil properties within ITR, which was only partly significant with respect to soil depth, induced by a moderate-term technological traffic, determined significant differences in root density in the environmental conditions of the region. Concerning the vertical distribution of roots in orchards, Liang *et al.* (2011) have shown that the maximum tree root length density was found at the soil depth of 0.2-0.3 m in the row and at 0.3-0.4 m depth between the rows, and from these depths the roots decreased deeper in the soil.

Of particular importance in orchards for both soil and trees is the role of the groundcover management systems for different fruit trees species and environmental conditions. Williamson *et al.* (1992), Ruiz-Sánchez *et al.* (2005), Gliński *et al.* (2008), Lipiec *et al.* (2011), and Liang *et al.* (2011) highlighted this aspect. In this context, Parker and Meyer (1996) have reported that the vegetation-free system had the highest number of roots developed deeper, in contrast with grass cover treatments. Yao *et al.* (2009) have reported that herbicide treatments possessed the highest number of roots and grass treatments the lowest, as grass roots competed with tree roots for soil nutrients and water, making tree roots develop deeper in the soil (Giovannini *et al.*, 2001; Hogue and Neilsen, 1987; Yao *et al.*, 2009). For our case study, it would be interesting to forecast the root density distribution towards the end of the orchard life span, for instance after 10-15 years; anyway, the vegetation-free groundcover management system used here enhanced the maximum root development. The answer to this question would help optimize the planting layout for cherry grafted on *Prunus mahaleb* in the region.

The correlation between root density and the main soil properties stressed the positive effect of soil nutrient content to the development of the cherry tree root system. For these fertile soils, the soil humus content accumulated within a large topsoil depth and the main macro-nutrients had a strong contribution to the growth of the root system, particularly associated with a slightly alkaline pH and balanced soil clay content. In addition to nutrients, precipitation and irrigation water was primarily stored in topsoil in the semi-arid conditions of the region. On the contrary, the soil carbonate and the moderately to strong alkaline chemical reaction played a negative role in the root development of cherry trees grafted on mahaleb. However, these relationships only give a rough idea on the influence of the above soil properties on root density in cherry, because some of these properties are also correlated to each other.

The present paper goes further than previous articles in quantifying the variation of spatial root distribution of cherry trees as a function of some of the main soil properties in the semi-arid conditions of the region.

In the study, we only used one rootstock, the most commonly used one. According to Black *et al.* (2010), total root biomass distribution does not differ significantly among cherry rootstocks, yet this finding cannot be confirmed or contradicted in this paper. Cherry roots horizontally occupied the entire soil space between the studied trees after 11 years from planting and, unlike apricot and peach trees (Paltineanu *et al.*, 2015, 2016), root density was much higher in the case of cherry, showing the great vigour of the rootstock. However, root density slightly decreased with distance from the trunk. According to these findings on root density and RCSA distribution as a function of distance from the trunk in a mature cherry orchard, the 5x5 m planting layout used on a large scale could be changed to increase the tree density/ha and fruit yield. The question is: how much could the planting distance be reduced? There is no accepted distance threshold between trees in inter-row or in-row in establishing the planting distance. In order to decide this matter, other factors related to the above-ground orchard should be also considered. Among these are: the ability of light to penetrate the canopy, the crown shape, the groundcover management system, fruit yield, *etc*.

The rooting pattern of cherry trees grafted on mahaleb also showed that precipitation was more efficiently used in the semi-arid regions due to the highest root density from the topsoil and from all the space between trees, including ITR. Irrigation water and fertilizers could be applied uniformly at the entire soil surface between trees by micro-sprinklers capable to wet a larger area than drip irrigation mainly used in the case of vegetative rootstocks.

## CONCLUSIONS

1. Inter-row soil compaction attributed to the technological traffic in the cherry orchard during moderate-term exploitation induced real worsening in soil physical properties of the Calcaro-Calcic Chernozem specific to the region. Thus, some physical properties were significantly different between the in-row versus the inter-row soil, where the situation was worse. In order to improve soil bulk density after orchard clearing, deep loosening and some years of rest are recommended, as well as cropping the soil with ameliorative crops.

2. After more than one decade of application of fruit growing technology in orchards with cherry grafted on mahaleb on such soils, the root density of total roots was significantly higher in IR versus ITR, and this differentiation was mainly caused by soil compaction. Most of the tree roots from all soil layers in both positions are fine roots (<1 mm).

3. Root density decreased with both soil depth and distance from the tree trunk, and stronger correlations were found between root density and soil depth versus the distance from the tree trunk. No root repulsive effect between adjacent trees occurred.

4. The pattern of root density distribution suggests that the cherry tree density and fruit yield could be increased, even in cherry orchards using generative rootstocks.

5. The rooting pattern of cherry trees found in this experiment suggests that irrigation water and fertilizers could be applied uniformly at the entire soil surface, while precipitations could also be more efficiently used with a clean cultivation ground cover management system.

6. If global warming scenarios come true, recommendations derived from this paper could be extended for other parts of Romania and other countries with similar environments.

**Conflict of interest:** The Authors do not declare conflict of interest.

## REFERENCES


**Aïvazian S., 1970.** Étude statistique des dépendances. Edition Mir, Moscou, Russia.

**Atkinson D., 1983.** The growth, activity and distribution of the fruit tree root system. Plant Soil, 71, (1-3): 23-35.

**Atkinson D. and Wilson S.A., 1980.** The growth and distribution of fruit tree roots: some consequences for nutrient uptake. Acta Horticulturae ISHS; Symposium on Mineral Nutrition and Fruit Quality of Temperate Zone Fruit Trees, 92: 137-150.

**Basile B., Bryla D.R., Salsman M.L., Marsal J., Cirillo C., Johnson R.S., and DeJong T.M., 2007.** Growth patterns and morphology of fine roots of size-controlling and invigorating peach rootstocks. Tree Physiology, 27: 231-241.

**Black B.L., Drost D., Lindstrom T., Reeve J., Gunnell J.D., and Reighard G.L., 2010.** A Comparison of root distribution patterns among prunus rootstocks. J. Amer. Pomological Soc., 64(1): 52-62.

**Böhm W., 1979.** Methods of Studying Root Systems. Springer-Verlag, Berlin, Germany.

**Ceausescu I., Negrila A., Isac I., and Lazar A., 1982.** Fruit growing (in Romanian). Publishing House Ceres, Bucharest, Romania.

**Dragavtsev A.P., 1936.** The root system of subtropical fruit plants growing in northern areas (in Russian). Trudy Sochinskoy op. stantsii subtr. i yuzhn. plodovykh kultur, 10.

**Dumitru E., Enache R., Dumitru M., and Gus P., 1999.** The Remnant Effects of Some Agricultural Practices on the Physical Soil State. Publishing House Risoprint, Cluj-Napoca, Romania.

**Ferrero A., Usowicz B., and Lipiec J., 2005.** Effects of tractor traffic on spatial variability of soil strength and water content in grass covered and cultivated sloping vineyard. Soil Till. Res., 84: 127-138.

**Florea N. and Munteanu I., 2012.** Romanian Soil Taxonomy System-SRTS. Publishing House Sitech, Craiova, Romania.

**Giovannini D., Scudellari D., Aldini A., and Marangoni B., 2001.** Soil management in an organic peach orchard. Rivista di Frutticoltura e di Ortofloricoltura, 63: 21-29.

**Glenn D.M. and Welker W.V., 1993.** Root development patterns in field grown peach trees. J. Amer. Soc. Hort. Sci., 118(3): 362-365.

**Gliński J., Lipiec J., and Stępniewski W., 2008.** Plant roots and soil physical factors (Ed. W. Chesworth). Encyclopedia of Soil Science, Springer.

**Hogue E.J. and Neilsen G.H., 1987.** Orchard floor vegetation management. Hort. Rev. Amer. Soc. Hort. Sci., 9: 377-430.

**Indreias A., 1997.** Pattern of the peach tree root system in Springrest cultivar grafted on six rootstocks. *Lucrari stiintifice*. Publishing House INFCON Constanta, Romania.

**Kolesnikov V., 1971.** The Root System of Fruit Plants. Mir Publishers Moscow, Russia.

**Liang Y., Gao S.R., Bo C.P., Yang Y., Wang S.W., Pan C.D., and Chen G.A., 2011.** Spatial distribution characteristics of absorbing roots of apricot trees in the intercropping systems. Xinjiang Agricultural Sciences, 48(5): 821-825.

**Lipiec J., Nosalewicz A., and Pietrusiewicz J., 2011.** Crop Responses to soil physical conditions. In: Encyclopedia of Agrophysics (Eds J. Gliński, J. Horabik, J. Lipiec). Springer Dordrecht, Heidelberg, London, New York.

**Oskamp J. and Batjer L.P., 1932.** Soils in relation to fruit growing in New York. II. Size, production and rooting habit of apple trees on different soil types in the Hilton and Morton areas, Monroe County. Cornell Univ. Agr. Expt. Stan. Ithaca, New-York.

**Paltineanu C., Septar L., Gavat C., Chitu E., Iancu M., Oprita A., Moale C., Lamureanu G., Calciu I., and Stroe V.M., 2015.** Spatial distribution of apricot roots in a semi-arid environment. Agroforestry Systems, DOI: 10.1007/s10457-015-9869-8

**Paltineanu C., Septar L., Gavat C., Chitu E., Oprita A., Moale C., Calciu I., Vizitiu O., and Lamureanu G., 2016.** Characterizing root density of peach trees in a semi-arid chernozem to increase plant density. Int. Agrophys., 30, 67-74, DOI: 10.1515/intag-2015-0079

**Parker M.L. and Meyer J.R., 1996.** Peach tree vegetative and root growth respond to orchard floor management. Hortscience, 31(3): 330-333.

**Ruiz-Sánchez M.C., Plana V., Ortuño M.F., Tapia L.M., and Abrisqueta J.M., 2005.** Spatial root distribution of apricot trees in different soil tillage practices. Plant Soil, 272(1): 211-221.

SURFER 8 Program (Golden Software Inc., Colorado 80401-1866, USA).

**Van Dijck S.J.E. and van Asch Th.W.J., 2002.** Compaction of loamy soils due to tractor traffic in vineyards and orchards and its effect on infiltration in southern France. Soil Till. Res., 63: 141-153.

**Williamson J.G., Coston D.C., and Cornell J.A., 1992.** Root restriction affects shoot development of peach in a high-density orchard. J. Amer. Soc. Hort. Sci., 117(3): 362-367.

World Reference Base for Soil Resources, **2006.** A framework for international classification, correlation and communication. FAO of the United Nations, Rome, Italy. Available at ftp://ftp.fao.org/agl/agll/docs/wsrr103e.pdf

**Yao Sh., Merwin I.A., and Brown M.G., 2009.** Apple root growth, turnover, and distribution under different orchard groundcover management systems. Hortscience, 44(1): 168-175.