

The Spatial Distribution of Root System in M9 Rootstock Is Affected by Apple Cultivar and Tree Age

Fadil Thomaj

Faculty of Agriculture and Environment, Agriculture University of Tirana, Tirana, Albania

E-mail: fadil_thomaj@hotmail.com

Hafuz Domi

ADAD, Tirana, Albania

E-mail: domihafuz@yahoo.com

Glenda Sallaku

Faculty of Agriculture and Environment, Agriculture University of Tirana, Tirana, Albania

E-mail: gsallaku@ubt.edu.al

Astrit Balliu (Corresponding author)

Faculty of Agriculture and Environment, Agriculture University of Tirana, Tirana, Albania

E-mail: aballiu@ubt.edu.al

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Abstract

The aim of study was to evaluate how different apple cultivars affect root morphology and spatial distribution of rootstock. The experiment was conducted with three different cultivars; 'Golden delicious', 'Gala' and 'Starking' grafted on M9 dwarfing rootstock. Nine and fourteen years old, French vertical axe trained trees were included in the experiment. The trench profile method was chosen to study the morphology of root system and the counted root intersects were divided into three classes; fine roots (<2mm), medium-sized roots (2-5 mm), and coarse roots (>5 mm). To analyze the spatial distribution of root system, the

respective cumulative number of fine roots at three successive distances from the base of tree trunk and the cumulative number of fine roots in three successive distances from soil surface were expressed as percentage versus the total fine roots. Significant effects of scion on the total number of fine roots, and as well, on their side and in depth distribution were found. The pattern of root distribution is changing over years, tending to shift the bulk of absorptive roots further from the tank and deeper into the soil. This tendency was more visible to high yielding and late maturity cultivars.

Keywords: grafting, scion, rootstock, root morphology, fine roots, spatial distribution

1. Introduction

Apple orchards are a major agricultural crop worldwide, with over 60 million tons of apples produced on more than 7 million hectares per year and are the focus of a large amount of research to improve their production efficiency and sustainability (Reyes *et al.*, 2016). The popularity of apples is not only a result of their taste, but also of their high nutritional value and healthful properties (Dobrowolska-iwanek and Adamska, 2015). In Albania, apple is the most important fruit tree; there are about 3.7 million apple trees and producing over 70 thousand tons apple fruits. Although, commonly apple in Albania is cultivated in its south-east continental part, recently is also expanded in the western coastal plain of the country in order to benefit from the advantages of earliness and vicinity to the main markets (Domi *et al.*, 2012).

Currently, the cultivation of apple grafted with dwarf rootstocks and close planting has become the trend and direction of the apple cultivation (Ding *et al.*, 2017; Ma *et al.*, 2013). They take up less room and can be planted close together to give good yields, the reduced size requires lower volumes of expensive pesticides and less labor for pruning and training, they produce fruit earlier and the size and color of the fruits are uniform, but the roots of dwarf apple trees are often not as well developed as in vigorous stock (Ma *et al.*, 2013). Apart from internal factors like rootstock genotype and scion vigor, root growth is affected by soil temperature and soil moisture (Psarras *et al.*, 2000) and irrigation practices (Tanasescu and Paltineanu, 2004). Since soil resources (water and nutrients) are unevenly distributed, or are subject to localized depletion the spatial deployment of the root system will in large determine the ability of grafted apple plants to exploit the available resources (Lynch, 1995). Hence, studying the development and the spatial distribution of root systems in dwarfing rootstocks, as well as an understanding of the relationship between the development of roots and shoots is of great significance for apple production (Ma *et al.*, 2013).

Fine roots are the main components of the root system through which plants absorb water and nutrients. These relatively thin roots, with a high specific root length (length: dry weight ratio), form the younger parts of the root system (De Silva *et al.*, 1999) and represent the most active and dynamic part of the root system, responsible for most water and nutrient uptake in plants. Given that fine roots are continually emerging, aging, and dying throughout the growing season, the composition of the fine fraction of root systems is very heterogeneous, with roots of different ages, lengths, diameters, colors, branching orders and degrees of mycorrhizal colonization (Artacho and Bonomelli, 2016). Although there are

evidences to suggest that within this single size class of roots exist differences in form and function, in most studies all roots less than 1 or 2 mm in diameter are treated as a single class of structurally and physiologically identical individuals (McCormack *et al.*, 2015; Wells *et al.*, 2001).

Although grafting is an important method of propagation in several horticulture plants, the mechanism through which the scion affects the absorption capacity of rootstock remains poorly understood (Shu *et al.*, 2017). While there are many publications regarding the effects of different rootstocks on the vegetative growth, yield and fruit quality of scions, there are few published reports on effects of scion cultivar on the rooting pattern of rootstock (Franco *et al.*, 1995). Root behavior is largely unknown and research in this regard is surprisingly limited (Hunter *et al.*, 2016), because it is easy to observe and record the growth and behavior of the aerial parts of a tree, but most difficult to make similar observations upon the root system (Swarbrick, 1930).

Considering, the limited information regarding the effects of the scion (cultivars) on the rootstock growth, and the practical importance of this information regarding proper spacing and proper crop management practices in intensive apple orchards, the aim of this study was to evaluate how could different apple cultivars used as scion in graft combination with the dwarfing rootstock M9 affects its root morphology and, as well, how its root morphology change in the course of years, under common commercial production conditions.

2. Materials and Methods

The study was conducted in a commercial apple orchard located in Dushk (41.0005 ° N, 19.6848 ° E), district of Lushnja, Albania, during the year 2015. The average air temperature of this site ranges from 5 ° C to 25 ° C. Winters are cool and wet with mean temperatures in December and January respectively 11.8 ° C and 9.8 ° C. The lowest air temperatures recorded are in the range from -1.5 ° C to -7 ° C (in January and February). However, the incidence of frost is very low. Summers have a mean temperature of 26 ° C and mean humidity of 60%. The maximum air temperatures recorded are in June and July, up to 42 ° C. Meanwhile the maximum winter air temperature recorded, range from 17 ° C up to 24 ° C. The highest soil temperatures are recorded in June, July and August. They range from about 23 ° C up to about 31 ° C. The lowest soil temperatures are recorded in January; the lowest ones recorded 6.7 ° C. The soil temperature (at 10 cm depth) exceeds 10 ° C in the middle of March. The area is under a xeric regime with relatively dry and hot summers. Average annual rainfall of this zone is 900-1400 mm, and more than 80% occurs during the rainy season from October to March. Therefore, irrigation is crucial for high agricultural production. The numbers of hours of sunshine is very high in June, July and August. It is approximately 110 hour for each ten day, but these figures are much smaller in winter months, no more than 30 to 40 hour of sunshine for each ten day.

The soil of the experimental site is classified as fluvisol. Sand, silt and clay composition at the upper soil layer (0-30 cm) were respectively 28.8%, 38.4% and 32%, and at the second (30-60 cm) layer, were respectively 21.6%, 40.4% and 38%.

The experiment engaged three different cultivars; ‘Golden delicious’, ‘Gala’ and ‘Starking’, each grafted on M9 dwarfing rootstock, all in the same commercial field plot. The planting distances were 3.8 x 1.3 m and plants were trained as French vertical axe. Common commercial practices were equally applied to all plants. Drip irrigation was installed and usually four cycles of irrigation with high, non-specified, water volumes were applied each year based on ‘rules of thumb’. Fourteen and nine (only for ‘Golden delicious’) years old plants were included in the experiment. For that purpose, five plants of each cultivar were randomly selected and observed from the start of vegetation until harvesting and several experimental data were successfully collected. The root morphology data itself were collected by the end of vegetation, in November 2015.

The trench profile method (var Noordwijk *et al.*, 2001) was chosen to study the morphology of root system. For that purpose a trench was excavated and a vertical plane perpendicular to the planting row was established. The vertical profile was extended up to 130 cm on both sides of tree trunk and reached the depth of 100 cm. The entire vertical profile was divided into 8 cm x 10 cm grid cells by a metallic net and in each grid cell roots were exposed using a small knife to remove surrounding soil. The root intersect method was used to count the roots (Tardieu, 1988); a root intersects was considered any intersection of a root with the vertical plane under study. The number of root intersects were counted in each grid cell (80 cm²) divided into three classes; fine roots (<2mm), medium-sized roots (2-5 mm), and coarse roots (>5 mm) (Ceccon, 2011).

The total root number and total number of each root category of the entire vertical profile (260 cm x 100 cm) were individually analyzed. The density of roots was calculated for each graft combination at three specified depths (0-40 cm, 40-80 cm and 80-120 cm) for the entire profile length (260 cm) and expressed as roots (total number) per 100 cm². In addition, in order to analyze the side distribution of root system, the respective cumulative number of fine roots (<2 mm) in three successive distances (0-40, 0-80 and 80-120 cm) from the base of tree trunk was counted and expressed as percentage versus the total fine roots of the entire vertical profile. Similarly, in order to analyze the in depth distribution of root system the cumulative number of fine roots (<2 mm) in four successive distances (0-20, 0-40, 0-60 and 60-90 cm) from soil surface was as well, counted and expressed as percentage versus the total fine roots of the entire vertical profile. By the end of October 2015, the diameter of trunk was measured by a caliper, 10 cm above the grafting point and based on that the trunk cross sectional area (TCA, cm²) was calculated. In addition, in order to estimate the annual vegetative growth of each cultivar, the length (cm) and diameter (1 cm above the insertion point, mm) of six randomly selected vegetative shoots were measured and recorded at each previously randomly selected tree (30 in total for each cultivar). Finally, the harvesting of fruits was conducted as fruits reached the maturity stage and the harvesting period and yield (kg tree⁻¹) of each previously randomly selected tree were individually recorded. Following that, yield efficiency (YE, kg cm⁻²) was calculated for each graft combination as the ratio of harvested yield per plant (kg tree⁻¹) with respective TCA (Fioravanço *et al.*, 2016).

Differences in root number and root density, percentage of fine roots at selected intervals versus their total, trunk cross sectional area, shoot length and diameter, and yield and yield

efficiency were tested by one-way ANOVA, using the personal computer (PC) program SigmaPlot 13 (Systat Software Inc., San Jose, CA, USA). Each significant ANOVA result ($p < 0.05$) was followed by a Holm-Sidak test at $p < 0.05$ as a post-hoc test to compare pair wise means within and among treatments. Values given throughout the text are means \pm SD.

3. Results

3.1 The Vegetative Growth and Production of Different Apple Cultivars

There were significant differences among apple cultivars grafted onto M9 rootstock regarding shoot growth parameters, either length or diameter, and yield. ‘Starking’ demonstrated the most vigorous annual growth. Its annual shoot length reached 68 cm, versus 58 cm and 48 cm, respectively reached by ‘Gala’ and ‘Golden delicious’. Similarly, shoot diameter of ‘Starking’ achieved 9.1 mm, while to ‘Gala’ and ‘Golden delicious’ it was respectively 7.1 mm and 6.8 mm. The weakest annual shoot growth was recorded in ‘Golden delicious’, although its differences with ‘Gala’ were not statistically significant (Table 1). Despite weak annual shoot growth ‘Golden delicious’ has the largest trunk cross sectional area (TCA, 21.18 cm²), followed by ‘Starking’ (18.56 cm²), both at the same statistical group. ‘Gala’ recorded the lowest value of TCA (12.23 cm²), significantly less than ‘Golden delicious’ and ‘Starking’. Opposite to vegetative vigor, ‘Starking’ recorded the lowest yield, only 6.8 kg tree⁻¹ and lowest yield efficiency (0.38 kg cm⁻²) (Table 1). ‘Golden delicious’ recorded the highest yield (26.2 kg tree⁻¹) and as well the highest yield efficiency. Interestingly, although it shows significant difference with ‘Gala’ regarding yield (26.2 vs. 15 kg tree⁻¹) no significant differences were found between them regarding yield efficiency (1.28 kg cm⁻² vs. 1.22 kg cm⁻²) (Table 1). Important to note, the harvesting time of ‘Gala’ was almost a month earlier than either ‘Golden delicious’, or ‘Starking’ (Table 1).

Table 1. Shoot growth fruit production parameters of 14 year old apple plants (respectively ‘Golden delicious’, ‘Gala’ and ‘Starking’ grafted onto M9 rootstock) under field conditions in Lushnja district, Albania

Cultivar	Vegetative growth parameters			Fruit production parameters		
	TCA (cm ²)	Shoot length (cm)	Shoot diameter (mm)	Harvesting period	Yield (kg tree ⁻¹)	Yield efficiency (kg cm ⁻²)
Golden delicious	21.18 \pm 5.0a	48 \pm 21 b	6.8 \pm 1.4b	Sept. 25	26.2 \pm 10.2a	1.28 \pm 0.5a
Gala	12.23 \pm 1.7b	58 \pm 20ab	7.1 \pm 2.2b	August 20	15.0 \pm 5.8ab	1.22 \pm 0.4a
Starking	18.56 \pm 3.9a	68 \pm 22 a	9.1 \pm 2.5a	Sept. 25	6.8 \pm 2.4 b	0.38 \pm 0.2b
Significance	0.009	0.002	0.004		<0.001	0.005

Different letters indicate significant differences within following parameters (Holm-Sidak test, $p < 0.05$; mean \pm SD).

3.2 The Influence of Scion Cultivar and Plant Age on Growth and Spatial Distribution of Rootstock Roots

The growth of root system was significantly influenced from the cultivar used as a scion in a specific graft combination. ‘Gala’ and ‘Starking’ have shown a significantly higher number of roots thinner than 2 mm compared to ‘Golden delicious’ (Table 2). Since roots thinner than 2 mm represents a very large portion of the total number of roots (nearly 90%), no doubt, both them have also a significantly higher total number of roots than ‘Golden delicious’ (Table 2). On the contrary, the picture regarding 2-5 mm and >5 mm fractions was different. ‘Gala’ has the highest number of intermediate (2-5 mm) roots, followed by ‘Golden delicious’ with a slightly smaller number of such roots (Table 2). ‘Starking’ has the smallest number of 2-5 mm roots, significantly less than Gala, but statistically equal with ‘Golden delicious’. Meanwhile ‘Gala’ has the smallest number of older, transport roots (>5 mm), significantly less than both ‘Golden delicious’ and ‘Starking’ (Table 2). Significant differences were also found between Golden delicious and Starking. The latest shows the highest number (21) of roots thicker than 5 mm. The morphology of root system was also significantly influenced by the age of grafted apple plants. Comparing 9 and 14 years old of M9 x Golden delicious plants was clear that the total number of roots was significantly reduced in older ones (Table 3). The reduction was proportional with the total number of roots for two first root categories; <2mm (67% less) and 2-5 mm (70%), but not regarding roots larger than 5 mm.

Table 2. Root number and root density of 14 year old apple plants (respectively ‘Golden delicious’, ‘Gala’ and ‘Starking’ grafted onto M9 rootstock) under field conditions in Lushnja district, Albania

Cultivar	Number of roots				Root density (total root 100 cm ⁻²)		
	Root diameter (mm)			Total root	In depth soil layer (cm)		
	< 2	2-5	> 5		0-40	40-80	80-120
Golden delicious	280±26b	26±4ab	17±3b	324±20b	1.25±0.05c	1.00±0.01c	0.95±0.03
Gala	342±20a	29±4 a	11±2c	382±21a	1.51±0.02b	1.15±0.01b	1.04±0.08
Starking	340±17a	22±3 b	21±3a	383±20a	1.63±0.09a	1.34±0.08a	0.96±0.06
Significance	<0.001	0.004	<0.001	<0.001	<0.001	<0.001	0.118

Different letters indicate significant differences within following parameters (Holm-Sidak test, $p < 0.05$; mean±SD).

Table 3. Root number of 9 year old and 14 year old apple plants (cv. Golden delicious grafted onto M9 rootstock) under field conditions in Lushnja district, Albania

Plant age	Number of roots			Total
	< 2 mm	2 – 5 mm	> 5 mm	
9 yr	417±16a	37±5a	28±3a	482±56a
14 yr	280±26b	26±4b	17±3b	324±20b
Significance	<0.001	0.004	<0.001	<0.001

Different letters indicate significant differences within following parameters (Holm-Sidak test, $p < 0.05$; mean±SD).

The pattern of fine root distribution in grafted apple trees was significantly influenced by individual scion characteristics. ‘Starking’ was more capable to keep the bulk of roots closer to the trunk by maintaining nearly to 40% of its total fine roots in the distance up to 40 cm far from the trunk (Figure 1A). The percentage of fine roots found in this distance for ‘Golden delicious’ (37%) was significantly less than ‘Starking’, while no significant difference was found between ‘Starking’ and ‘Gala’ (38%). This capability of ‘Starking’ becomes more evident counting the percentage of fine roots found in the distance up to 80 cm from the base of trunk (71%), this time statistically significant versus both; ‘Golden delicious’ (66%) and ‘Gala’ (67%) (Figure 1B). Contrary to above, ‘Starking’ has the smallest portion of total roots situated in the distance 80-120 cm (24%). Both, ‘Golden delicious’ (30%) and ‘Gala’ (28%) did have significantly higher portions of their roots moved away from the trunk (Figure 1C). Interesting to note, significant differences did also exist between ‘Golden delicious’ and ‘Gala’.

The individual characteristics of scion did also have significant effects on the in depth distribution of the rootstock roots. ‘Starking’ recorded the highest root density in 0-40 cm and 40-80 cm depth (respectively 1.63 and 1.34 roots per 100 cm²), significantly higher than ‘Gala’ (respectively 1.51 and 1.15 roots per 100 cm²) and ‘Golden delicious’ (respectively 1.25 and 1.0 roots per 100 cm²). Significant differences did also exist between ‘Gala’ and ‘Golden delicious’ at the same soil depth, but no significant differences were found among cultivars at 80-120 cm soil depth (Table 2).

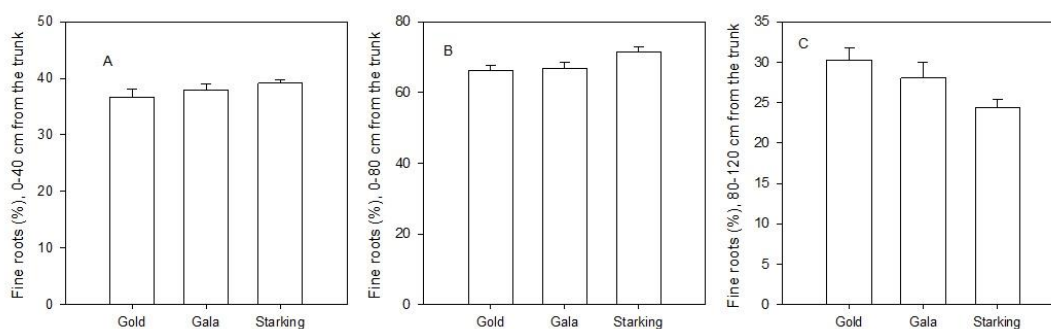


Figure 1. The number of fine roots of M9 rootstock (percentage over total number of fine roots), at different by side distances (0-40, 0-80 and 80-120 cm) from the base of trunk, grafted with different apple cultivars (Golden Delicious, Gala and Starking)

‘Starking’ provided the largest portion of fine root numbers down to 20, 40 and 60 cm deep; respectively 26%, 60 % and 84%. The differences were significant versus both, ‘Gala’ and ‘Golden delicious’ at each analyzed depth. The lowest presence of fine roots in the upper layers of the soil (20, 40 and 60 cm) was found in ‘Golden delicious’ plants. There were only 12% of its total fine roots found up to 20 cm depth, 47% up to 40 cm depth and 73% up to 60 cm depth (Figures 2A, 2B, 2C), much less than either ‘Starking’ or ‘Gala’. Contrary to the above soil layers, ‘Starking’ had the smallest percentage of fine roots in the deeper soil layers (60-90 cm), only 24%, significantly less than both, ‘Gala’ (28%) and ‘Golden delicious’ (30%). The differences between ‘Gala’ and ‘Golden delicious’ were also statistically significant (Figure 2D).

The spatial distribution of fine roots was significantly affected by the age of grafted plants. The effects were expressed either in the side distribution of roots, or in depth. Owing to ageing, the bulk of roots in M9 x Golden delicious grafted plants were gradually moved away from the trunk of plant. Indeed, compared to nearly 55% in 9 year old plants, only nearly 35 % of the fine roots were found within the distance of up to 40 cm from the trunk in 14 year old plants (Figure 3A). Similarly, while nearly 80 % of roots in 9 year old plants were found within the distance of 80 cm far from the trunk, only nearly 60 % of them were found in 14 year old plants (Figure 3B). Nearly 30% of total fine root number in 14 year old plants were situated in the belt lays between 80 and 120 cm far from the trunk, while much less (only 15%) were found to the same distances for 9 year old plants (Figure 3C).

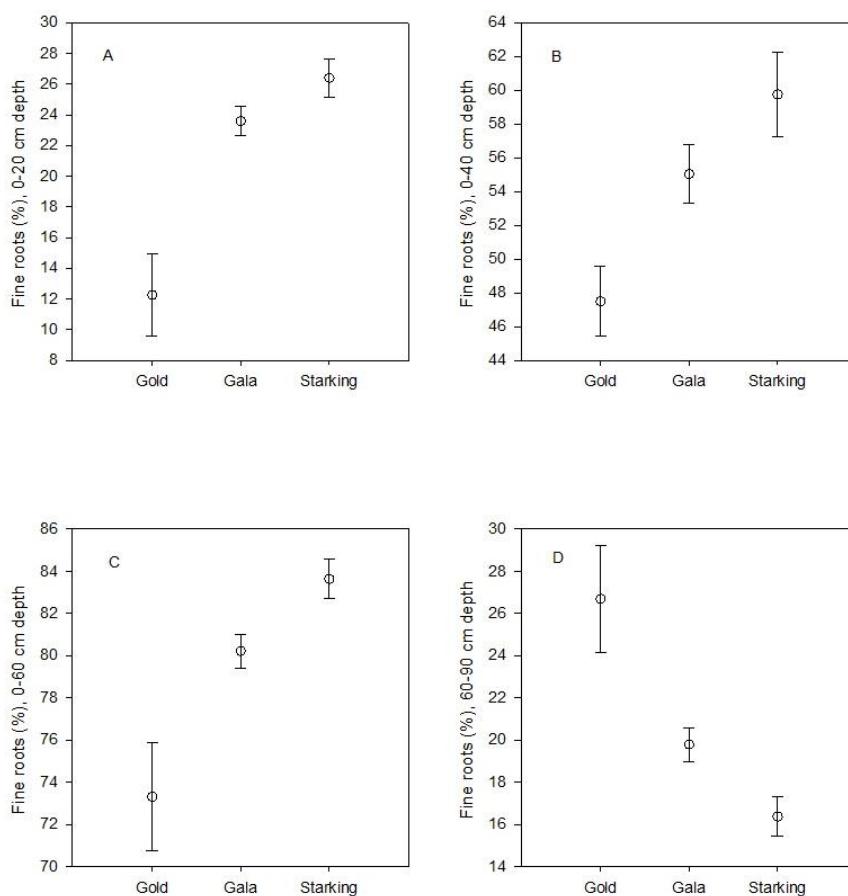


Figure 2. The number of fine roots of M9 rootstock (percentage over total number of fine roots), at different in depth distances (0-20, 0-40, 0-60 and 60-90 cm) from soil surface, grafted with different apple cultivars (Golden Delicious, Gala and Starking)

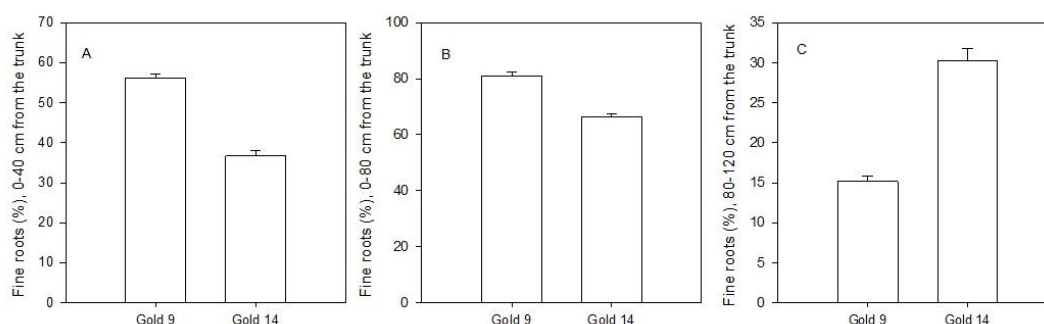


Figure 3. The number of fine roots of M9 rootstock (percentage over total number of fine roots), at different side distances (0-40, 0-80 and 80-120 cm) from the base of trunk, grafted with Golden Delicious apple cultivar, respectively 9 and 14 years after transplanting

The plant age has also significantly affected the in depth distribution of roots. As plants getting older, the bulk of roots of the rootstock were gradually moving into deeper layers of the soil. As it can easily see from Figure 4, in the younger plants (9 year old) the majority of

roots was situated in the upper layers of the soil. Respectively nearly 25% and nearly 60 % of fine roots in 9 year old plants were found in depths up to 20 cm and up to 40 cm. The difference with the respective proportions of 14 year old plants was significant and quite large; respectively nearly 12 % and nearly 45% (Figures 4A, 4B). The advantage of 9 year old versus 14 year old plants remains statistically significant until 60 cm deep (Figure 4C), but the difference between them is getting smaller (nearly 80% vs., nearly 74%). On the contrary, a significantly higher percentage of fine root number was found in depth between 60 and 90 cm in 14 year old plants (nearly 27%), compared to nearly 21 % in 9 year old plants (Figure 4D).

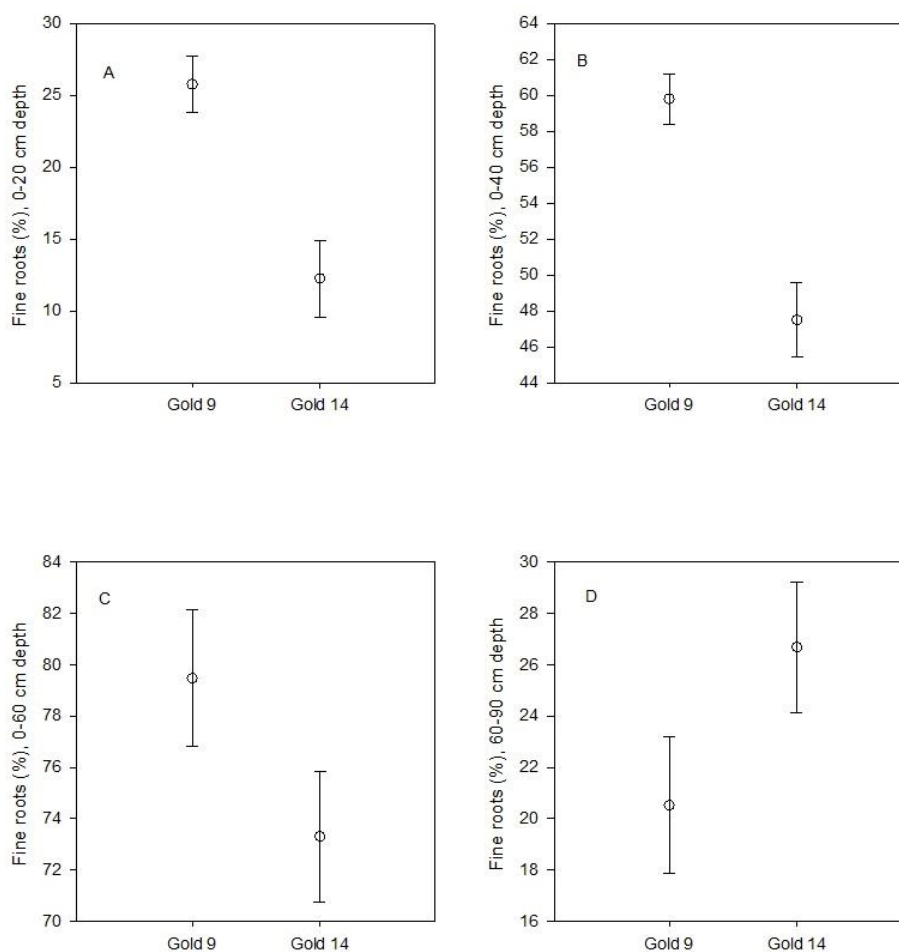


Figure 4. The number of fine roots of M9 rootstock (percentage over total number of fine roots), at different in depth distances (0-20, 0-40, 0--60 and 60-90 cm) from soil surface, grafted with Golden Delicious apple cultivar, respectively 9 and 14 years after transplanting

4. Discussions

Since fine roots have an increased mycorrhizal colonization rate, and are largely marked as the primarily absorptive roots (McCormack *et al.*, 2015; Paltineanu *et al.*, 2016), our discussion is based on the number and spatial distribution of this category. As a matter of fact, root and shoot growth in apple is asynchronous reflecting this way the competition for

carbohydrates between aboveground and belowground organs (Eissenstat *et al.*, 2001; Franco *et al.*, 1995) and the period of active root growth extended beyond that of aboveground vegetative growth. It begins before the leaves unfolded and continuing after shoot growth ceased. As already proved (Eissenstat *et al.*, 2001; Abrisqueta *et al.*, 2017), root growth of apple rootstocks increased once harvesting was completed and the canopy was big enough to distribute the required photo assimilates to organs that would ensure a successful yield the following season.

Apparently, this happen because different organs, compete among each other for assimilate (Goyal and Bishnoi, 2017). According to Kramer and Kozolowski (1979) (after Abrisqueta *et al.*, 2017) the differential sink capacities of the different organs depends on the organ activity and distance from the carbohydrate source and follow the following hierarchy: fruits > young leaves and stem tips > mature leaves > cambium > roots > storage tissues. Being the organ with the highest sink capacity (Abramoff and Finzi, 2015; Artacho and Bonomelli, 2016; Ding *et al.*, 2017), fruit load determines the growth rate of other vegetative or storage organs. Hence, since the differences regarding the yield among cultivars included in our experiment were significant, significant differences regarding the growth rate of either shoots or roots were logically expected. Indeed, ‘Starking’ with the lowest fruit yield (only 6.8 kg tree⁻¹) had the longest and the thickest shoots, and as well, the highest number of thin (<2 mm) roots.

Heavy fruit production in apple tree has been associated with high root mortality (Eissenstat *et al.*, 2001), and we also assume that is a reason why ‘Golden delicious’ have the lowest number of thin (<2 mm) roots. In addition, the number of roots was been related with the time of fruit maturity (Artacho and Bonomelli, 2016); a decrease in root production was observed due to the presence of growing fruits in late-maturing cultivars (Abrisqueta *et al.*, 2017). Similarly, we found that although there were no significant differences regarding yield efficiency (YE, kg cm⁻²) between ‘Golden delicious’ and ‘Gala’ the differences regarding the number of roots less than 2mm and the total number of roots were significantly different. Being harvested almost one month earlier allows ‘Gala’ to supply roots with larger amounts of assimilates and hence achieving in the upper layer of the soil (0-40 and 40-80 cm) a significantly higher root density than ‘Golden delicious’.

Similar to very early report of Swarbrick (1930) and recent ones of Zhu *et al.*, (1999), Psarras *et al.*, (2000) and Harrison *et al.*, (2016) we found that root morphology of M9 dwarfing rootstock was significantly affected by scion vigour. ‘Starking’ did not only have the largest number of fine roots; as well it was capable to keep the bulk of its roots closer to the base of tree trunk. Practically, nearly 70% of less than 2mm roots in M9xStarking graft combination was found in the distance of up to 80 cm far from the trunk. The differences with ‘Gala’ and ‘Golden delicious’ were statistically significant, indicating a higher root regeneration rate by ‘Starking’, a conclusion supported by findings of Fernandez *et. al* (2014) whose have found positive correlations between the vigor of scion and root number. Having fewer carbohydrates addressed towards the root system, due to higher YE, M9xGolden delicious and M9xGala were less capable to maintain their root system close to the trunk. As the result, their bulk of absorptive roots were gradually shifted further away from the base of trunk. A considerable number of fine roots were found further than 80 cm far from the trunk in

M9xGolden delicious and M9xGala (respectively 30% and 28%) and as a consequence, an increased competition for water and nutrient elements is expected among the trees in the row. A similar concern is raised by Paltineanu *et al.*, (2016) in apple and plum tree.

Our results proved that there were significant effects of scion on the in depth root distribution, too. Indeed, being capable to produce higher amounts of assimilates due to its larger above ground biomass and addressing a larger portion of them to the root system due to limited fruit load, ‘Starking’ was capable to maintain the bulk of its absorptive roots in the upper, more fertile, soil layers.

There are evidences that the phenology of root system is affected by the age of tree (Wu *et al.*, 2012). Studying young (1-3 yrs after transplanting) trees Watson *et al.*, (2006) found a decreasing root length into deeper soil layers. However, referring to previous publications (Hughes and Gandar, 1993) they admitted that the soil volume occupied by the root system reaches its maximum at 4 years old plants and that a more uniform root distribution exists to older (4-14 year old) apple trees. Ma *et al.*, (2013) also reports that in very young orchards, the root distributions are bowl-shaped, with the roots centered near the stem, whereas older trees have a more layered structure with a higher root density further away from the trunk. Our results confirm these findings. By studying the patterns of root distribution in 9 and 14 year old M9xGolden delicious plants, we found the bulk of absorptive roots in older plants was shifted further away from the base of trunk and had gone deeper into the soil. That was different from what Bouillet *et al.*, (2002) have reported in forest tree. We assume the differences are caused by quite different crop management practices. While the forest trees exploit the gradually increased concentration of nutrients in the top soil layers due to the decomposition of the forest floor (Bouillet *et al.*, 2002), the apple trees have been subject of frequent soil tillage, which periodically have pruned off the roots scattered in the upper layers of the soil, and intensive irrigations which drain the nutrient elements into deeper soil layers.

5. Conclusions

It is clear that the tested apple cultivars have a quite distinctive performance. Considering yield efficiency (kg cm^{-2}) as an important index of orchard productivity we should say that because of very low index (0.38 kg cm^{-2}), M9x‘Starking’ combination is not appropriate in that specific area. Although ‘Golden delicious’ and ‘Gala’ have statistically equal yield efficiency indexes, one should consider that the latest is less vegetative and occupies a smaller volume. Because of that, it might be planted in higher densities to achieve higher orchard productivity. The right planting distances needs to be experimented, considering also light penetration and the mechanization of orchard.

The pattern of root distribution is highly influenced by scion vigor and productivity. Being the less productive cultivar in that specific area, ‘Staking’ was been able to construct the most vigor root system and maintain it closer to the trunk. Although ‘Golden delicious’ and ‘Gala’ have similar vegetative vigor and productivity indexes, due to earlier maturity the latest was been capable to maintain a higher root density in the upper, more fertile soil layers, and as well, closer to tree trunk.

The specific characteristics of each cultivar should be considered during irrigation and fertilization to better fit the distance of drip lines from the trunk and the distance between the emitters, as well as the irrigation frequency and volume with the horizontal and in depth root distribution of each specific cultivar.

The pattern of root distribution was changing over years. The plants tend to shift the bulk of absorptive roots further from the trunk, risking to bring them closer to the next fruit tree and increase the in row competition among apple trees. Simultaneously, roots go deeper, into less fertile soil layers. This tendency was more visible to high yielding and late maturity cultivars. Due to that, the irrigation and fertilization practices should be adapted to changes of root distribution in the course of plant life cycle. It would be wise considering the increase of water volumes at every irrigation cycle in older orchards.

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