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Determination of the interrelations between the apple root system and the physico-chemical soil properties

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Abstract

The research objective was to determine the interrelationship between the root system of the eight year old apple trees (Malus domestica Borkh.) and the physical and chemical properties of the soil. Research was performed at the Moara Domneasca Research Station, located in the Romanian Plain, with the annual mean temperature of 10.5^{o}C and annual mean rainfall of 548 mm. The soil is Chromic Luvisol with (clayey) argic Bt horizon. To determine the root system distribution and the root section area in July 2015 we sampled two soil profiles from the apple plantation and performed comparative measurements with a 10/10 cm biometrical frame. Measurements were performed on the root system of Florina and Topaz (Vf) varieties, both grafted on M9 rootstock. Although the two varieties had different growth vigour and were grafted on the same low-vigour M9 rootstock, rooting was normal. Nevertheless, root system distribution was different, depending on the specific vigour of the variety: higher (1363.83 mm^2) in the Florina variety and lower and more superficial (451.6 mm^2) in Topaz (Vf). Comparing soil permeability to water (K sat. - mm/h) with the models for the root system distribution in the two varieties we noticed a relatively stable correlation.

Keywords: biometrical measurements, root system distribution, soil properties, soil permeability

1.Introduction

The root distribution patterns of apple trees have been studied by several authors. K. MMOLAWA & al. [8] reported that the greater abundance of apple-tree roots near the soil surface occurred when topsoil was not very dense, having a rather coarse texture and an optimal moisture and nutrient content. Edaphic volume reduced is recorded at skeletal soils with different percentages of skeleton on soil profile which is a limiting factor for the development of the root system of plants (M. MIHALACHE & al. [7]). The soil management treatments (SMT) (pre-emergence herbicide (Pre-H), postemergence herbicide (Post-H), mowed sod grass (Grass), and hardwood bark mulch (MFULCH) affected the root number and root depth distribution patterns. Despite microsprinkler irrigation, the hot and dry weather conditions coincided with decreased root growth, increased root mortality, and reduced root median lifespan. The GMS treatments affected root growth, turnover, and distribution in this orchard, and these differences were linked with long-term trends in tree growth and fruit production (S. YAO & al. [18]). The positive influence of the mulch on root development has been demonstrated for the K_2O concentration available in soil. Also, the positive effect for root development was obtained by optimal or high concentrations of plant available P_2O_5, Mg^{2+}, Ca^{2+}, S and Cu, but negative – high concentration of Mn. Using cluster analysis, soil profile pixels were grouped to explain the positive influence of mulch on the root development was found for concentration of K_2O available in soil (V. SURIKOVA & al. [12]). The undertaking of research in a wide range of natural conditions existent in Romania showed that the soils for fruit trees, rootstocks with deep roots main mass (approx. 75%) were favourable at 20-60 cm depth (V. VOICULESCU & al. [14], [15]; V. VOICULESCU [16], [17]). Any change in the physical and chemical properties of the soil beyond the optimal range for each fruit species resulted in roots reacting and avoiding the restrictive horizons, both above and below them. Any soil factor related to the depth (parental material, non-penetrating hard rock roots, excessive moisture in the first 100cm etc.) limited the soil volume explored by the root system which spreads towards horizons where it is not exposed to climatic stress (M.D. GLENN [3]). Other researchers pointed out that nutrients uptake was hindered under conditions of limited moisture (R.G. EVANS & al. [2]. For this type of rooting, periodic destruction of parts of the newly formed roots reduced root mass, while growth slowed the trunk thickness and reduced the longevity of the plantation (V. VOICULESCU [17]). The clayey layer acted as a barrier for the root development of the *P. mahaleb* L. rootstock. It hardly passed the edaphic barrier from the soil profiles (developing above and below it), which led to specific incompatibility symptoms (G. DUDU & al. [1]). Root distribution was perfectly overlapping with the hydraulic conductivity, mirroring the pattern of water infiltration and root penetration into the soil (G. DUDU & al. [1]. The cumulative effect of compaction, due to both natural and anthropic causes, were more significant at 20-40 cm depth (R. TEODORESCU & al.[13]). The values of the variation of mobile phosphorus, mobile potassium, organic carbon and total nitrogen varied significantly under the influence of the conditions provided by the respective year. The highest values of their concentrations were determined in the wheat and maize crops, and the lowest in the uncultivated soil and the orchard (A. ONET & al. [9]). The research carried out over a period of 40 years at Valu lui Traian–Constanta has shown modifications of the main agro-chemical soil indices, both for chemical and organic fertilisation (V.M. SIMIONESCU [11]).

Our research was aimed to determine the influence of physical and chemical properties of the soil on the root development pattern of apple trees (*Malus domestica* Borkh.) from an orchard in the 8^{th}year of growth.

2.Materials and Methods

The experiment was carried out at the Moara Domneasca Research Station (belonging to UASVM-Bucharest), Ilfov county, in July 2015. The experimental plot was located on the Vlasiei Plain, the Romanian Plain, in the transition area from steppe to forest steppe. The general relief was flat while the microrelief contained numerous depressions of different shapes and sizes. The soil was Chromic Luvisol (according to WRB-ST-1998). Research was performed in the 8^{th}year old orchard, N-S oriented, with drip irrigation system. The most appropriate methods for the study of the soil-trees relation in the Romanian conditions proved to be Oskamp-Dragavțev modified by Voiculescu. In order to observe the relationships of the root system with the soil characteristics, two soil profiles were sampled and root system distribution determinations were performed in the Florina/M9 and Topaz (Vf)/M9 varieties. The smooth wall profile size was 100 x 100cm, which was oriented at the trunk at the distance of 1m. The observations were recorded in specially designed field sheets where there was a systematic identification profile, as well as information about relief, natural vegetation, soil and plants. The soil samples collected from the three pedo-genetic profile horizons were analysed and the analytical data was interpreted according to the *ICPA Methodology (1987*) [19]. The biometrical measurements of the tree-roots were performed by the metric frame (Figure1).

Figure 1.Metrical frame for tree-root measurements

For the Oskamp-Dragavţev method a number of improvements were made, which resulted in a more accurate reflection of the relationships between the soil properties and the distribution of the root system. Therefore, the roots grouping was modified by the diameter and thickness of the roots, recording sheets with thickness of 10 mm in diameter. The method we used in our research is known as Oskamp-Dragavţev modified by Voiculescu (C. LAZĂR [5]). The primary recordings were processed through the use of biometrics indicators and synthesized in a quantified form summarizing the main characteristics of the root system. Thus, root frequency (RF) and the root-sectional area (RSA) were determined to obtain relevant results. They were correlated with the main physical and chemical properties of the soil, determined according to the ICPA Methodology, 1987[19]. Root frequency (RF) is the number or amount of roots, calculated on orders depth of 10 to 10cm, the soil profile up to 100cm deep, according to the formula:

$$\mathrm{RF\%} = \frac{\mathrm{n}}{\mathrm{N}} \mathrm{x}\ 100$$

where: RF=roots frequency, n= the number of the same group root diameter and N=the total number of roots in the same depth range.

The root-sectional area (RSA) is an indicator that synthesizes a quantifiable number of branch roots and their ramification capacity. The RSA was expressed in mm^2 and calculated the depth order of 10 to 10cm, with the depth of 100 cm. To sum up, the root surfaces of four root groups led to the total RSA at depth level (0-10, 10-20.....90-100cm) and pedogenetic horizons. A root system distribution index (RDI) was used to express the rooting type of a profile through a single indicator which comprise dall the information on the distribution of the root system. Admitting that, if all the roots of a tree were in the 0-10cm depth this could benoted with 1 and for all roots located at a depth of 90-100cm with 10, the index formula distribution roots on the soil profile included:

$$\mathrm{RDI} = \sum_{i=1}^{10} = \frac{\mathrm{i\ x}\ s_i}{S}$$

where: RDI = Roots Distribution Index on soil profile depth divided into 10 orders; i = depth order (1 ...10); s_i =root surface and at depth order (mm^2); S=surface root section total depth of 100cm (mm^2).

The Root Distribution Index (RDI) was used to detect the effect of soil properties on the use of the frequency distribution of the root system and the root-sectional area of each side of the profile. Normal rooting for type RDI recorded values of 3-5, rooting superficial type, and type values < 3 deep rooting, >5 values, these limits were valid for rootstocks with great vigour.

3.Results and Discussions

Relations between the root system and soil characteristics in the Florina/M9 variety

The analysis of the data in Figure 2 and Table 1 shows that a root section area (SSR) of 1363.83 mm^2 was obtained, distributed over the 100 cm where the roots were identified and measured. It can be noticed that in the Florina / M9 variety (Figure 3), most of the roots developed in the first part of the soil profile, under the conditions of drip irrigation. Normal root growth was recorded to a depth of 40 cm. It could also be noticed that, the surface of the root section was 1265.93 mm^2 on the depth of 0-40 cm, the presence of the 27 roots with a thickness between 4-10 mm^2 indicating the predominance at this level of the supporting roots, which was 1227.99 mm^2 (75%). On the same depth (0-40 cm) the active roots were present in large numbers, with a frequency of 25%, decreasing continuously with the depth. The largest area of the root section (SSR) was recorded on a depth of 20 cm (Figure2), where it exceeded 400 mm^2 (Table 1).

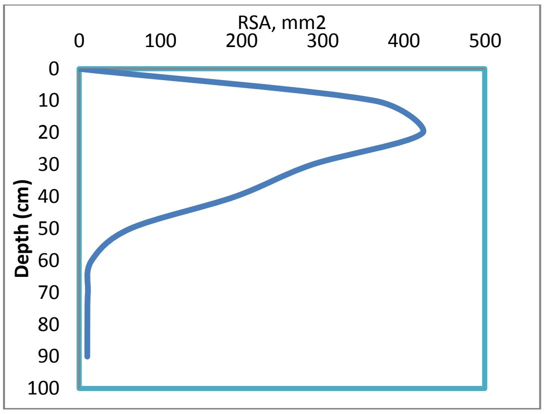

Figure 2. Surface of the root section area (RSA) in Florina cv/M9

The distribution of apple roots has been also subject to other researchers and have been put in direct relation with water uptake (S. GREEN & CLOTHIER B. [4]) or with ground management systems (S.YAO & al. [18]; I.A MERWIN & al [6]). In our conditions of drip irrigation and mowed grass between the rows, we noticed that the root section area (SSR) drastically decreased with depth so that it reached under 70 mm^2 on 50 cm in depth and 15 mm^2 on 60 cm in depth (Figure3 and Table 1).

Figure 3. Metrical frame for tree-roots measurements in Florina cv/M9

Table 1. RSA and physico-chemical data in Florina cv/M9

Depth	RSA	Humus (Ct 1.72)	Clay (<0.002mm)	BD*	TP	DC	pH_{H2O}	TN	P mobile	K mobile
cm	mm^2	%	%	g/cm^3	%v/v	+05	pH units	%	mg/kg	mg/kg
10	364.60	3.43	31.5	1.42	46.4	+15	6.74	0.186	98	255
20	423.45	3.43	31.5	1.42	46.4	+15	6.74	0.186	98	255
30	286.06	2.43	32.1	1.54	42.1	+15	6.74	0.134	32	101
40	191.82	1.69	32.1	1.55	41.7	+15	6.65	0.092	17	94
50	62.84	1.25	32.1	1.56	41.3	+15	6.55	0.092	17	94
60	15.36	1.25	37.1	1.56	41.3	+15	6.55			
70	10.82	1.25	37.7	1.56	41.3	+15	6.54			
80	4.14	-	37.7	1.60	39.8	+25	6.28			
90	5.54	-	37.7	1.60	39.8	+25	6.28			
100	0.20	-	36.6	1.62	39.8	+25	6.16			
Total	1363.83									

*) BD = bulk density; TP = total porosity; DC=compaction index;TN = total nitrogen; P mobile = mobile phosphorus (available); K mobile = mobile potassium (available).

The analysis of the granulometric fractions showed a medium texture (medium clay) in the first 32 cm and fine clay (loamy clay) in the rest of the profile. Analysing the clay content (<0.002 mm) on the soil profile to the depth of 100 cm, a clay content of between 28.0 and 36.1% was found. The clay content was 31.5% on 0-20 cm in depth, increasing to 32.1% on 30-50cm and reaching 37.1-37.7% on 90 cm. However, it decreased to 36.6% on 100 cm in depth (Table 1). Three physical indicators were used to characterise soil compaction: *bulk density* (DA g/cm^3), *total porosity* (PT% v/v) and *compaction index* (GT% v/v). *Bulk density* was medium, i.e. 1.42 g/cm^3 (0-20 cm), high 1.54-1.56 g/cm^3 (30-70 cm) and very high, around 1.60g/cm^3 (80-100 cm) (Table 1). *Total porosity* was medium, i.e. 46.4% v/v (0-20 cm), low 42.1 %v/v (20-70 cm) and very low 39.8 %v/v in the clayey horizons corresponding to 70-100 cm in depth (Table 1). The soil was slightly compact (+05) on 0-20 cm in depth, equivalent to the Ap horizon, moderately compact (+15) on 20-70 cm, equivalent to the Atp, Am and A/B horizons, and strongly compact (+25) on 70-145 cm in the Bt_1, Bt_2 and B/C horizons. In terms of soil compaction, the medium values of the bulk density and total porosity associated with a low degree of compaction in the upper part of the soil profile (0-20 cm) created more favourable conditions than in depth. In the rest of the profile, where apparent density was high-very high, total porosity was low-very low and compaction was strong, which resulted in unfavorable conditions for the aero-hydric regime of the soil. The unfavorable soil compaction had an unfavorable influence on the water regime with negative implications for root growth and development of the fruit trees.The value of saturated hydraulic conductivity (K sat mm/h) was medium (7.52 mm/h) at the top of the soil profile (0-20 cm). In the rest of the profile, the values were small-very small (0.10-1.08 mm/h) on the depth of 20-100 cm, which showed that soil compaction did not allow the entry and circulation of water in the soil. Thus, it cannot be stored in a larger quantity so that it could subsequently be made available to plants (Figure 4).

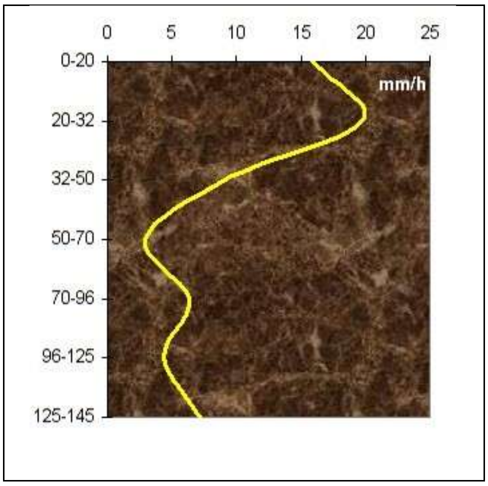

Figure 4. Soil permeability (K sat. mm/h) in Florina cv/M9

The analytical data resulted from the chemical analysis showed that the typically studied chromic luvisol had a slightly acidic reaction on a depth of 0-100 cm, with pH values within the limits of 6.16-6.74 (pH units) (Table 1). The humus content in soil was medium (3.43 %) on 0-20 cm in depth, low (1.69-2.43 %) on30-40 cm and very low (1.25 %) on 50-70 cm (Table 1). The humus reserve (calculated for 0-50 cm in depth) was high, i.e. 184 t/ha^{-1}. The soil supply with important elements for fruit tree nutrition was assessed on the basis of the analytical data concerning total nitrogen (Nt -%), mobile phosphorus (P - mg / kg) and mobile potassium (K - mg / kg) on the active layer for the apple-tree roots (0-50 cm). The total nitrogen supply (Nt%) was medium, i.e. 0.186% (0-20 cm), low 0.134 % (20-30 cm) and very low 0.092 % (40-50 cm). The total phosporus supply (P - mg/kg) was very high, i.e. 98 mg/kg (0-20 cm), medium 32 mg/kg (30 cm) and low 17 mg/kg (40-50 cm) (Table 1). The mobile potassium supply (K_{Al} mg/kg) was high, i.e. 255 mg/kg (0-20 cm); low 94-101 mg/kg (20-50 cm).

Relations between the root system and soil characteristics in the Topaz (Vf)/M9 variety

The profile in the Topaz (Vf)/M9 variety showed a 451.6mm^2 root-area (SSR) (Figure 5, Table 2), with a root frequency (FR) lower than in Florina/M9. The surface of the root section did not exceed 200 mm^2, most of the roots were recorded in the first 30 cm in depth (Figure 6). As E. Sanchez & al. [10] showed, permanent cover with different species influence the roots distribution and the soil activity and properties. This is reflected consequently in the yield and growth of the apple trees.

There was superficial rooting (Figure 8) with a low depth distribution of the root system (Figure 6). Under drip irrigation conditions, the distribution of the root system was altered, so that the roots did not develop deeply into the soil, in close correlation with the low vigour specific to the Topaz (Vf) variety.

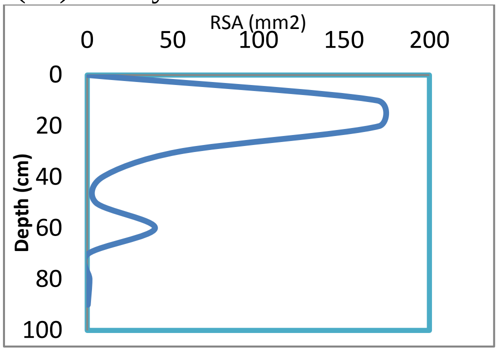

Figure 5. Surface of the root section area (RSA) in Topaz/M9

Figure 6. Development of the Topaz/M9 tree-roots in the upper 20 cm of the soil

Table 2. RSA and physico-chemical data in Topaz (Vf)/M9

Depth	**RSA**	**Humus** (Ct 1.72)	**Clay** (<0.002mm)	**BD***	**TP**	**DC**	pH_{H2O}	**TN**	**P mobile**	**K mobile**
cm	mm^2	%	%	g/cm^3	%v/v			%	mg/kg	mg/kg
10	169.62	3.37	29.6	1.45	45.4	+05	6.16	0.157	61	207
20	170.7	3.37	31.1	1.45	39.1	+05	6.16	0.113	34	122
30	53.69	2.25	31.1	1.67	39.1	+05	6.73	0.113	34	122
40	8.88	1.44	33.6	1.67	37.2	+15	6.86	0.068	24	107
50	5.14	1.44	33.6	1.67	37.2	+25	6.86	0.068	24	107
60	39.67	1.31	36.2	1.66	37.4	+25	6.59			
70	1.8	1.31	36.2	1.66	37.4	+25	6.59			
80	1.6	-	35.3	1.60	38.5	+15	6.57			
90	0.5	-	35.3	1.60	38.5	+15	6.57			
100	-	-	34.6	1.64	38.1	+25	6.4			
Total	**451.6**									

*) BD = bulk density; TP = total porosity; DC= compaction index; TN = total nitrogen; P mobile = mobile phosphorus (available); K mobile = mobile potasium (available).

The clay content (< 0.002 mm) analysed on the entire soil profile (0-100 cm in depth) recorded values ranging between 29.6 and 36.2% (Table 2). It was 29.6 – 31.1% on 0-30 cm in depth, increased to 33.6% (40-50 cm) and 34.6-35.3% (80-90). However, it decreased to 34.6 on 100 cm in depth. In both soil profiles, the high clay content, i.e. 34.6-35.3% in Florina/M9 and 34.1-36.1 in Topaz (Vf)/M9, was the result of the loamy-claying pedogenetic process that determined the formation of the horizon (Bt). Bulk density was medium-high, i.e. 1.45-1.62 g/cm^3(0-33 cm) and very high 1.60-1.67 g/cm^3. Total porosity was low-medium, i.e. 39.1-45.5 % v/v on 0-30 cm in depth and decreased to very low (37.2-38.5% v/v) on 40-100 cm. Soil compaction was slight-moderate (+0.5-+15) on the first two depths (0-30 cm) and strong (+25) on 31-100 cm (Am-B/C horizons). The medium-high bulk density, low-medium total porosity and slight-moderate compaction on 0-30 cm in depth resulted in less favourable conditions for soil compaction. The same conditions were recorded in the horizons with a high clay content on 40-100 cm in depth, where bulk density was very high, total porosity was very low and compaction was strong. This resulted in unfavourable conditions for the aero-hydric regime of the soil and emphasized the need for deep loosening works in order to improve the situation. The soil permeability to water (K sat. - mm/h) was low-extremely low, with values ranging between 0.10-0.92 (on 150 cm in depth) and medium 5.55 mm/h (on 50-170 cm, at the base of the soil profile, in the Cca horizon) (Figure 7).

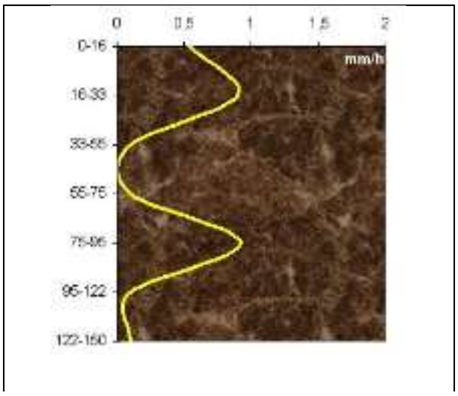

Figure 7. Soil permeability (K sat. mm/h) in Topaz(Vf)/M9

Concerning the **chemical characteristics** of the soil (Table 2) the analytic data whoed that soil reaction was slightly acid throughout the entire profile, where pH recorded 6.4-6.86. The humus content of the soil was relatively high (3.37 %) in the upper part of the profile, where (Cx 1.72) was medium. It drastically decreased with the depth, reaching 2.25-1.44 % on 30-70 in depth. The humus reserve (calculated on 0-50 cm in depth) was very high, i.e. 230 t/ha^{-1}. The N, P, K analytic data showed the soil supply with nutrients. The total nitrogen supply (Nt %) was medium (0.157 %) in the upper part of the soil profile, low (0.113 %) on 20-30 cm and very low (0.068 %) on 40-50 cm (Table 2). The total phosphorus supply (P - mg/kg) was high (61 mg/kg) in the surface horizon (0-10 cm) and medium (24-34 mg/kg) on 20-50 cm (Table 2). The toal potassium supply (K- mg/kg) was high (207 mg/kg) on the first depth (0-10 cm) and medium, between 107 and 122 mg/kg, on 20-50 cm (Table 2). Regarding the values of soil permeability to water (K sat. - mm/h) in the two situations under analysis (Figure8), they were extremely low in the Topaz (Vf)/M9 variety, compared with Florina/M9.

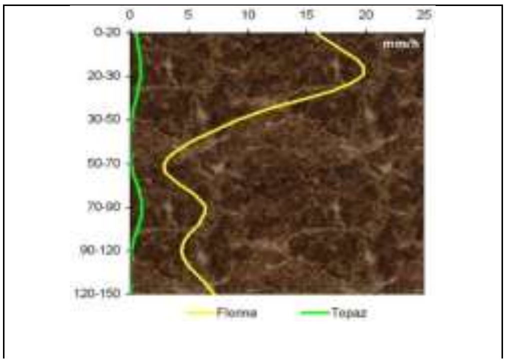

Figure 8. Soil permeability (K sat. mm/h) in Florina/M9 and Topaz(Vf)/M9

The further comparison between the values of soil permeability to water (K sat. - mm/h) in the two varieties (Florina/M9 and Topaz/M9) (Figure9 A) and the distribution models of their root sections (Figures 9 B and C) results in a relatively stable correlation.

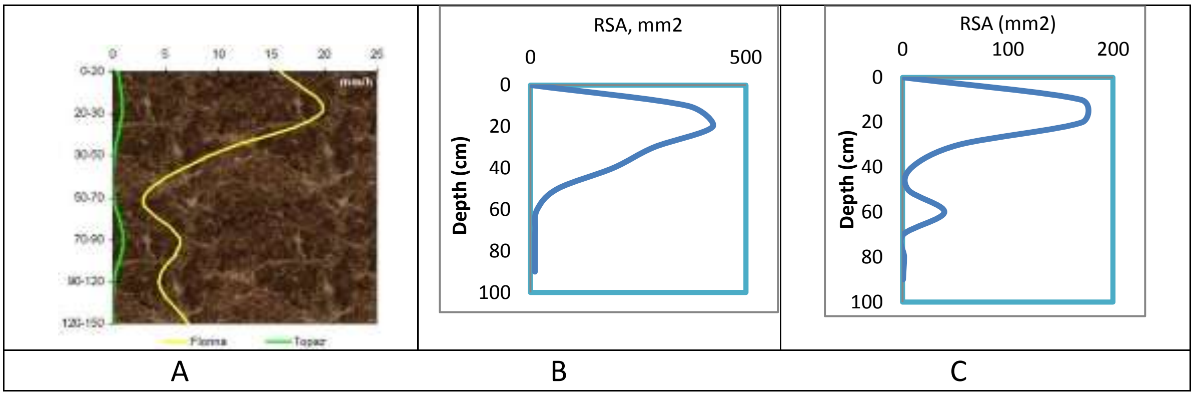

Figure 9. A) Soil permeability (K sat. mm/h) in Florina/M9 and Topaz(Vf)/M9 (left); B) Surface of the root section area (RSA) in Florina/M9 (middle); C) Surface of the root section area (RSA) in Topaz(Vf)/M9 (right)

Our research showed that the red preluvosoil of Moara Domneasca was characterised by medium humus content (3.43 %) on 0-20 cm in depth, low (1.69-2.43 %) on 20-50 cm and very low (1.25 %) towards the soil base. Soil reaction was slightly acid on 0-100 cm in depth, with pH ranging between 6.10-6.74 (pH units). The medium bulk density and total porosity associated with the slight compaction in the upper part of the soil profile (0-20 cm) resulted in less favourable conditions for soil compaction. The rest of the profile recorded high-very high bulk density, low-very low total porosity and strong compaction, which created unfavourable conditions for the aero-hydric regime of the soil. The root system distribution of the apple trees was influenced by drip irrigation. Thus, the roots do not grow deep into the soil, in close correlation with the low vigour which is characteristic to the Topaz (Vf) variety. The variation range of the analysed hydro-physical indicators correlated with the compaction status of the soil outlined the unfavourable water regime for the root growth and development due to the increased clay content in the soil profile. Although the two varieties, Florina și Topaz (Vf), had different growth vigour and were grafted on the same M9 rootstock of low vigour, rooting was normal. However, the distribution of their root system was different, depending on the specific vigour of the variety, as follows: higher in the Florina variety

(1363.83 mm^2) and lower and shall ower in Topaz (451.6mm^2). Comparing the values of soil permeability to water (K sat. - mm/h) in the two varieties (Florina/M9 and Topaz/M9) (Figure 9 A) with the distribution models of their root sections (Figures 9 B and C), we noted a relatively stable correlation (Figure 9).

4. Conclusion

►Normal rooting with root mass distribution in the area between 20 and 60 cm in depth results in adequate ramification capacity and thickness growth. This had a positive influence on the extraction of sufficient amount as mineral elements from the soil, as well as on the quality and amount of fruit.

►The high amount of clay had a negative influence on the soil compaction in depth, also resulting in the negative influence on the root system of the studied varieties.

►Rooting was normal despite the fact that two varieties had a different growth vigour and were grafted on the same M9 rootstock of low vigour. Their root system recorded a different distribution depending on the specific vigour of the variety, as follows: higher in the Florina variety (1363.83 mm^2) and lower and shallower in Topaz (451.6 mm^2).

►The variation of the hydro-physical indicators correlated with the unfavourable soil compaction showed an aero-hydric regime that was unfavourable to the growth and development due to the increased clay content in the soil profile.

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